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Interorganizational Collaboration and Systemic Change Framework for Building Information Modeling (BIM) Adoption

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INTERORGANIZATIONAL COLLABORATION AND SYSTEMIC CHANGE FRAMEWORK FOR BUILDING INFORMATION MODELING (BIM) ADOPTION

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I dedicate this research to GOD Almighty for all the blessings in life, including completion of this work, and to the memory of my Father.

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS iii

ABSTRACT vii

CHAPTER 1: INTRODUCTION 1
1.1 Problem Statement 3
1.2 Specific Research Objectives 4
1.3 Research Overview 5
1.4 Format and Flow of this Dissertation 6

CHAPTER 2: EXTENDING TECHNOLOGY-ORGANIZATION-ENVIRONMENT FRAMEWORK FOR INTERORGANIZATIONAL BIM ADOPTION 7
2.1 Synopsis 7
2.2 Introduction 7
2.3 Comparative Analysis of Critical Factors from Case Review 10
2.4 Integration and Theory Refinement 21
2.5 Conclusion: Extending Technology-Organization-Environment Framework for Interorganizational BIM Adoption 24

CHAPTER 3: CRITICAL FACTORS FOR INTERORGANIZATIONAL COLLABORATION AND SYSTEMIC CHANGE IN BIM ADOPTION 26
3.1 Synopsis 26
3.2 Introduction 26
3.3 Literature Review 28
3.4 Method and Settings 36
3.5 Ethical consideration 38
3.6 Results 39
3.7 Discussion 64
3.8 Research Implication and Limitations 69
3.9 Conclusion: Critical Factors for Interorganizational Collaboration and Systemic Change in BIM Adoption 70

CHAPTER 4: EVALUATION GUIDE FOR INTERORGANIZATIONAL COLLABORATION AND SYSTEMIC CHANGE IN BIM ADOPTION 72
4.1 Synopsis 72
4.2 Introduction 72
4.3 Method and Settings 74
4.4 Ethical Consideration 79
4.5 Results 79
4.6 Discussion 82
4.7 Implication 83
4.8 Limitations and Suggestions 83
4.9 Conclusion – Evaluation Guide for Interorganizational Collaboration and Systemic Change in BIM Adoption 85

CHAPTER 5: GENERAL CONCLUSION AND CONTRIBUTION 87
5.1 From Chapter Two 89
5.2 From Chapter Three 90
5.3 From Chapter Four 91

REFERENCES 92

APPENDIX A: CONSENT FORM 98

APPENDIX B: RESEARCH INSTRUMENT 100

APPENDIX C: ROTATED COMPONENT MATRIX 108

APPENDIX D: TOTAL VARIANCE EXPLAINED 109

APPENDIX E: ITEM-TOTAL STATISTICS 110

APPENDIX F: RESEARCH VARIABLES (ENABLERS AND INHIBITORS) 111

VITA 113

ABSTRACT

It was found that an integrated framework needs to be developed for the construction industry that allows optimized interorganizational collaboration and systemic change while using Building Information Modeling (BIM) technologies. The framework needs to be effective so the industry can adopt BIM through a set of interdependent activities beyond their organizational boundaries. The adoption has been proven difficult because of industry competitiveness and a fragmented work environment. Meanwhile, existing frameworks vary between studies. This research developed an integrated framework, identified critical factors, and provided an evaluation guide for interorganizational collaboration and set of coordinated changes necessary to adopt BIM. This was accomplished by incorporating the Collaborative Systemic Changes (CSC) framework that extends the classic Technology-Organization-Environment (TOE) theory. It provided a way to adequately categorize the critical factors interrelated beyond organizational boundaries. An inductive case research used Formal Grounded Theory (FGT) to determine collaborative (social, interoperability, legal) factors that link the basic TOE factors in an integrated framework structure. Comparative analysis revealed collaborative sub-factors varied between studies and was more numerous than anticipated…too numerous to embrace and use. To establish a clear consensus, an online survey was conducted. A representative sample of 165 US contractors participated in the survey. Statistical analysis identified six factors - organizational variety, team BIM capability, scope of work, duty of care, risk and liability, and data preservation, as being distinct measures critical to the interorganizational BIM adoption. These six factors provided a guide for evaluating interorganizational BIM adoptability (I_BIMA). Utilization of the I_BIMA guide was demonstrated using quantitative data from three most recent BIM projects.

CHAPTER 1: INTRODUCTION

Adopting Building Information Modeling (BIM) requires an integrated framework to maximize adoption and implementation, which is currently lacking. There is lack of a clear consensus on the critical influential factors interdependent beyond organizational boundaries. BIM users lack an evaluation guide that simplifies strategic decisions as they interact in practice.

BIM-related technologies, commonly defined to include virtual workspace, necessitate interorganizational collaboration and systemic change to adopt to the fullest extent. This condition has proven difficult because of the industry competitiveness and a fragmented work environment. BIM uniquely shares the characteristics and is considered the core concept of virtual design and construction (VDC) technologies. It has the potential to expose inefficiencies that reduce the construction industry productivity (Eastman, et al., 2008). However, literature suggests the industry has not been able to fully utilize the technology, and its productivity has not improved. According to non-farm industry statistics, it is the construction industry whose productivity has decreased since 1964 (Dyer, *et al.*, 2012). The lack of an integrated framework to adopt BIM (AGC, 2010; Azhar, *et al.*, 2008) has made the adoption process sporadic, incomplete, and prohibitively shallow, particularly at an interorganizational level (Deutsch, 2011).

The extant literature offers various definitions, along with the many ways of categorizing the factors, in effort to explain the important difference between levels of BIM adoption, which may not be self explanatory to everyone. For example, researchers describe BIM as a cross-boundary technology (Oluwole, 2011) whose benefits are best realized when BIM generated data is shared at an interorganizational level (Ashcraft, 2008; Fox & Hietanen, 2007). Other studies consider interorganizational BIM as big BIM or a systemic innovation (Mutai, 2009; Taylor &

Levitt, 2004) that impacts projects over the long term. Other studies describe this adoption level as BIM Stage 3 (Succar, 2009), or Cloud BIM (Redmond, *et al.*, 2012). Interorganizational BIM is also described as collaborative BIM (AGC, 2005; Ashcraft, 2008; Singh, *et al.*, 2011). Useful frameworks along with the factors for enhancing the adoption and implementation of BIM have been presented. Despite a significant body of knowledge, the lack of an integrated framework for interorganizational BIM adoption prompted this study.

Besides an integrated framework, a clear consensus on the critical factors influences interorganizational BIM adoption. Grilo and Jardim-Goncalves (2010) found that previous research on BIM mainly discussed interoperability issues in connection with information systems. They argued that much less of the interoperability discussion includes cultural values, business process, and contractual relations that play a significant role among project team participants. On a similar perspective, Taylor and Bernstein (2009) noted that integrated technology benefits cannot be fully unleashed by only focusing on the issues of technological interoperability. This position was supported by Neff, *et al.* (2010) who found that organizations utilizing BIM technology were "tightly coupled technologically but organizationally separated". According to Mutai (2009), construction industry stakeholders lack a full understanding of the factors most influential to BIM adoption for best realization of benefits. Hence, establishing a clear consensus on the critical influential factors can enhance understanding to embracing the factors for best results.

Utilizing the critical factors as an evaluation guide that simplifies strategic decisions in practice is another important factor influencing BIM adoption. Studies (Grilo & Jardim-Goncalves, 2010; Taylor & Bernstein, 2009) commonly found that companies engaged in the sharing of BIM data across organizations essentially fall within four levels of interaction. The

four levels include, communication, coordination, collaboration, and network-based. According to Taylor and Bernstein (2009), nearly half of the companies studied had difficulty transitioning beyond coordination level. Their findings indicated a positive correlation between the levels of interaction and the number of BIM projects completed. However, further correlation between knowledge of the critical factors and the levels of interaction in practice was lacking. This correlation is necessary to simplify strategic decision choices confronting companies as they interact in practice.

1.1 Problem Statement

It was found that an integrated framework needs to be developed for the construction industry that optimizes interorganizational collaboration and systemic change while using BIM technologies. The framework needs to be effective so the industry can adopt BIM through a set of interdependent activities beyond their organizational boundaries. The adoption has been proven difficult because of industry competiveness and a fragmented work environment.

1.2 Specific Research Objectives

To solve the research problem, this study attempted to achieve the following three specific objectives (Figure 1.1).

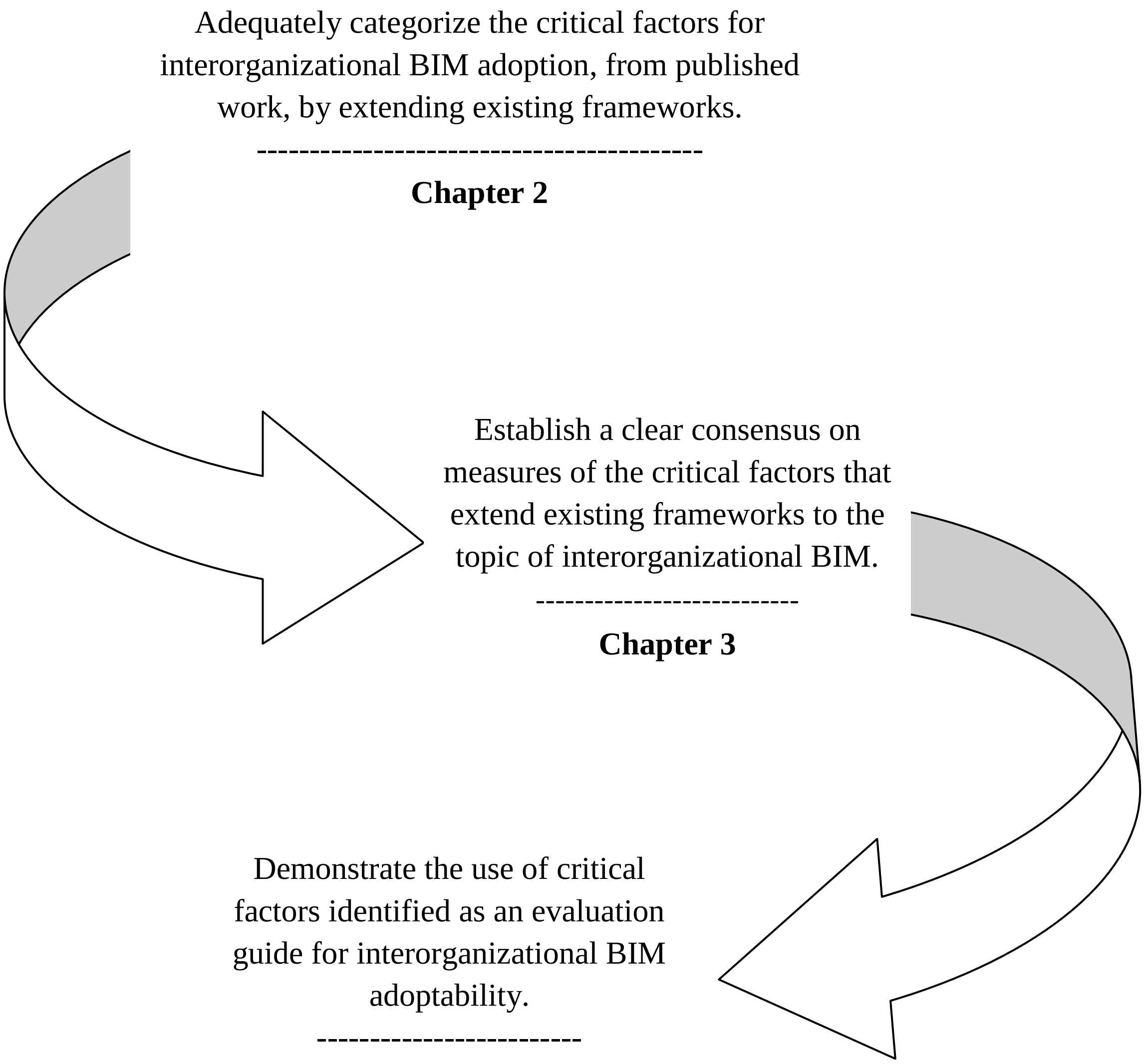

Figure 1.1: Specific research Objectives

1.3 Research Overview

Overview of the research design is provided next (Figure 1.2).

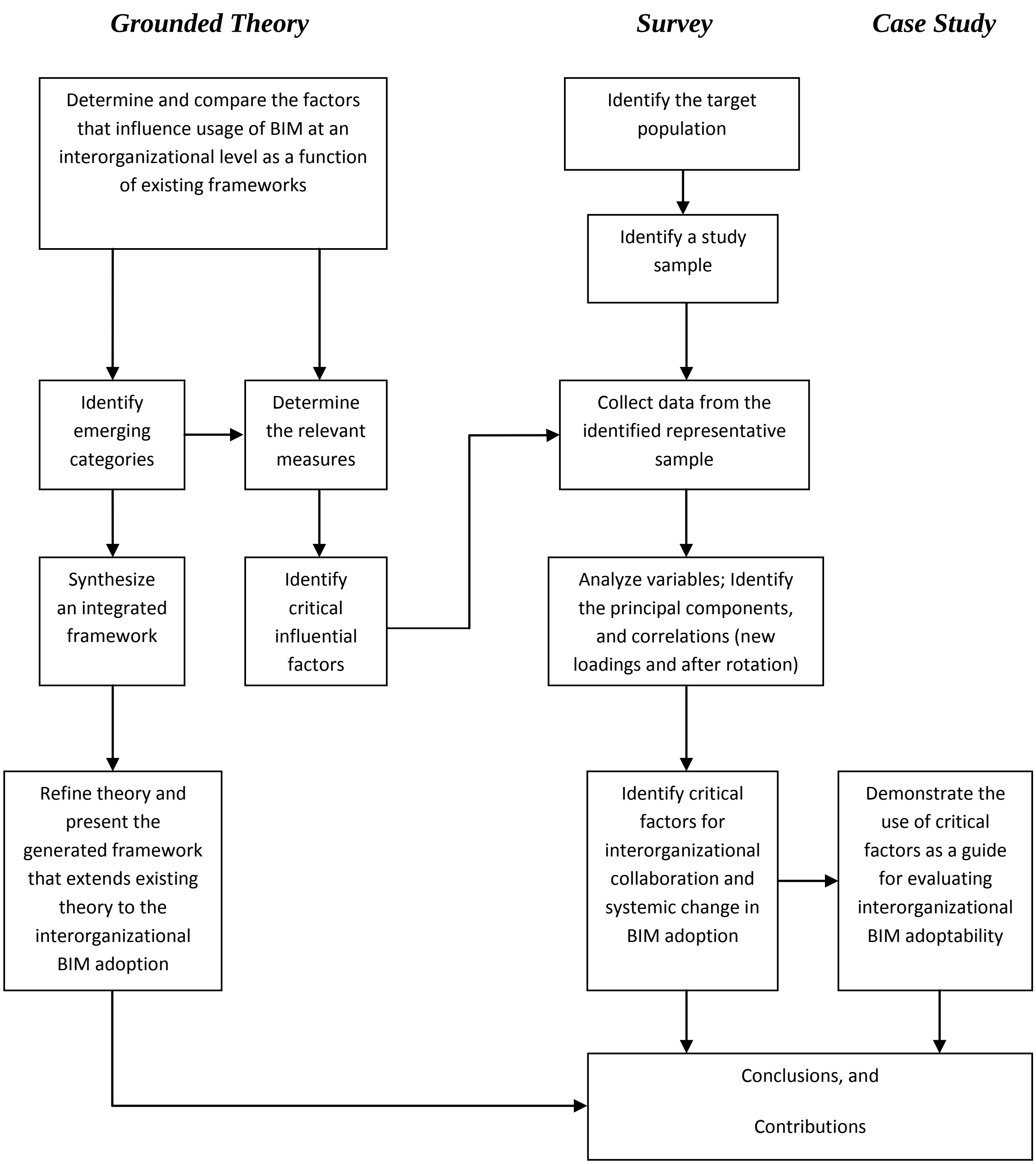

Figure 1.2: Research Overview

1.4 Format and Flow of this Dissertation

The results presented in this research followed the “journal article” format. Chapter 2 provides an inductive case research that made the Formal Grounded Theory (FGT) method more appropriate for use. This method extended existing theories to the topic of interorganizational BIM. Chapter 3 identifies the critical factors for interorganizational collaboration and systemic change necessary to adopt BIM. An online survey involved a representative sample of 165 US contractors. Chapter 4 demonstrates utilization of the identified critical factors, as an evaluation guide for interorganizational BIM adoptability (I_BIMA), using quantitative data from most recent BIM projects. Results further validated the identified factors as an evaluation guide for interorganizational BIM adoption. The use of I_BIMA simplifies strategic decision choices confronting BIM users as they interact in practice. Chapter 5 provides conclusions and contributions of the study, followed by a list of references and appendices.

CHAPTER 2: EXTENDING TECHNOLOGY-ORGANIZATION-ENVIRONMENT FRAMEWORK FOR INTERORGANIZATIONAL BIM ADOPTION

2.1 Synopsis

The construction industry lacks an integrated framework for interorganizational Building Information Modeling (BIM) adoption as existing frameworks do not adequately categorize the critical factors interdependent beyond organizational boundaries. Using a Formal Grounded Theory (FGT) approach, this study generated an interorganizational BIM adoption framework by determining and comparing factors that influence usage of BIM as a function of the classic Technology-Organization-Environment (TOE) framework. A Collaborative Systemic Changes (CSC) framework is presented, which integrates the two categories of factors that emerged from the analysis, representing organizational and interorganizational contexts, respectively: *basic factors* (technology-organization-environment), which are consistent with the TOE framework; and *collaborative factors* (interoperability-legal-social), which relate to the interdependency of activities beyond organizational boundaries. The CSC framework defines the specific practice environments (SPEs) of interorganizational BIM with the goal of informing construction stakeholders of best practices in maximizing interorganizational BIM adoptability.

2.2 Introduction

Building Information Modeling (BIM) offers the potential for more efficient construction project delivery, but requires an integrated framework to maximize adoption and implementation. Through digital representation of facility physical and functional characteristics (Mutai, 2009) using a relational database that offers active access for data use and sharing among stakeholders (Azhar, *et al.*, 2008; Mutai, 2009), BIM is a revolutionary technology that facilitates identification of inefficiencies that reduce productivity. The data sharing and collaboration inherent in BIM best suit it to the interorganizational level, where a multidisciplinary team of

companies is required to collaborate and accept changes in a coordinated fashion. However, a universal framework for its application in the construction industry is still needed (AGC, 2010; Azhar, *et al.*, 2008), which has made the BIM adoption process sporadic, incomplete, and prohibitively shallow, particularly at an interorganizational level (Deutsch, 2011).

The interorganizational scope of this study rendered adoption theories such as Technology Acceptance Model (TAM; Davis, *et al.*, 1989), TAM-2 (Venkatesh & Davis, 2000), Diffusion of Innovation Theory (DOI; Rogers, 1995), and Task Technology Fit (TTF; Goodhue & Thompson, 1995) inappropriate for use due to their units of analysis. Tornatzky and Fleischer (1990) provided a more appropriate organizational-level adoption theory through the Technology-Organization-Environment (TOE) framework, which is distinctive from other adoption theories in that it takes into account the influence of technological characteristics (Nikas, *et al.*, 2007). The factors comprising the TOE framework are: 1) T*echnology*, defined in terms of both the internal and external technologies relevant to the firm/organization, including existing technologies inside the organization and the pool of available technologies in the market; 2) *Organization*, defined in terms of organization size and scope; centralization, formalization, and intricacy of managerial structure; quality of human resources/required skills set; and internal slack resources; and 3) *Environment*, defined as the arena in which an organization conducts its business, including its industry, competitors, access to external resources, and government interaction (Tornatzky & Fleischer, 1990). The TOE framework is an often-cited theory that has demonstrated stability across multiple settings (e.g., technological, industrial, and national/cultural; Baker, 2012) and researchers agree that it has a solid theoretical basis for application to Information Systems (IS) innovation domains (Baker, 2012; Zhu, *et al.*,

2003). Hence, the TOE framework is the basis upon which an interorganizational BIM adoption theory was developed in this dissertation.

Baker (2012) found that researchers concur in principle that TOE factors influence adoption at a basic level, but assume that for each specific technology or context, there is a unique set of associated issues. For interorganizational BIM, factors outside the basic TOE factors have been identified, but have not been consistently defined (e.g. Mutai, 2009; Nikas, *et al.*, 2007; Oluwole, 2011; Succar, 2009; Taylor & Levitt, 2004; Thomson & Miner, 2006), nor has an integrated framework that describes all identified factors been developed. In its classical implementation, the TOE framework provides an inadequate theory for interorganizational BIM because it does not conceptualize collaborative factors that link basic TOE factors (Figure 2.1).

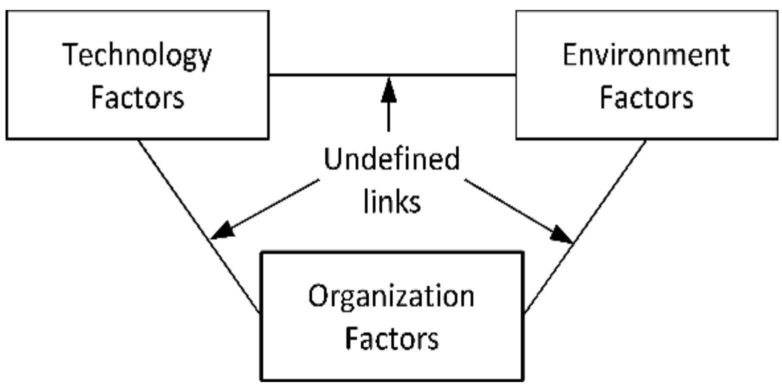

Figure 2.1: Existing TOE Framework does not have Defined Linkages Between Factors.

This study formalized a Collaborative Systemic Changes (CSC) framework that extended the classic TOE framework theory of general technological innovation adoption to the interorganizational context by defining the collaborative factors that link basic TOE factors in interorganizational BIM adoption specific practice environments (SPEs). The results of the formal grounded theory analysis showed that TOE factors are *basic factors* that influence BIM adoption with many *sub-factors* that are fully within the scope of TOE basic factors; however,

these basic factors do not fully describe issues that emerge as projects extend beyond organizational boundaries. *Collaborative factors* are defined as those that significantly influence the adoption process, are related to the interdependence of activities beyond organizational boundaries, and link basic factors in project-level SPEs. The identification of basic and collaborative factors will inform construction stakeholders of the SPEs where interdependent activities beyond organizational boundaries significantly affect the interorganizational BIM adoption process and the results of this study will provide an instrument for best practices in maximizing interorganizational BIM adoption.

2.3 Comparative Analysis of Critical Factors from Case Review

Creating a comprehensive framework for best practices in BIM adoption required identification of factors that influence utilization of BIM at an interorganizational level. Formal grounded theory (FGT) is a method in which a new theory is generated by building on prior research knowledge through constant comparative analysis (Eisenhardt & Graebner, 2007; Glaser & Strauss, 1967; Strauss & Corbin, 1998; Suddaby, 2006). Through FGT, the TOE framework was extended to the topic of interorganizational BIM adoption through comparative analysis of critical factors from case review, identification of emerging categories, and integration and theory refinement.

The review of previous work includes comparative analysis of critical factors among interorganizational BIM-related studies, and between interorganizational BIM-related studies and the classic TOE framework. This analysis sought to disclose varying interorganizational BIM adoption frameworks and identify the critical factors within the interorganizational context while synthesizing a unified structure through coherent concepts and categories. Thirteen cases were reviewed, two of which used and modified the classic TOE framework.

The following discussion and analysis reviewed relevant literature to describe the factors that have been identified as critical for interorganizational BIM adoption in order to identify emerging patterns and develop a theoretical framework. Figure 2.2 summarizes the discussion by presenting factor-patterns that identify emerging categories in descending date order.

Note: ☒ = Factor that was categorized as sub-factor in original work

Author & Year	Basic Factors			Collaborative Factors			**Total**
	Technology	Organization	Environment	Social	Interoperability	Legal	
Redmond, *et al.* (2012)		☒	☒	☒	X	X	**5**
Oluwole (2011)					☒	X	**2**
Singh, *et al.* (2011)		☒		☒	X	X	**4**
Deutsch (2011)	X	X		X	X	X	**5**
Grilo and Jardim-Goncalves (2010)					X		**1**
AGC (2010)	X			X			**2**
Mutai (2009)	X	X			☒	X	**4**
Succar (2009)	X	X	X		X	X	**5**
Ashcraft (2008)		☒				X	**2**
Nikas, *et al.* (2007)	X	X			☒		**3**
Thomson and Miner (2006)						X	**1**
Taylor and Levitt (2004)				X	X	X	**3**
Chau and Tam (1997)	X				☒		**2**
Frequency	**7**	**6**	**2**	**5**	**10**	**9**	**39**

Figure 2.2: Factor-Patterns and Emerging Categories

The sub-factors presented in the literature were categorized by identified factors in Figure 2.3, using only the authors' original words. The reader is encouraged to explore the original source for more information than can be coherently presented here. Figure 2.3 is also presented in descending date order.

T = Technology; O = Organization; E = Environment; S = Social; I = Interoperability; L = Legal

Basic	**T**	• Cost (Deutsch, 2011) • Technological challenges (Deutsch, 2011) • Technical (AGC, 2010) • Technology cost (Mutai, 2009) • Perceived technology difficultly (Mutai, 2009) • Software, hardware (Succar, 2009)	• Existence of separate IT department (Nikas, *et al.*, 2007) • Satisfaction with existing systems, (Chau & Tam, 1997) • Perceived barriers (Chau & Tam, 1997)

Figure 2.3a: Categorized Factors and Sub-Factors by Factor

O	• Education (Redmond, *et al.*, 2012) • Autonomy (Deutsch, 2011) • Education (Deutsch, 2011) • Project decision support (Singh, *et al.*, 2011) • Server administration support (Singh, *et al.*, 2011) • Help support and training (Singh, *et al.*, 2011) • Training (Mutai, 2009) • BIM experience (Mutai, 2009) • Job relevance (Mutai, 2009) • Internal support (Mutai, 2009)	• Leadership, infrastructure, human resources, products and services (Succar, 2009) • Top management support (Mutai, 2009) • Lack of immediate benefits accruing to the key adopter (Ashcraft, 2008) • Training in the last 3 years (Nikas, *et al.*, 2007) • Cost reduction (Nikas, *et al.*, 2007) • Number of employees (over 100) (Nikas, *et al.*, 2007), • Turnover category (over 50 M euro) (Nikas, *et al.*, 2007)
E	• Vendors (Redmond, *et al.*, 2012) • Preparatory (Succar, 2009)	• Regulatory environment (Succar, 2009)
S	• Training and cultural issues (Redmond, *et al.*, 2012) • Firm culture (Deutsch, 2011) • Communication (Deutsch, 2011) • Trust (Deutsch, 2011) • Working in teams (Deutsch, 2011) • Team communication and interaction (Singh, *et al.*, 2011)	• Psychological (AGC, 2010) • Communication improvement (Nikas, *et al.*, 2007) • Change in population of contractors from project to project (Taylor & Levitt, 2004) • Degree of interdependence (i.e. pooled, sequentially, or reciprocal) (Taylor & Levitt, 2004)
I	• Bandwidth (Redmond, *et al.*, 2012) • Interoperability of BIM software (Redmond, *et al.*, 2012) • Transparency (Redmond, *et al.*, 2012) • Drivers for Cloud BIM (Redmond, *et al.*, 2012) • Standard business practice (Redmond, *et al.*, 2012) • Technology shift (Redmond, *et al.*, 2012) • Energy performance analysis/identifying energy usage and demand (Redmond, *et al.*, 2012) • Using an internet platform to host data for post-occupancy calculations, specifications, and building performance (Redmond, *et al.*, 2012) • Interoperability (Deutsch, 2011; Mutai, 2009; Oluwole, 2011) • Standardization (Oluwole, 2011) • Value integration/intrinsic conflicts (Oluwole, 2011) • Commitment to IT innovation and deployment of the same in multidisciplinary context (Oluwole, 2011) • New set of skills required (Oluwole, 2011) • Integrated services (Oluwole, 2011) • Service framework (Oluwole, 2011) • Workflow (Deutsch, 2011) • Number of models (Deutsch, 2011)	• BIM model organization (Singh, *et al.*, 2011) • Model access and usability (Singh, *et al.*, 2011) • User Interface (Singh, *et al.*, 2011) • Design visualization and navigation (Singh, *et al.*, 2011) • Procedural flows (Succar, 2009) • Network (Succar, 2009) • Team BIM capability (Mutai, 2009) • Data misuse (Ashcraft, 2008) • Internet connection (Nikas, *et al.*, 2007) • ISO process certificate (Nikas, *et al.*, 2007) • % of employee with internet access (Nikas, *et al.*, 2007) • Usefulness digital transfer of data/information (Nikas, *et al.*, 2007) • IS standardization (Nikas, *et al.*, 2007) • Use of email for exchange of documents (Nikas, *et al.*, 2007) • Scope of the innovation (Taylor & Levitt, 2004) • The number of boundaries between trades that are spanned by a given systemic innovation (Taylor & Levitt, 2004) • Perceived importance of compliance to standards, interoperability and interconnectivity (Chau & Tam, 1997)

Figure 2.3b: Continued

L	• Security and legality (Redmond, *et al.*, 2012) • Current contracts (Redmond, *et al.*, 2012) • Design and operate (Redmond, *et al.*, 2012) • Model ownership (Oluwole, 2011) • Exposure of trade information (Oluwole, 2011) • Copyright issues (Oluwole, 2011) • Authorization of e-documents (Oluwole, 2011) • Validity and unauthorized uses of models (Oluwole, 2011) • Standard remuneration (Oluwole, 2011) • New sets of professional responsibilities (Oluwole, 2011) • Addendum to professional scales of fees (Oluwole, 2011) • Cyber security (i.e. snooping, theft, virus and worms, and hacking) (Oluwole, 2011) • Indefatigability of e-documents as evidence (Oluwole, 2011) • E-contracts (Oluwole, 2011) • Disclaimer clauses (Oluwole, 2011) • Errors emanating from other contributors (Oluwole, 2011) • Responsibility (Deutsch, 2011)	• Features supporting confidentiality, integrity, and availability (Singh, *et al.*, 2011) • System security (Singh, *et al.*, 2011) • User authentication (Singh, *et al.*, 2011) • Data security (Singh, *et al.*, 2011) • Access control (Singh, *et al.*, 2011) • Encryption (Singh, *et al.*, 2011) • Legal and contractual support (Singh, *et al.*, 2011) • Liability (Mutai, 2009) • Scope of work (Mutai, 2009) • Risk factors (Mutai, 2009) • Re-evaluation of contractual relations (Succar, 2009) • Risk-allocation models (Succar, 2009) • Intellectual property (Ashcraft, 2008) • Legal status of the model (Ashcraft, 2008) • Standard of care (Ashcraft, 2008) • Design delegation (Ashcraft, 2008) • Loss of data (Ashcraft, 2008) • Information ownership and preservation (Ashcraft, 2008) • Absence of standard contracts (Ashcraft, 2008) • Project delivery method (Mutai, 2009) • Rigid boundary that separate the impacted trades for a given systemic innovation (Taylor & Levitt, 2004)

Figure 2.3c: Continued

In the literature, there are consistencies in both factors and definitions of the interdependency of activities beyond organizational boundaries; however, collaborative factors have not been distinctly categorized at the same level as the basic TOE factors.

Through factor-patterns provided in Figure 2.2 and further categorized into sub-factors in Figure 2.3, collaborative *social*, *interoperability*, and *legal* factors clearly emerged that necessitated extension of the TOE framework beyond organizational boundaries (i.e., the interorganizational context). The following analysis describes three collaborative factors: *social* – people-oriented factors, including thoughts, processes, and issues toward BIM technology applications; *legal* – legal instruments, including laws, regulatory frameworks, codes and industry standards; and *interoperability* – related to the need to pass data between BIM

applications allowing multiple architecture, engineering, and construction (AEC) experts to contribute their input to the design and construction.

Factors from the reviewed literature were categorized in accordance with the definitions presented in this work. When factors from the literature were identical to basic and collaborative factors identified in this research, these factors were presented in italics, with sub-factors, when clearly provided, subsequently listed in plain text. In many cases, factor names with similar intent appeared in the literature (e.g. “human factors” fall under the organizational factor in the TOE framework) – in these instances, the original authors’ words were used, followed by the first letter of the categorized factor in parentheses (i.e., T, O, E, S, I, L, indicating technology, organization, environment, social, interoperability, and legal, respectively). In some studies, factors were categorized as sub-factors as indicated in Figure 2.3. Care was taken to present the original authors’ taxonomy of sub-factors; however, when individual sub-factors were classified under one of the six basic and collaborative factors defined in this study, the first letter of the categorized factor was listed in parentheses after individual sub-factors. In some cases, many issues were discussed in single-factor papers; however, only those clearly presented as sub-factors were listed.

Redmond, *et al.* (2012) interviewed eleven experts regarding “Cloud BIM”, which is comparable to interorganizational BIM, and identified the following critical factors for collaborative work environments and faster and more economic information exchange: capability of cloud computing (I), defined in terms of security /legality (L), bandwidth, and education (O); interoperability of BIM software (I); contractual issues (L), defined in terms of current contracts, training and cultural issues (S), vendors (E), and transparency; business process (I) defined in terms of drivers for Cloud BIM, standard business practice, technology shift, and design and

operation (L); information exchange (I), defined in terms of energy performance analysis/identifying energy usage and energy demand; and Cloud-Based BIM life cycle (I), defined as the use of an internet platform to host data for post-occupancy calculations, specifications, and building performance (Redmond, *et al.*, 2012). Using a focus group and case study, Singh, *et al.* (2011) identified the following technical requirements for using BIM-server as a multi-disciplinary collaboration platform: BIM model management-related requirements (I), defined in terms of BIM model organization, model access and usability, and user interface; design review-related requirements (I), defined in terms of design visualization and navigation, and team communication and interaction (S); data security-related requirements (L), defined in terms of features supporting confidentiality, availability, and integrity, user authentication, system security, data security, access control, and encryption; and the set-up of BIM-server, its implementation, and requirements to assist its usage (O), defined in terms of project decision support, server administration support, help support and training, and legal and contractual support (L).

Mutai (2009) surveyed the US construction industry for BIM use and identified the following as critical factors: human (O), defined in terms of top management support, training, team BIM capability (I), BIM experience, job relevance, and internal support; *technology*, defined in terms of perceived technology difficulty, interoperability (I), technology cost; and risk factors (L), defined in terms of scope of work (I), liability, and project delivery method. Mutai referred to interorganizational BIM as big BIM, defined as a coordinated interdepartmental and interorganizational use of BIM-generated data (Mutai, 2009). Applying a mixed-method approach, including inductive inference of BIM concepts through observation and discovery, Succar (2009) determined that some observables could be usefully grouped to generate

conceptual clusters. An interlocking BIM framework was developed comprising: *technology*, defined in terms of software, hardware, network (I); process (O), including leadership, infrastructure, human resource, product and services; and policy (E), defined in terms of contractual (L), regulatory, and preparatory. In a specific discussion of BIM Stage 3 (i.e., network-based integration), Succar (2009) described that its adoption requires major re-evaluation of contractual relations (L), risk-allocation models (L), and procedural flows (I).

Oluwole (2011) focused primarily on the *legal* factor, defining *legal* limitations of BIM use in terms of duty of care (i.e. model ownership, exposure of trade information, copyright issues, authorization of e-documents, and validity and unauthorized uses of models), obligations (i.e. new set of skills required, integrated services, and service framework), consideration (i.e. standard remuneration, new sets of professional responsibilities, and addendum to professional scales of fees), jurisdiction (i.e. indefatigability of e-documents as evidence, e-contracts, disclaimer clauses, and errors emanating from other contributors), tools (I) (i.e. interoperability, standardization, value integration/intrinsic conflicts, and commitment to IT innovation and deployment of the same in multidisciplinary context), and cyber security (i.e. snooping, theft, virus and worms, and hacking). The study defined BIM as a cross-boundary technology whose legal instruments are limited by geographical boundaries whereas virtual enterprising enjoys unlimited boundary of the ‘global village’ (Oluwole, 2011). Ashcraft (2008) defined the *legal* barriers to BIM use in terms of data translation/interoperability, data misuse, intellectual property, loss of data, legal status of the model, standard of care, design delegation, and information ownership and preservation. The study also defined commercial barriers in terms of lack of immediate benefits accruing to the key adopter (O), and absence of standard contracts. Thomson and Miner (2006) also discussed the *legal* issues in BIM use, including the question of

ownership of the BIM data and how to protect it through copyright and other laws, as well as who will control the entry of data into the model and be responsible for any inaccuracies in it. Other issues identified were responsibility for proper technological interface among various programs, and the fluidity and speed by which an electronic design can be changed. Although these studies focused primarily on legal issues rather than presenting a more comprehensive framework, they add valuable information to the definition of the legal factor in an integrated framework.

Using a modified mixed-influence model to include the various types of innovation at a market level, Taylor and Levitt (2004) identified the following factors as critical to systemic innovations adoption: organizational variety (S), defined as the change in population of contractors from project to project; degree of interdependence (S), defined as pooled, sequentially, or reciprocal; boundary strength (L), defined in terms of rigid boundary that separate the impacted trades for a given systemic innovation; span (I), defined in terms of the number of boundaries between trades that are spanned by a given systemic innovation; and scope of the innovation (I), referring to this as systemic as opposed to incremental innovations. The study concluded that the diffusion rate of systemic innovations in construction is negatively related to the influential factors identified. A study by Mutai (2009) likened big BIM to systemic innovations, which impact projects over the long term while necessitating a change by multiple organizations in a coordinated fashion (Taylor & Levitt, 2004). However, both cases did not integrate the identified critical factors with the specific technology and environment circumstances of an adopting organization.

Grilo and Jardim-Goncalves (2010) summarized *interoperability* challenges of BIM use in terms of heterogeneous applications and systems typically in use by the different stakeholders,

and the dynamics and adaptability needed to operate in the AEC sector. Adopting normalized methodologies and platforms has been recommended to seamlessly share BIM-generated data at a project level (Grilo & Jardim-Goncalves, 2010). In their study, Nikas, *et al.* (2007) presented a framework capturing the factors that influence adoption of collaboration technologies in the construction industry. The study applied and further modified the TOE framework by Tornatzky and Fleischer (1990), separating adoption factors into antecedents and drivers. Focusing the analysis on the organizational level, the authors surveyed 285 companies in the Greek construction industry. Significant antecedents included; technological installed base (I), defined as internet connection, percent of employee with internet access, and usefulness digital transfer of data/information; IT department quality (T), defined in terms of existence of separate IT department, and training in the last 3 years; top management support (O) referred to ISO process certificate (I); and collaborative work practices (I) that was defined in terms of use of email for exchange of documents. Significant drivers included organizational drivers (O), defined as cost reduction, IS standardization (I) and communication improvement (S); and organizational characteristics (O), which includes number of employees (over 100), and turnover category (over 50 M euro). A collaborative technology was defined as a sociotechnical technology in which people, systems, and processes continuously interact (Nikas, *et al.*, 2007), and is comparable to interorganizational BIM. However, Nikas, *et al.* (2007) discussed web-based collaborative technologies, which researchers argue that the level of trust placed in web-based applications and services like email and social sites that synchronize data, time, and place has not transferred over to construction management solutions (CTI, 2012). This explains why the legal factor is latent in their framework.

Chau and Tam (1997) developed an open systems model based on the TOE framework by Tornatzky and Fleischer (1990). The study interviewed 89 respondents and the following factors were identified significant to open systems adoption: organizational technology (O), defined in terms of satisfaction with existing systems (T); and characteristics of the "open systems technology" innovation (T), defined in terms of perceived barriers, interoperability, interconnectivity, and perceived importance of compliance to standards (I) (Chau & Tam, 1997). The study described open systems as a major paradigm shift in information systems development and management, similar to interorganizational BIM. They challenged the locus of this pervasive development, arguing that it requires increasing attention focused on standard compliance. Chau and Tam added that such a change not only affects the technical aspect of an information technology-IT infrastructure but also requires a redesign of its administrative procedures and operation mechanism.

Deutsch (2011, p. 23) summarized twelve obstacles to successful adoption of BIM and integrated design collaboration: cost (T), *interoperability*, responsibility (L) workflow (I), firm culture (S), number of models (I), autonomy (O), education (O), communication (S), technological challenges (T), trust (S), and working in teams (S). Deutsch noted that people-oriented factors present a greater challenge than resolving the software, business, and technical issues related to BIM implementation. This insight is shared by the AGC (2010) that described challenges to BIM adoption as being 10% technical (T) and 90% psychological (S), describing the psychological factors as changing ways of working and thinking to a lateral, rather than linear, fashion and adopting the concept that success or failure is a team responsibility.

Thirty-nine factors were defined in the thirteen reviewed studies that focused on interorganizational BIM adoption (Figure 2.3). Basic factors (i.e., TOE) constituted 38.5% of

the identified factors (15 of 39). Of these basic factors, technology, organization, and environment were identified with frequencies of 17.9% (7 of 39), 15.4% (6 of 39), and 5.1% (2 of 39), respectively. It is noteworthy that although Succar (2009) identified all three basic factors, this study was not founded in the TOE framework. Conversely, the TOE framework was modified by Nikas, *et al.* (2007) and Chau and Tam (1997), who both found environment factors to be insignificant in the interorganizational context. Although environment factors appear most infrequently, many traditional environment factors fall under interoperability at the interorganizational level, and a corresponding increase in interoperability factors is evident.

Collaborative factors (i.e., SIL) constituted 61.5% of the identified factors (24 of 39). Of these collaborative factors, social, interoperability, and legal were identified with frequencies of 12.8% (5 of 39), 25.6% (10 of 39) and 23.1% (9 of 39), respectively. While research indicates social factors present the most significant barrier and one that significantly influences the success of BIM adoption (AGC, 2010; Deutsch, 2011; Yan & Damian, 2008), there has been a dearth of social factor research related to interorganizational BIM adoption.

Table 2.2 comprises one hundred thirteen (113) sub-factors closely reflecting the frequencies of the six factors presented in Table 2.1. The basic (TOE) sub-factors were infrequently identified with a total frequency of 25.7% (29 of 113) and respective frequencies of 8.0% (9 of 113), 15.0% (17 of 113), and 2.7% (3 of 113) compared to the collaborative (SIL) sub-factors with a total frequency of 74.3% (84 of 113) and respective frequencies of 8.8% (10 of 113), 31.9% (36 of 113), and 33.6% (38 of 113). While sub-factor frequencies are relevant to development of an interorganizational BIM adoption theory, the sub-factors listed in Figure 2.3 constituted raw data, where future refinement to develop factor ontology and taxonomy would provide valuable information about distinct sub-factors that are critical for BIM adoption.

The vast majority of the reviewed studies generally presented collaborative factors as sub-factors, and when framework structures were provided, they were similar to the classic TOE framework (Figure 2.1) without visualization of factor interaction. Of all the reviewed studies, only Succar (2009) presented factors in an integrated, overlapping structure. Based on Succar's process-based framework structure and the cross-classification of basic and collaborative factors and sub-factors present in the other studies reviewed, the results of the FGT analysis pointed to the need for a modified framework structure that defines collaborative factors as links connecting the basic TOE factors.

2.4 Integration and Theory Refinement

To generate a Collaborative Systemic Changes (CSC) framework theory, basic and collaborative factors were integrated with collaborative factors present at the nexus of two basic factors, yielding specific practice environments (SPEs) at an interorganizational level where collaborative factors significantly affect the adoption process as the adoption of BIM increases from organizational to an interorganizational level. The overlapping basic factors yielded three SPEs: Technology-Interoperability-Organization, Organization-Legal-Environment, and Technology-Social-Environment.

2.4.1 Technology-Interoperability-Organization SPE

Utilization of BIM at a project level brings together a multidisciplinary team of companies to co-create a boundary object, which necessitates re-evaluation of technological platforms to seamlessly share information (Eastman, *et al.*, 2008; Taylor, 2005). Due to heterogeneity of technology platforms, dynamics and adaptability are needed to successfully utilize the technology (Grilo & Jardim-Goncalves, 2010). Interoperability issues are therefore described in

this present study at the nexus of the basic technology and organization factors in practice, yielding the Technology-Interoperability-Organization SPE (Figure 2.4).

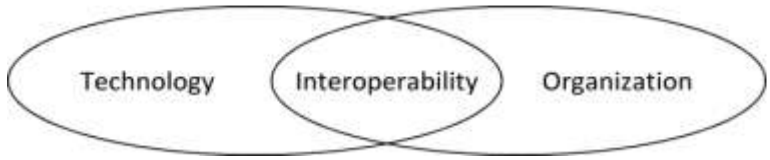

Figure 2.4: Technology-Interoperability-Organization Specific Practice Environment

2.4.2 Organization-Legal-Environment SPE

Although the construction industry is shifting toward innovative processes to improve project performance, existing contractual frameworks are prohibitive to universal transactions (Ashcraft, 2008; Oluwole, 2011). Organizations are legally distinct; as a consequence, working in collaboration requires addressing legal issues resulting from contractual agreements to protect organizations from potential risks that may discourage full implementation of BIM. This implied the legal factor overlaps the organization and environment basic factors. This overlap yielded the Organization-Legal-Environment SPE (Figure 2.5).

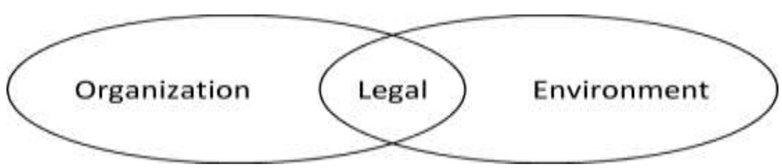

Figure 2.5: Organization-Legal-Environment Specific Practice Environment

2.4.3 Technology-Social-Environment SPE

The challenge of BIM adoption is considered more sociological (90%) than technical (10%) (AGC, 2010). The structural mechanisms of project-based organizations require organizations

involved with BIM projects to invest in extra coordination to pursue team objectives while enhancing teamwork (Taylor & Levitt, 2004). This understanding was particularly important in considering the influence of social factors on the BIM adoption within the interorganizational context. Universal changes required at an interorganizational level in BIM projects shift traditional approaches to a more collaborative environment (Wikforss & Löfgren, 2007). This shift changes ways of working and thinking to a lateral, rather than linear, fashion (AGC, 2010). This required that the social factors of BIM technology overlap the technology and environment basic factors, yielding the Technology-Social-Environment SPE (Figure 2.6).

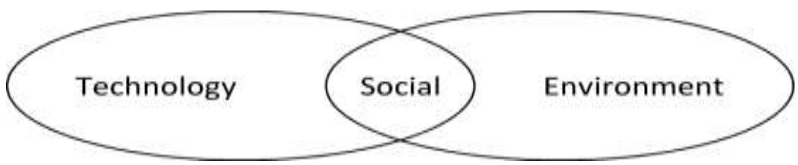

Figure 2.6: Technology-Social-Environment Specific Practice Environment

2.4.4 Summary of Findings

Successful implementation of interorganizational BIM technology necessitates collaboration and systemic change across multiple companies. To reflect such characteristics, this study generated a Collaborative Systemic Changes (CSC) theoretical framework that defines critical adoption factors, as well as the relationship between factors. Overlapping sections of the CSC framework (Figure 2.7) provided SPE where collaborative factors significantly affect the process as BIM adoption increases from organizational to an interorganizational level. The intersection of all critical factors provided a fully interactive environment where BIM is most effectively implemented.

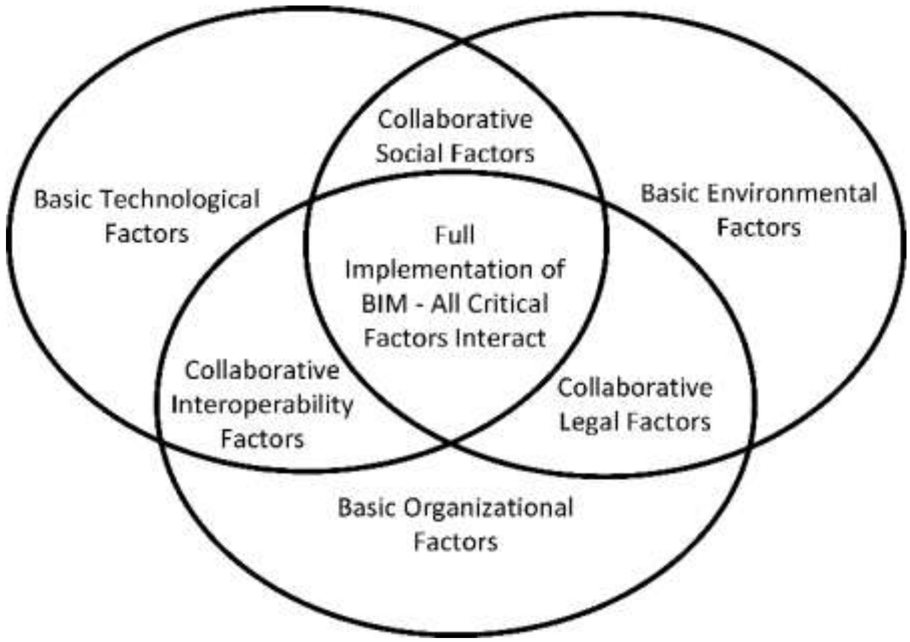

Figure 2.7: Collaborative Systemic Changes (CSC) Framework

2.5 Conclusion: Extending Technology-Organization-Environment Framework for Interorganizational BIM Adoption

There are many ways of categorizing the factors influential to the adoption of technologies that involve interdependency of activities at a project level, too numerous for the AEC community to embrace and use. In this study, a comprehensive CSC framework for the adoption and implementation of BIM at an interorganizational level was developed. The CSC framework represents best practices that allow multiple companies to more effectively interact and accept changes in a coordinated fashion than existing BIM adoption frameworks. This framework embraced both the fragmented nature of the construction industry and the unique characteristics of the technologies that involve interdependency of activities at a project level. The developed framework introduced basic and collaborative factors, respectively representing organizational and interorganizational contexts. Collaborative factors link the basic TOE factors in an integrated framework structure that is novel to classic TOE theory. The CSC enhances understanding of the

distinction between organizational and interorganizational BIM factors, which is vital to managing challenges within specific adoption contexts.

The developed CSC framework informs stakeholders of best practices for facilitating and enhancing teamwork within the competitive construction environment. It facilitates an integrated information infrastructure, and addresses legal issues resulting from contractual agreements to shield organizations from potential risks that may discourage the adoption and use of BIM at an interorganizational level.

CHAPTER 3: CRITICAL FACTORS FOR INTERORGANIZATIONAL COLLABORATION AND SYSTEMIC CHANGE IN BIM ADOPTION

3.1 Synopsis

Interorganizational collaboration and systemic change are necessary for best realization of Building Information Modeling (BIM) benefits but can be difficult where a clear consensus on the critical influential factors is lacking. This study identified those distinct factors that are critical to the interorganizational BIM adoption. Through Formal Grounded Theory (FGT), measures interrelated beyond organizational boundaries were termed collaborative. The identified measures, however, were numerous and varied between studies. An online survey of 165 US contractors yielded six critical factors that established a clear consensus on measures spanning 13 interorganizational BIM literatures. The identified factors (organizational variety, team BIM capability, duty of care, risk and liabilities, scope of work, and data preservation), formed the final scale that provided an instrument for evaluating collaboration and systemic change necessary to adopt BIM.

3.2 Introduction

Interorganizational collaboration and systemic changes are necessary to adopting Building Information Modeling (BIM) for best realization of benefits but can be difficult where a clear consensus on the critical influential factors is lacking. The extant literature identifies significant influential factors for BIM or virtual design and construction (VDC) technologies, e.g. open systems (Chau & Tam, 1997), collaborative technologies (Nikas, *et al.*, 2007), BIM (Ashcraft, 2008; Deutsch, 2011; Mutai, 2009; Oluwole, 2011; Redmond, *et al.*, 2012; Singh, *et al.*, 2011; Succar, 2009), and systemic innovations (Taylor & Levitt, 2004). Despite previous efforts, variations between studies make the distinct critical measures unclear, requiring further research.

BIM uniquely shares the characteristics of VDC technologies and is considered the future of the construction industry (Eastman, *et al.*, 2008). However, utilizing BIM for best results requires an integrated universal framework that adequately categorizes the critical factors, which is currently lacking (Azhar, *et al.*, 2008). A Collaborative Systemic Changes (CSC) framework was generated (Chapter 2) through a Formal Grounded Theory (FGT) approach. The CSC framework extended the classic technology-organization-environment (TOE) framework (Tornatzky & Fleischer, 1990), integrating *basic factors* (technology-organization-environment), which are consistent with the TOE, and *collaborative factors* (interoperability-legal-social) that relate to the interdependency of activities beyond organizational boundaries; respectively representing organizational and interorganizational contexts, as indicated in Figure 3.1.

Distinct measures for the basic factors fall entirely within the scope of the TOE framework and, as a consequence, were accepted here as critical to the adoption of BIM at an organizational or a company level. Meanwhile, the identification of collaborative measures was numerous and varied between studies.

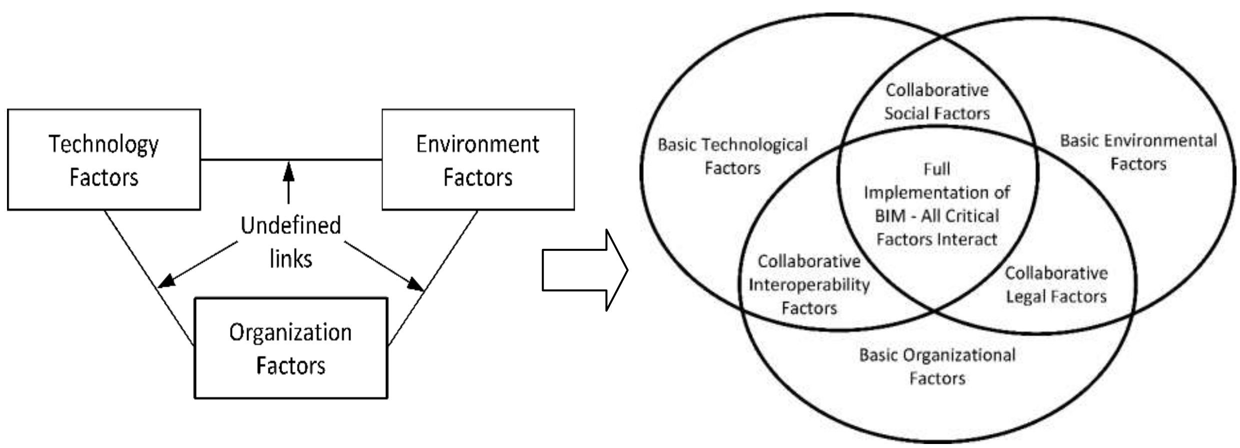

Figure 3.1: Extending the Technology-Organizational-Environment (TOE) Framework for Interorganizational BIM Adoption

The variation necessitated further research to determine those distinct measures that are critical to the interorganizational level. The following section examined background information to the study and evidence that begins to address the need for establishing distinct measures for interorganizational collaboration and systemic change in BIM adoption, with survey results from a representative sample of the US contractors.

3.3 Literature Review

Understanding the context of adoption is vital as it significantly contributes to any type of critical factors' interaction between the context and the technology being adopted (Linderoth, 2010). BIM is an example of VDC technologies that have been defined as socio-technical systems in which people, systems, and processes are the culture bed of information infrastructure and are in a continuous interaction (Ciborra, 2000; Nikas, et al., 2007). However, there are currently various ways of categorizing and describing the factors influencing interorganizational BIM adoption that may not be self explanatory to everyone. Moreover, the extant literature indicates the identified influential factors are not perceived as an interconnected facet to reflecting the defined interactivity. For example, despite the argument that social/cultural factors are the biggest barrier to the adoption of BIM (Yan & Damian, 2008), literature review found a dearth of research on the social factors (i.e. social factors were least represented in frequency compared to interoperability and legal factors). A later study (Ku & Taiebat, 2011) also reveled that contractors perceive interoperability as an issue for software developers rather than their knowledge domain.

Interoperability has been described as inclusive of the entire project practices in the interorganizational exchange of BIM data. However, Grilo and Jardim-Goncalves (2010) found that interoperability issues have been discussed in terms of connecting information systems and

much less included values related to culture, business process, as well as contractual relations that play a significant role among project team participants. Taylor and Bernstein (2009) noted that focusing on the issues of technological interoperability alone cannot fully unleash the benefits of an integrated technology. Neff, et al. (2010) later supported this position, noting, organizations utilizing BIM technology were “tightly coupled technologically but organizationally separated”. Developing an integrated framework was therefore necessary to incorporate all the critical adoption factors to the adoption of BIM, and define the relationship between the factors relative to the specific contexts of adoption to facilitate contextual specific strategies.

3.3.1 Comparison with previous studies

Most BIM or VDC studies identify the factors influencing the adoption process but do not particularly focus on the interorganizational context (Becerik-Gerber & Rice, 2010; Deutsch, 2011; Eastman, *et al.*, 2008; Gu & London, 2010; Khanzode, *et al.*, 2006; Mutai, 2009; Neff, *et al.*, 2010; Nikas, *et al.*, 2007; Succar, 2009; Taylor & Levitt, 2004; Thomson & Miner, 2006; Won, *et al.*, 2013). For studies that include a discussion on the interorganizational context, results vary between studies, lacking a common agreement on the critical influential factors. Moreover, only a few of these studies presented their report as a result of a survey. It is assumed that respondents’ perception and knowledge is representative of their organization’s view point in terms of philosophy and company goals (Ku & Taiebat, 2011).

Among the reviewed cases leading to this present study is a dissertation by Mutai (2009). Mutai surveyed 113 leading construction companies in the US and examined the factors influencing BIM use. The study was general to BIM adoption, although discussed big BIM that was likened to interorganizational BIM (Fox & Hietanen, 2007) and systemic innovations

(Taylor & Levitt, 2004). Mutai's theoretical model was derived from theories including, Technology Adoption Model (TAM) (Davis, *et al.*, 1989), TAM-2 (Venkatesh & Davis, 2000), Diffusion of Innovation (DOI) (Rogers, 1995), and Task-Technology Fit (TTF) (Goodhue & Thompson, 1995). Unlike the TOE framework, these theories have been criticized for not considering the influence of technological characteristics of the novel technology being adopted (Nikas, *et al.*, 2007).

Nikas, et al. (2007) examined factors influencing the adoption of web-based collaborative technologies, through modification of the TOE framework. Their research surveyed a sample of 285 design, construction, and consulting companies. However, it has been noted that the level of trust placed on web-based applications, and similar services such as email and social sites that synchronize information, has not yet transferred to the construction managements solutions (CTI, 2012). Further research was necessary to determining the critical factors that commonly apply to the construction management solutions, particularly BIM. Chau and Tam (1997) also modified the TOE framework and developed a model for open systems adoption. Significant factors were identified through a survey of 89 construction companies. However, the factors were not conceptualized as being interrelated, and the end structure did not differ from the TOE framework.

Redmond, et al. (2012) interviewed 11 experts on "Cloud BIM" and identified significant influential factors. However, conceptualization of factors was different from the present study. In addition, generalization of results to a larger population of BIM users is limited by sample size. Utilizing a focus group and a case study, Singh, *et al.* (2011) focused on identifying the technical requirements for using BIM-server, which was described as a platform for multidisciplinary collaboration. While provided a detailed discussion on collaboration, focusing on the technical

requirements suggested the need to adequately incorporate non-technical requirements for a comprehensive strategy. Other studies (Ashcraft, 2008; Oluwole, 2011; Thomson & Miner, 2006) identified influential factors to BIM adoption, primarily focusing on legal factors.

Through BIM ontology, Succar (2009) identified influential factors to BIM adoption. The research developed an interlocking framework, which was not derived from the TOE theory and did not conceptualize the factors as basic and collaborative in an interrelated fashion. In addition, the study was general to BIM adoption and did not particularly provide clear distinction relative to the contexts of adoption. Deutsch (2011) identified influential factors to BIM adoption by examining a design/architectural company as a case study. However, literature indicates that design companies take the lead in BIM adoption while contractors lag behind (Mutai, 2009; Suermann & Issa, 2009). Expanding research to other stakeholders, particularly contractors, was necessary contribute to a more comprehensive interorganizational BIM strategy.

Adopting interorganizational BIM presents major challenges, among them the need to link up information systems across company borders, transform contractual arrangements to guide the shared information, and increase mutual adjustment among team members. The three challenges are respectively categorized here as *collaborative* interoperability, legal, and social factors (Chapter 2). These factors have previously been well researched but mostly in separation and in some cases as sub-factors to one another, as described in the review of literature. A summary of the influential factors identified through the aforementioned studies is shown in Figure 2.3, page 11.

3.3.2 The level of BIM use

It has been noted that issues related to the use of BIM technology arise from either the technology itself or from the way the technology is used (Ashcraft, 2008). Further, Ashcraft

noted that utilizing BIM internally, within organizational boundaries, such as for production of better quality design documents, receives limited resistance from users. However, when used for collaborative data sharing, BIM creates not only opportunities for reforming project delivery, but also new challenges that need to be addressed and resolved (Ashcraft, 2008; Mutai, 2009).

Different studies have discussed the need for all project teams to be able to use BIM technology; referring to this as team BIM capability (Eastman, *et al.*, 2008; Fox & Hietanen, 2007; Succar, 2009). The challenge, however, is to ensuring that every participant to the project has the requisite technology and skill set, and the willingness to participate in the creation and use of BIM models (Eastman, *et al.*, 2008). The reason being, companies involved with BIM projects are required to commit in collaborative arrangements and accept changes in a coordinated fashion. This requirement is contrary to a fragmented work environment of the construction industry that promotes competition and does not support collaboration. It was therefore expected that interorganizational BIM users would have more encounters with the collaborative factors than companies that exchange data within organizational boundaries.

3.3.3 Project delivery method

Depending on the project delivery method, however, the level of challenges encountered at an interorganizational level may vary between companies. New approaches such as integrated delivery methods have been proposed to solve fragmentation related problems and case studies on the successful use of the approaches have been documented (Khanzode, *et al.*, 2006). It is argued, for example, that the set-up of design/build companies supports BIM adoption due to the fact that team collaboration is made easier (Ashcraft, 2008; Eckblad, *et al.*, 2007) as everything is done under one roof.

Researchers on BIM note that the design/build delivery system helped the construction industry take a step toward a more collaborative project environment. They believe that that integration of BIM technology into the process will be the industry's next revolutionary step (Thomson & Miner, 2006). The generated CSC framework (Chapter 2) represents best practices for interorganizational collaboration and systemic changes in the construction industry. The integration of the six critical factors in the CSC framework echoes the design/build companies' set-up. The CSC framework can, therefore, be viewed as a hypothetical design/build set-up company. It was expected that design/build companies, whose team collaboration is made easier, would find the collaborative factors significantly less inhibiting important in practice than non-design/build companies.

3.3.4 Levels of Interaction in BIM Projects

In effort to clarifying the impact of BIM technology on projects, its adoption has been described in various ways including, interaction types (Grilo & Jardim-Goncalves, 2010), BIM paradigm trajectories (Taylor & Bernstein, 2009), BIM stages (Succar, 2009), impact level (Taylor & Levitt, 2004), or scale (Mutai, 2009). Grilo and Jardim-Goncalves (2010) described inter-company processes at coordination and cooperation levels as having no difference from the traditional approaches. This suggested that certain elements of cooperation are shared both at the coordination and collaboration levels. They exemplified the cooperation level by supply chain activities. Meanwhile, Taylor and Bernstein (2009) and Succar (2009) both put supply chain at the highest level (level 4) of interaction. Similarly, interdisciplinary BIM models and complex analyses were presented at the highest level of interaction (Succar, 2009). As a consequence, this present study adapted the four levels of interaction that share common features across these studies; communication, coordination, collaboration, and network-based that includes supply

chain (Table 3.1). These were incorporated into the survey instrument for determining the most influential factors relative to the company's level of interaction.

Taylor and Bernstein (2009) found that nearly half of the companies that utilized BIM were still at the coordination (second) level of interaction. The highest (fourth) level of interaction was reached by those companies that had a wealthy of experience in BIM use (completing between 6 and 25, or more than 26 BIM projects). According to their study, none of BIM users at the coordination level had completed more than five BIM projects. This explained the significance of BIM experience in attaining the requisite BIM capability as the levels of interaction evolve in practice. Taylor and Bernstein further described their findings to suggest that most companies' face difficulty transitioning beyond the coordination level. Meanwhile, literature suggests that large size companies, backed up by the amount of resources available, are more likely to adopt new innovations, such as BIM, than small size companies.

While the factors influencing specific related technologies have been identified in previous research, a broader and more inclusive assessment of the factors from the perspective of interorganizational collaboration and systemic change necessary to adopting such technologies in a fragmented and competitive work environment has not been conducted. This study begins to fill that knowledge gap. The research identified those distinct factors that are critical for interorganizational collaboration and systemic change necessary to adopt BIM. The aim was to establish a clear consensus on the critical influential factors to enhancing understanding of the challenges and enabling measures that can be implemented to maximize interorganizational BIM adoptability.

Table 3.1: Levels of Interorganizational Interaction in BIM Projects

<table>
<tr><td>Author and Year</td><td colspan="5">Level of Interaction</td></tr>
<tr><td>Grilo and Jardim-Goncalves (2010)</td><td>Communication
3D Objects Visualization</td><td>Coordination
Clash detection</td><td>Cooperation
Full3D BIM</td><td>Collaboration
3D BIM Collaborative Environment</td><td>Channel
Service-Oriented-Architecture 3D BIM</td></tr>
<tr><td>(Taylor & Bernstein, 2009)</td><td>Visualization
The first stage in BIM practice paradigm</td><td>Coordination
Within the firm and across the project network</td><td colspan="2">Analysis
Across-company sharing of electronic files</td><td>Supply Chain Integration
Sharing files in the supply chain</td></tr>
<tr><td>(Succar, 2009)</td><td colspan="2">BIM Stage 1
Object-based modeling/ No significant interdisciplinary interchanges</td><td colspan="2">BIM stage 2
Model-based collaboration: e.g. Design–Construction interchange</td><td>BIM Stage 3
Network-based
e.g. Supply chain</td></tr>
<tr><td>(Mutai, 2009)</td><td>Small BIM
Localized BIM use only within one department</td><td>Medium BIM
BIM shared between departments - only within organization</td><td colspan="3">Big BIM
Coordinated interdepartmental and interorganizational use of BIM generated data</td></tr>
<tr><td>(Taylor & Levitt, 2004)</td><td colspan="2">Incremental innovation
Provide a measureable impact on productivity</td><td colspan="3">Systemic innovation
Necessitates multiple firms to change their practice in a coordinated fashion</td></tr>
<tr><td>Adapted in this present study</td><td>Communication
3D Objects Visualization</td><td>Coordination
Clash detection</td><td colspan="2">Collaboration
3D BIM Collaborative Environment</td><td>Network-based
Supply chain integration</td></tr>
</table>

3.4 Method and Settings

The purpose of this study was to identify those distinct factors that are critical to the interorganizational BIM adoption. Various hypotheses were tested to determine statistical significant differences between groups of respondents, based on the level of BIM use, primary service offered to clients, level of interorganizational interaction, company size, company set-up (design/build vs. non-design/build), and the level of BIM experience. Results are presented in the following sections following the research method.

3.4.1 Method

As utilized in some of the aforementioned studies (Chau & Tam, 1997; Mutai, 2009; Nikas, *et al.*, 2007), a survey methodology was applied in this present study to examining 64 research variables (32 enablers and 32 inhibitors) in the form of an online survey questionnaire. The survey methodology has the advantage of involving, in the process, the real end users and is relatively easy in administration, although can be limited by subjectivity in opinions and the lack of face to face interaction (Vuolle, *et al.*, 2008). The present study derived its strength from, including into the research instrument, only previously identified measures, some of which have been tested through a survey methodology.

3.4.2 The research instrument

The research instrument/questionnaire comprised a total of seventeen questions addressing three parts including, company profile, level of BIM use, and evaluation of the variables. The collaborative variables presented in Figure 2.3 (page 11) were used with some necessary validation and wording changes being made. Half of the variables were worded with proper negation (inhibitors) in order to ensure the desired balance and randomness in the questionnaire. The remaining items were considered enablers to the exchange of BIM data across organizations.

This approach also served as a reliability check (in a form of alternate-form evaluation). Grouping the two was supported by consistencies found in literature (Appendix G), where barriers/inhibitors appeared to mirror the enabling factors. The items were then randomly sequenced to reduce the potential ceiling (or floor) effect. This is the effect that induces monotonous responses to the items for measuring a particular criterion (Hung, *et al.*, 2003). The variables were measured using a five-point Likert-type scale with anchors ranging from *"unimportant"* to *"very important"* for enablers, and *"strongly disagree"* to *"strongly agree"* for inhibitors. Unlike previous studies, the developed questionnaire required only BIM users to evaluate the variables in order to obtain more practical knowledge regarding the interorganizational BIM use rather than speculative responses from non-BIM users. The variables were reviewed by a panel of five experts, including a statistician, to refining the research instrument before it was distributed to the research participants.

3.4.3 Research participants

A representative sample of the US contractors completed an online survey about their adoption of BIM. Contractors have been reported to lag behind architects and engineers in BIM adoption (Gilligan & Kunz, 2007; Mutai, 2009; Suermann & Issa, 2009). Literature notes the need for extensive collaboration with downstream project stakeholders to offer opportunities for sharing valuable input at early stages of projects (Khanzode, *et al.*, 2006). It was, therefore, expected that the collected data will provide insight into the challenges facing the US contractors as they interact with other companies in BIM projects, and the factors that can be embraced to maximizing adoptability for best realization of benefits. Respondents' contact information was obtained from various sources, including those retrievable from the online nationwide database of the Associated General Contractors (AGC) of America, request through the AGC Membership

contact in the South Region, Business Report 2014, request through the Construction Industry Advisory Committee (CIAC), and some direct contacts.

3.4.4 Distribution of the research instrument

Data for this study was collected for the period between September and November of 2014. An introduction email, with the survey link, was sent to a total of 1001 email contacts. There were 184 permanent failure delivery notices (i.e. only 817 emails were delivered). The first reminder was sent out two weeks later, following introduction to the survey. Three more reminders, including a thank you note stating the date of closing the survey, were sent out at an interval of three weeks. At the closing of the survey, 224 responses (accounting for 27.4% of the delivered emails) were received. This rate is very comparable to similar surveys in previous studies.

Through data sort, 59 responses were found incomplete and were excluded from further analyses. The study sample comprised 165 complete responses. Of these, 68 companies (41.2%) identified themselves as BIM users, hence, had the opportunity to evaluate the variables. Among the 68 BIM users, 59 companies utilized BIM at an interorganizational level, and only 9 companies utilized the technology at an organizational level. The remaining 97 companies (58.8%) had not adopted BIM at the time of the survey. This group was directed to an alternative question that inquired the reason for not implementing BIM technology on their projects. Summary of their responses is presented in Figure 3.2.

3.5 Ethical consideration

Ethical clearance for conducting this research was obtained from the Institutional Review Board (IRB) of Louisiana State University (LSU); IRB Approval #8345 (Appendix A). Consent was sought from the study participants, in the form of a clearly written explanation of the aims and objectives of the study, prior to answering questions.

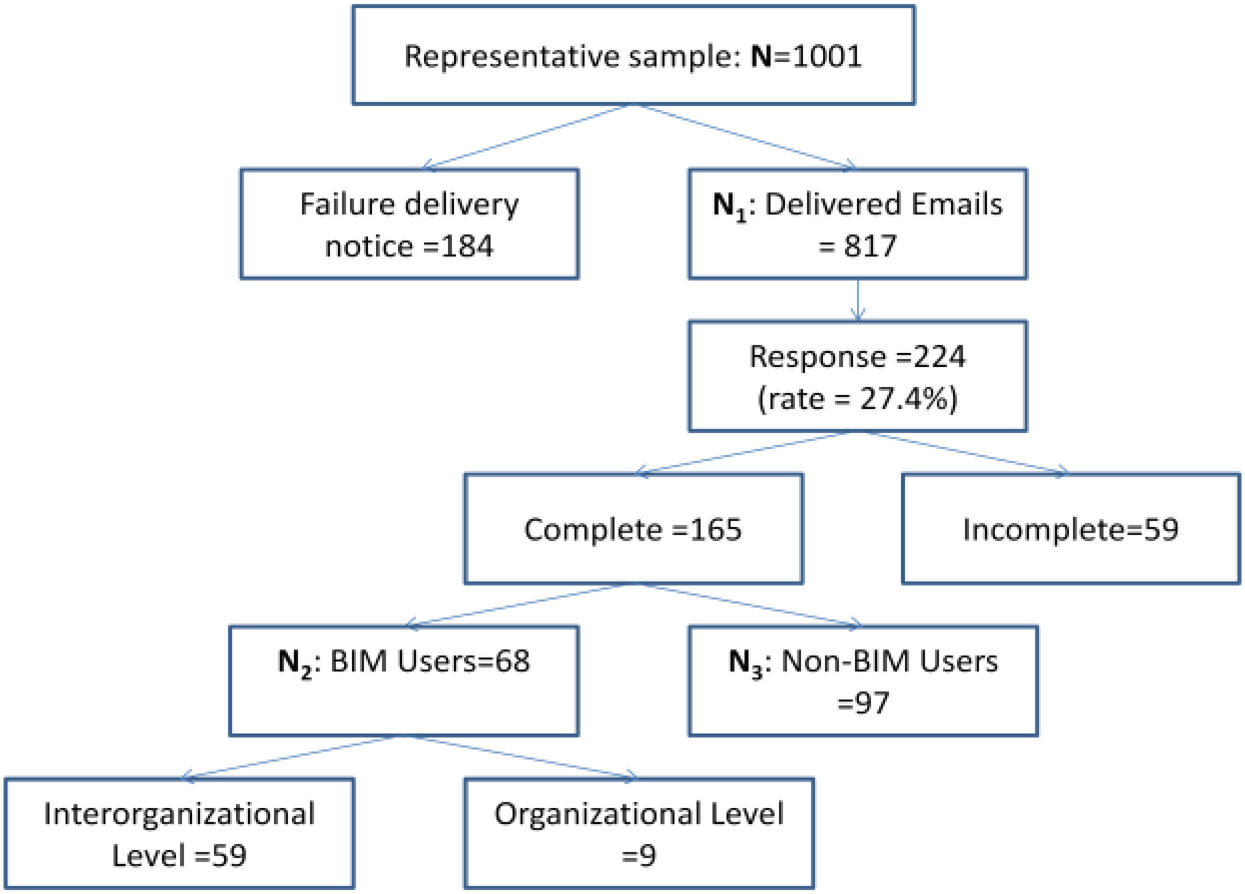

Figure 3.2: Survey Response

3.6 Results

Descriptive analysis was utilized on questions that did not involve evaluating the research variables. Results are presented in frequencies, percent, valid percent, and cumulative percent figures. Meanwhile, quantitative analysis involved statistical analysis of the research variables.

3.6.1 Descriptive analysis

Among 165 respondents, 97 (58.8%) indicated they had not utilized BIM technology on their projects (non-BIM users), while only 68 (41.2%) of respondents had used BIM technology (BIM users). Respondents to this study (Figure 3.3) predominantly held top management positions (31.3%) followed by project managers (23.9%) and CAD/BIM managers (20.9%).

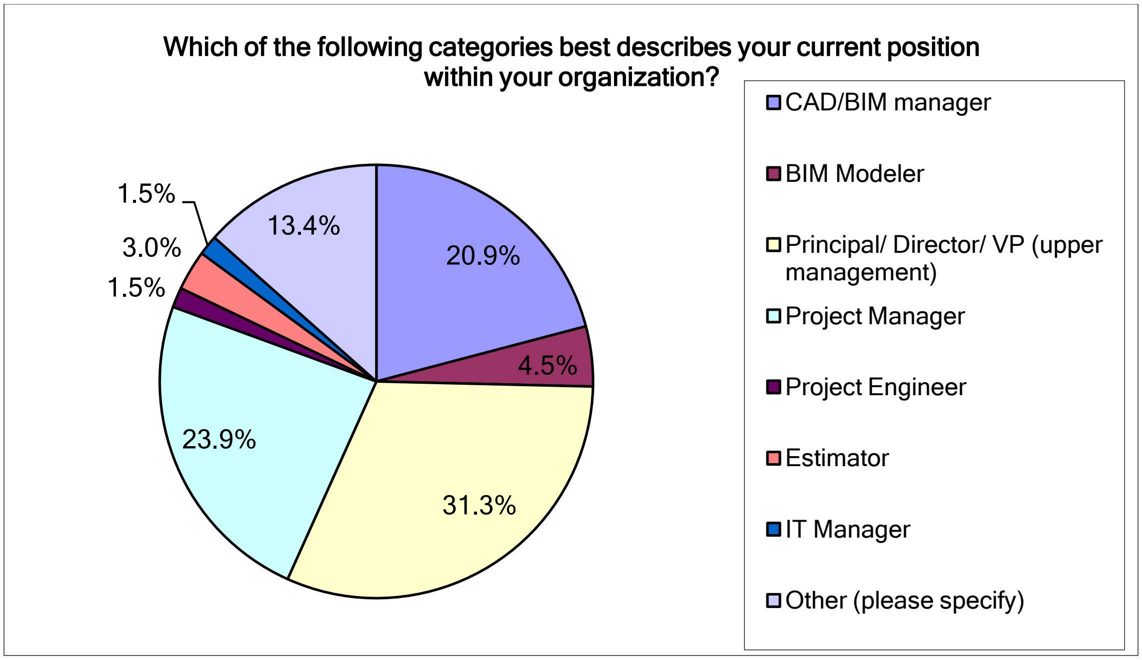

Figure 3.3: Respondents Categories

The surveyed contractors came from a variety of company sizes (Figure 3.4). A half of the respondents came from very large companies while the other half accounted for large, medium and small companies, with the small companies being the least represented category.

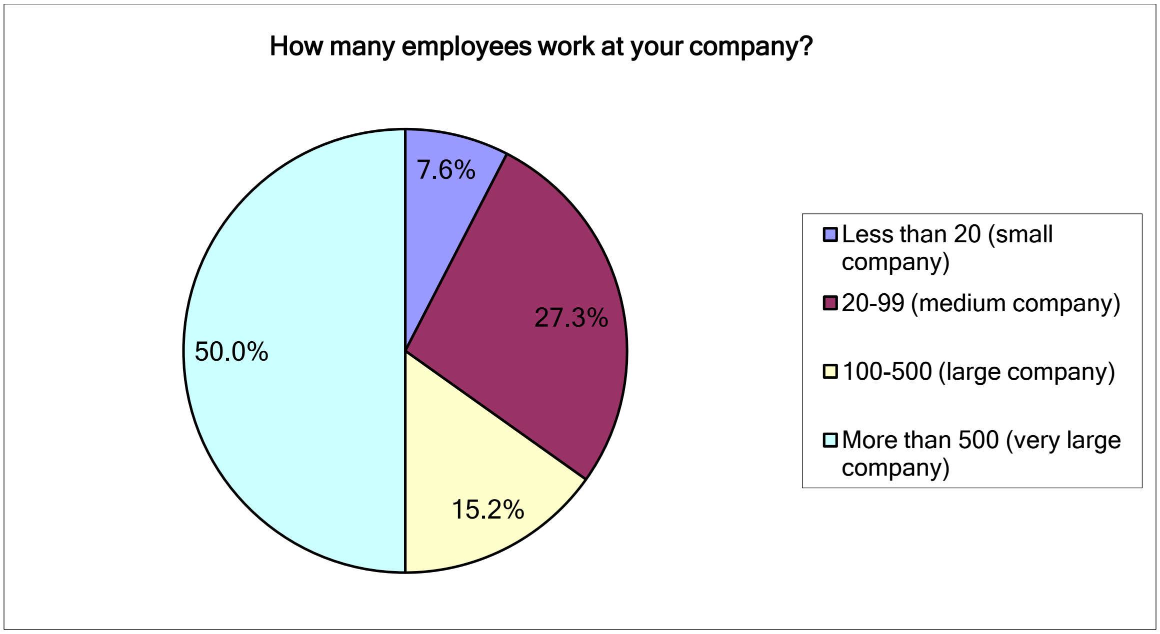

Figure 3.4: Company Size

Services offered by respondents covered wide geographical regions, including nationwide and international companies. Majorities came from the South region, as indicated in Figure 3.5. One explanation for a more positive response from the South region could be the location of the researching institution (LSU).

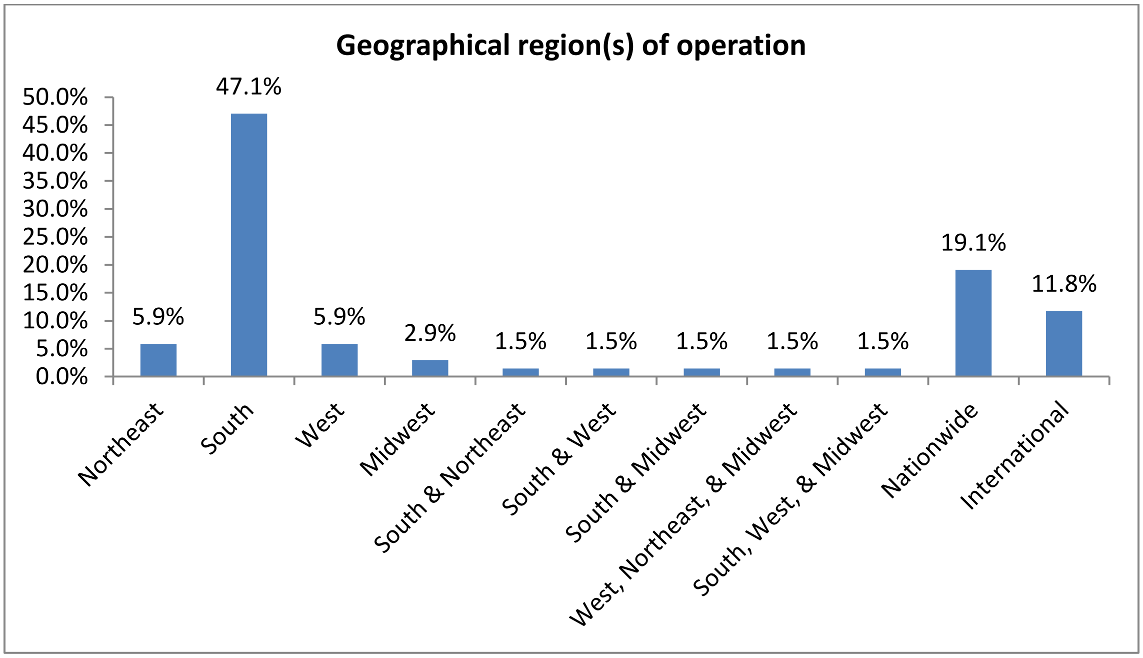

Figure 3.5: Geographical Region(s) of Operation

Surveyed companies indicated they offered a variety of services (Figure 3.6). The "Other" group represented services not specifically listed among options. Results also showed that most BIM users (86.8%) utilized BIM at an interorganizational level, versus 13.2% (at an organizational level).

Most respondents had an intermediate level of BIM experience (39.7%), closely followed by advanced experienced companies (35.3%). Only about 10% of the respondents described their company BIM experience as expert (Figure 3.7). BIM was utilized on a variety of project types (Figure 3.8) but mostly on commercial construction (63.6%). This was consistent with previous studies (Mutai, 2009; Suermann & Issa, 2009). "Institution, government, and other public

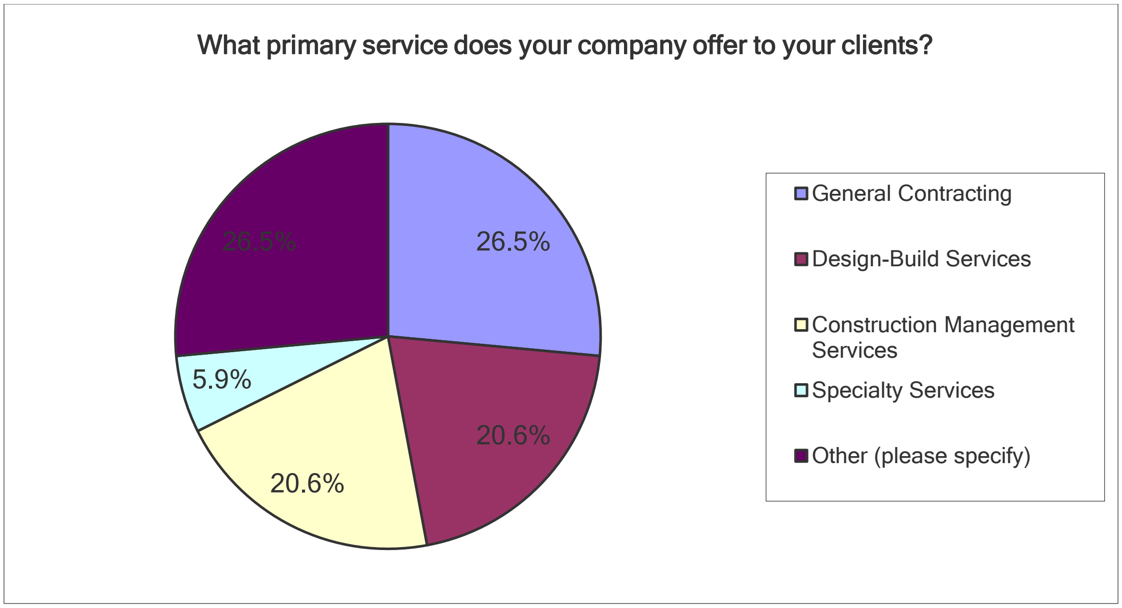

Figure 3.6: Type of Services Offered to Clients

buildings" was another area where BIM technology is mostly utilized, following commercial buildings. Medical facilities came third, closely followed by educational and industrial buildings in fourth place. It was also noted that interorganizational BIM users interacted at various levels in practice (Figure 3.9). The four levels were described in terms of BIM functions.

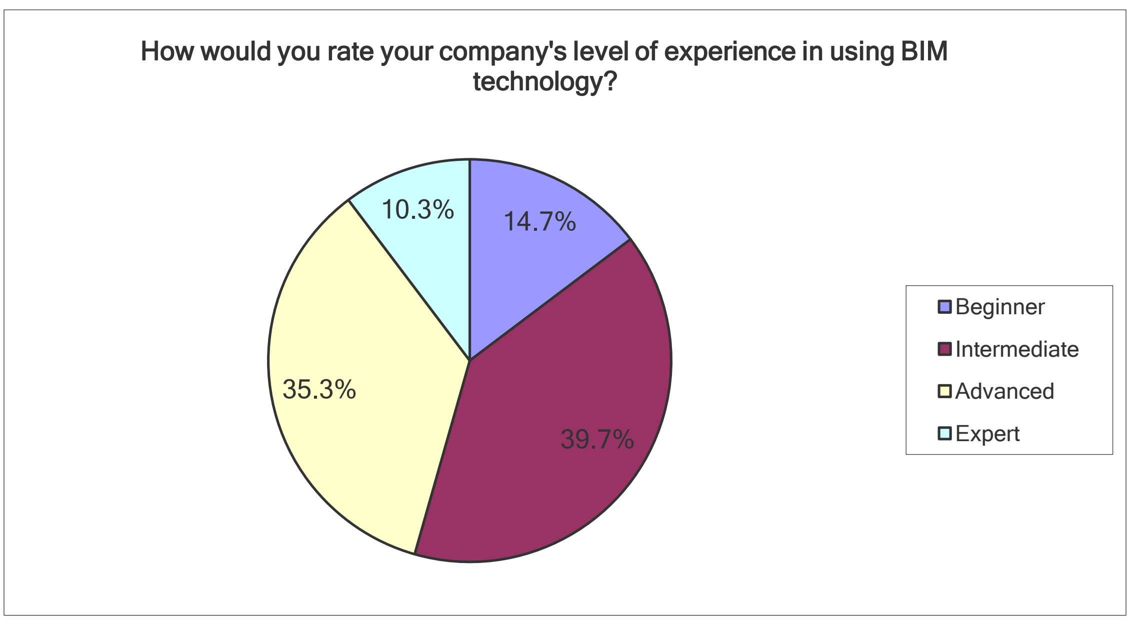

Figure 3.7: Respondents' Level of Experience in BIM Use

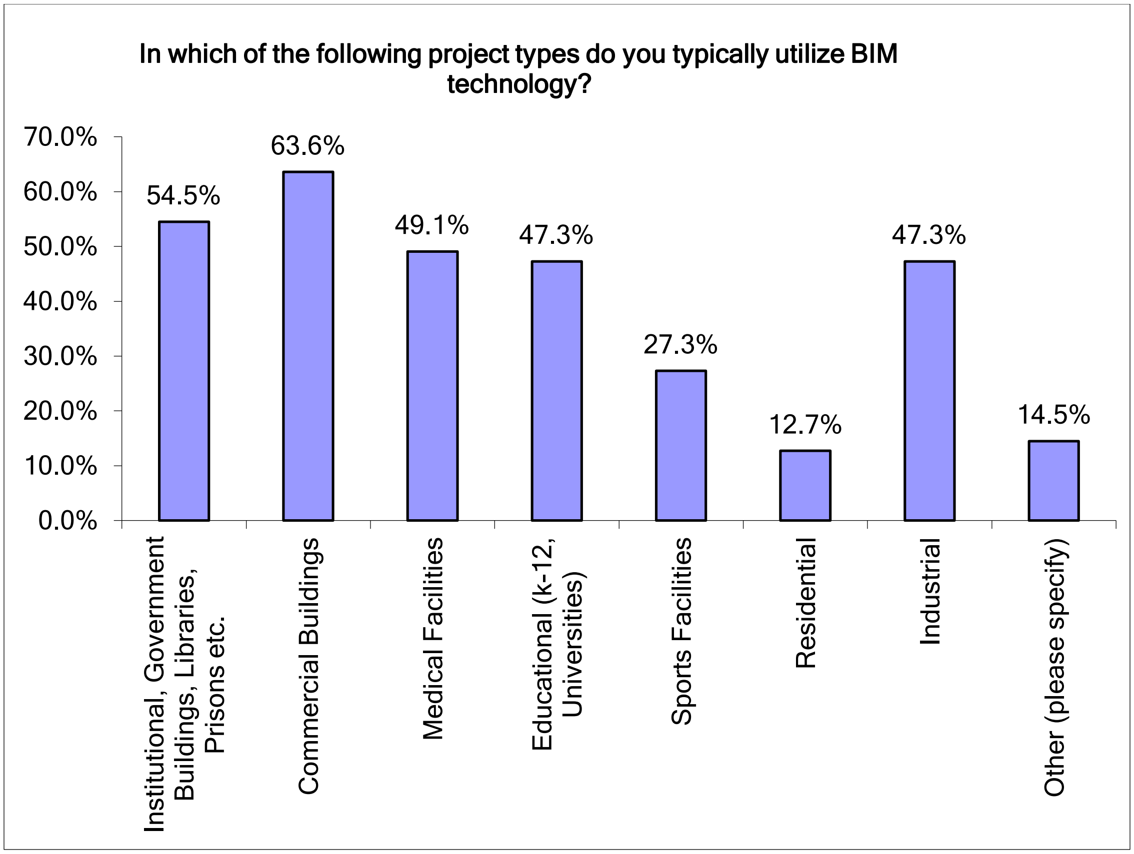

Figure 3.8: Project Types on which BIM was Utilized

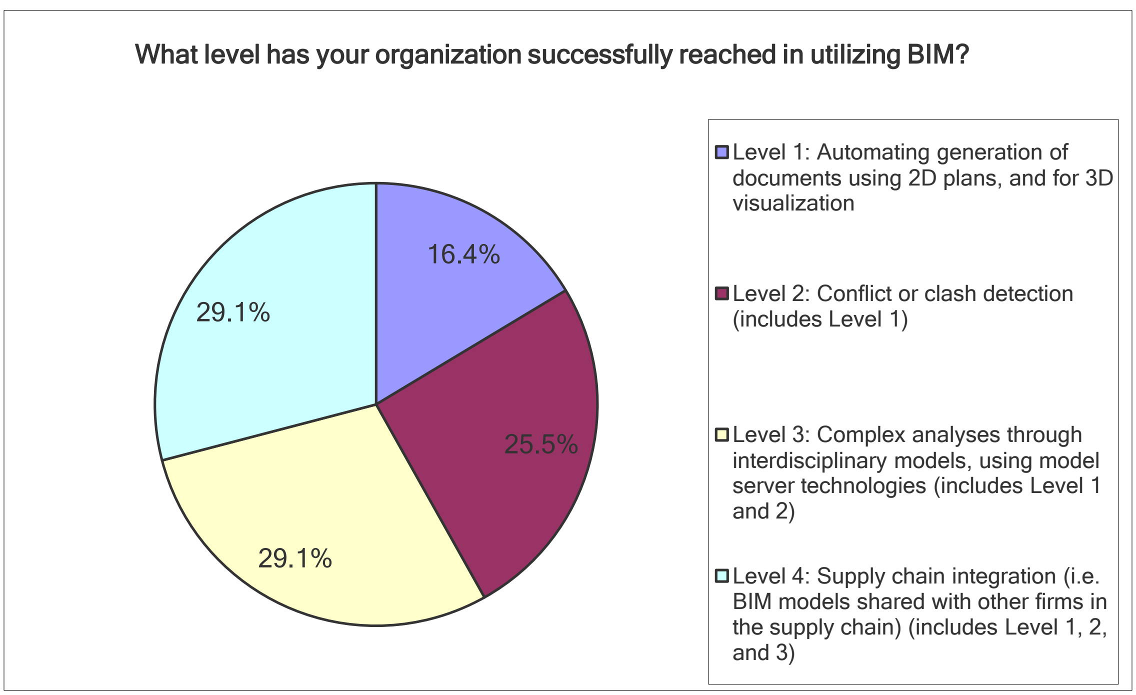

Figure 3.9: Interaction Levels at an Interorganizational Level

Respondents were also asked to identify their companies' biggest concern in BIM use. Although not explicitly stated, this question summarized all the 64 variables provided in the questionnaire. The study intended to examine, from a general perspective, the influence of the three categorical factors, and whether the outcome supports the three collaborative factors introduced in the CSC framework. Of the 68 respondents, 60 (88.2%) indicated their biggest concerns as, interoperability (24 = 35.3%), legal (15 = 22.1%), and social (21 = 30.9%), as shown in Figure 3.10. Other respondents, 8 (11.8%), selected more than one option. These were not included in the figure. Based on response percentages, the findings suggest that the three collaborative factors, as presented in the CSC framework, influence the sharing of BIM across organizations. Non-BIM users also provided their reasons for not utilizing BIM technology on their projects. Responses were grouped in ten categories (Figure 3.11).

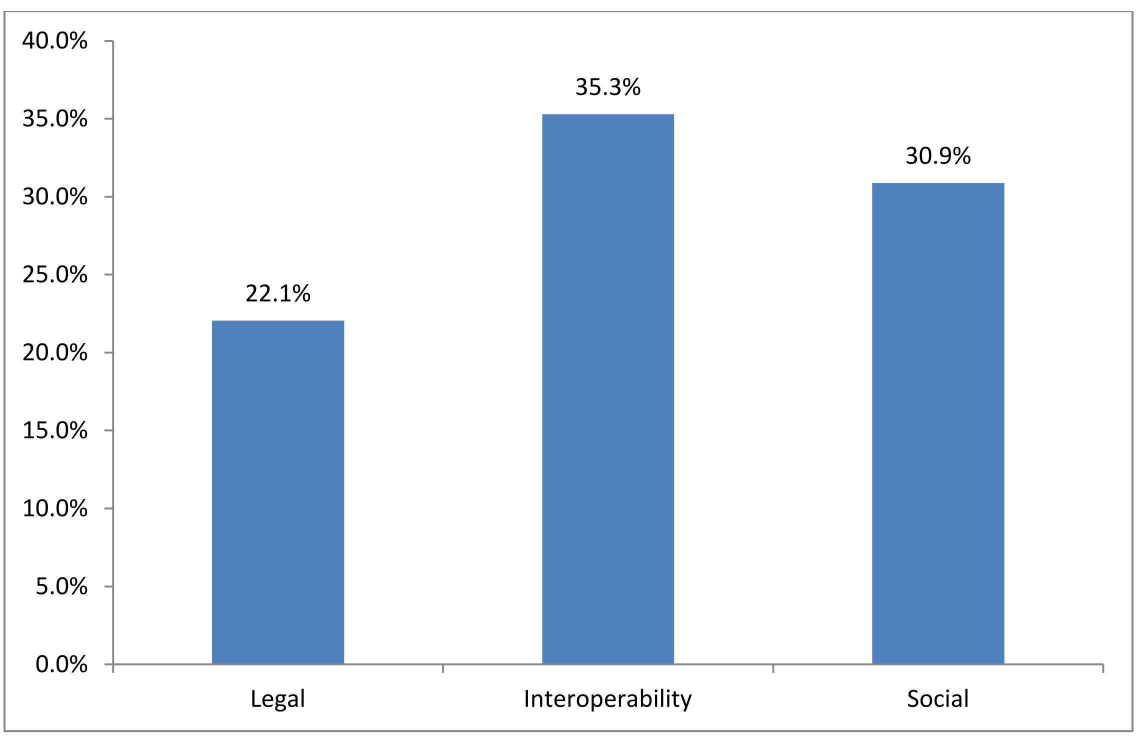

Figure 3.10: Companies' Biggest Concern in BIM Use

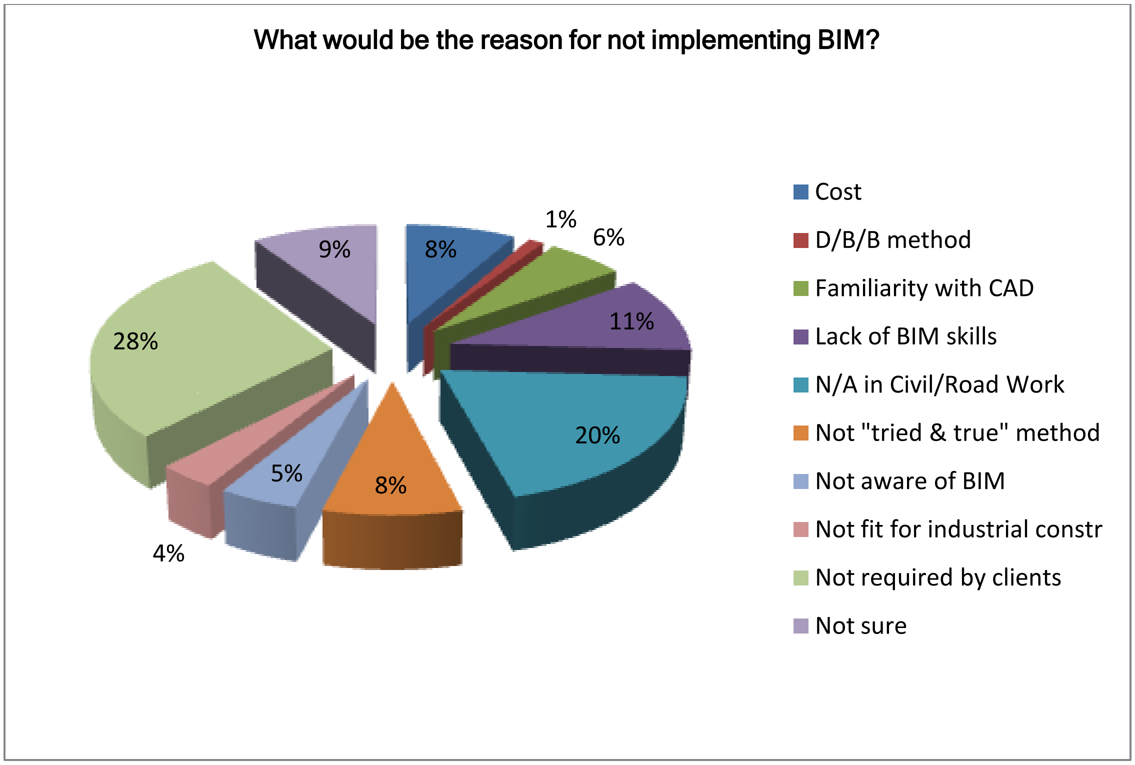

Figure 3.11: Reasons for not Implementing BIM on Projects

3.6.2 Quantitative analysis

The aim of the statistical analysis through principal components analysis procedure was to reduce the number of variables to the latent factors that account for the large portion of the total variance in the original variables. Reliability analysis was determined through Cronbach's alpha (α), which verified internal consistency among items effectiveness of questionnaire to measuring the same construct (Nunnally, 1978). This procedure also helped to identify problem items that needed to be excluded to improving the reliability of scale. A minimum of 0.7 α-value is recommended for a reliable scale (Nunnally, 1978), where as values 0.8 and above are considered optimal, and values above 0.9 very good. The questionnaire utilized in this study had a minimum Cronbach's alpha value of 0.920 (Appendix E), which indicated high internal consistency. This value indicated the items were independent measures of the same concept, hence, reliable instrument for measuring the research domain. The content validity of the survey

was based on previous studies from which the factors were grounded (Chapter 2), as well as a review by a panel of experts.

To address the aim of this study, 68 respondents (BIM users), who evaluated the variables, were considered for principal components analysis (PCA) procedure to indentify the factors that accounted for the most variance (Wold, *et al.*, 1987). PCA is a data reduction technique that is used to identify "latent" dimensions in the data and a small set of variables accounting for a large portion of the total variance in the original variables (Huang & Bolch, 1974). The three main steps of the PCA included; factors extraction, defining number of factors, and interpretation and naming of the factors. The data analysis for this study was generated using SPSS 22.0 statistical software (IBM Corp, Released 2013).

It has been suggested that large sample size is necessary to ensure stable assessment of the raw correlations, with some studies suggesting a minimum of 100 subjects (Gorsuch, 1983), while others recommend a larger sample. Some researchers argue that the variable to subject ratio is more crucial than absolute sample size. For example, they recommend a sample to be at least 10 times the number of variables (Nunnally, 1978), or at least 5 to 1 ration (Gorsuch, 1983). Meanwhile, other studies consider the stable assessment as dependent on communalities of the variables and the number of variables per factor-at least three (MacCallum, *et al.*, 1999; Velicer & Fava, 1998). This consideration was utilized in this present study.

Kaiser-Meyer-Olkin (KMO) test was performed for sampling adequacy to test the data for appropriateness of the statistical approach/factor analysis procedure (Kaiser, 1974). The KMO measure for this study was 0.826. Values closer to 1 indicate the clusters of factors are valid and the statistical technique used is robust. Hence, the use of factor analysis procedure was

appropriate for the study. The number of factors retained in PCA was first determined based on the commonly used Eigen values greater than 1.0 (Norusis, 1985), supported by the scree plot.

For better interpretation of the questions, a varimax rotation procedure was performed to get better correlations of the questions with the items. This rotation is a standard technique that is considered the most popular to minimizing cross loading and retain variances that have a high loading on a factor (Velicer & Fava, 1998). Correlation values of 0.3 are generally acceptable to describing a factor. Retained factors in this present study were described by items correlating at loadings of 0.50 and above (Appendix C). This was attained by observing the requirement of at least 3 items per factor, the Cronbach's alpha values, and eliminating cross-loading items. Six factors were retained, with a minimum Eigen value of 1.019; accounting for a cumulative variance of 71.1%. Factor mean scores and Cronbach's alpha values are presented in Table 3.2, along with the specific items describing the factors at correlation loadings of ≥ 0.50.

3.6.2.1 Data characteristics for parametric testing

The research specific objective was to identify critical factors (enablers and/or inhibitors) for interorganizational collaboration and systemic change in BIM adoption. Various hypotheses were tested to determine the differences between groups of respondents based on, the level of BIM use, type of primary service offered to clients, company set-up, the level of interorganizational interaction, BIM experience, and company size.

Normality test measures, supported by their respective histograms, normal-Q-Q plots, and box plots, showed that the data were slightly negatively skewed (Cramer & Howitt, 2004; Doane & Seward, 2011), although enablers were approximately normally distributed ($p = .339$). Sample characteristics showed that a Shapiro-Wilk's test ($p < .05$) for inhibitors; ($p > .05$) for enablers; and ($p < .05$) for both inhibitors and enablers combined.

Table 3.2: Item Means, Factor Means, and Cronbach's Alpha Values

Factor	Factor ID	Factor Items	Item Mean Score	Factor Mean Score	Factor Mean Cronbach's Alpha
F1	Organizational variety	Imp_Team_trust	4.26	4.13	.923
		Imp_Transparency	4.06		
		Imp_Conflict_strtgy	4.07		
F2	Team BIM capability	Inh_Rigid_bound	3.12	3.31	.920
		Inh_Errors	3.53		
		Inh_Industry_std	3.53		
		Inh_Unauthor_use	2.90		
		Inh_Workflow	3.47		
F3	Duty of care	Imp_Access_contr	3.57	3.62	.920
		Imp_Clear_own	3.56		
		Imp_Clear_w_flow	4.13		
		Inh_std_compenst	3.22		
F4	Risk and liability	Inh_Liability_shift	3.40	3.34	.922
		Inh_BIMrisk	3.26		
		Imp_Disclaimer	3.81		
		Inh_Model_security	2.87		
F5	Scope of work	Inh_Change_scope_wk	3.35	3.19	.921
		Inh_Data_loss	3.07		
		Inh_Scope_innov	3.15		
F6	Data preservation	Imp_Data_confidentl	3.71	3.88	.921
		Imp_Clear_deliver	4.06		
		Imp_Clear_roles	3.87		

The test also showed the data had skewness of -.687 (SE= .291) and kurtosis = 1.733 (SE= .574), for inhibitors; skewness = -.559 (SE= .291) and kurtosis = .805 (SE= .574) for enablers; and skewness = -.680 (SE= .291) and kurtosis = .495 (SE= .574), for both inhibitors and enablers combined). Test results are presented in Figure 3.12. To meet the assumption of normality for parametric tests, the data were transformed (through a reflection process). Test results of the transformed data are presented in the following Figure 3.13.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Inhibitors	.132	68	.005	.956	68	.018
Enablers	.067	68	.200*	.980	68	.339
Var_Enablers_Inhibitors	.117	68	.021	.959	68	.025

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Figure 3.12: Test of Normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Var_Enablers_Inhibitors_Rlog10	.086	68	.200*	.985	68	.587
Var_Enablers_Rlog10	.052	68	.200*	.988	68	.739
Var_Inhibitors_Rlog10	.122	68	.014	.961	68	.034

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Figure 3.13: Test of Normality of the Transformed Data

Normality test after the data transformation showed that the data were approximately normally distributed. Figure 3.14 presents a histogram for transformed variables (enablers and inhibitors combined).

3.6.2.2 Reliability of the I_BIMA Scale

In addition to the internal consistency that provided coefficient alpha (Cronbach, 1951), several other ways exist to validating reliability of scales, including; test-retest, split-halves, and alternate-form (immediate or delayed) (Anastasi & Urbina, 1997). Test-retest method requires administering the same measurement scale twice on the same group of respondents, with time delay recommended within an interval of two to three weeks (Polit & Beck, 2004, p. 417).

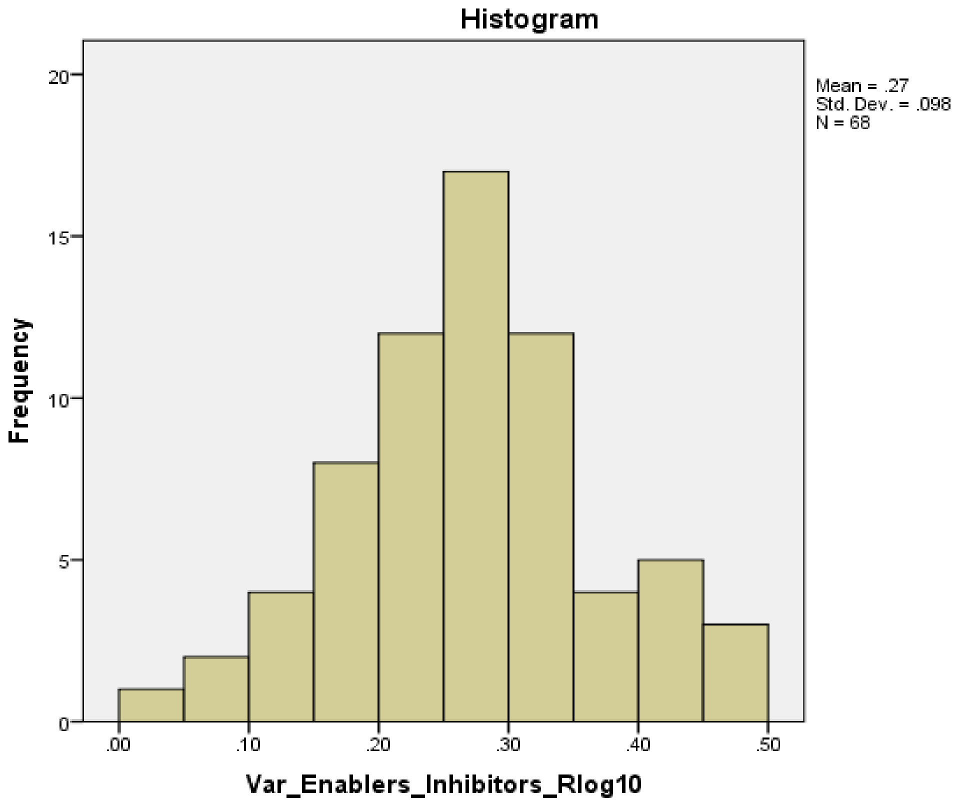

Figure 3.14: Test of Normality for Transformed Data

Meanwhile, the alternate-form approach requires administering two equivalent scales to the same subjects, with or without time interval. On the other hand, split-halves requires single administration of a single form of a measurement scale. In field studies, split-halves approach of administering a single form of measurement works well, given the challenges of time interval to re-testing the instrument, as well as the change in knowledge of respondents the second time an instrument is administered. Split-halves method was performed, in addition to Chronbach's alpha values, to further examine reliability of the measurement (Cronbach, 1951). Spearman-Brown Coefficient (0.709) indicated the final 25-item instrument was an efficient measure of the interorganizational BIM adoptability.

External reliability analysis was tested and attained using alternate-form method. The advantage of alternate-form over test-retest method is that it is considered to be free of the memory issues, but can be challenged by the number of variables involved. In this present study, development of the research instrument considered a half of the variables as enablers and the other half as inhibitors (Appendix F), which served as an alternate-form method. The research instrument asked respondents to rate the importance of each of the enabling factors provided, and their level of agreement that the lack of such enabling factors inhibits their practice of sharing BIM generated data across organizations. Correlation between enablers and inhibitors was performed to test external reliability of the research instrument. Equivalency of the two sets of questions was also supported through descriptive statistics, in terms of means and standard deviations (Figure 3.15). Results, using both Pearson (parametric test-Figure 3.16), and Spearman (non-parametric test-Figure 3.17), indicated the two sets of variables were significantly correlated.

Correlations: Descriptive Statistics

	Mean	Std. Deviation	N
Inhibitors	3.2073	.53381	68
Enablers	3.7574	.52009	68

Figure 3.15: Descriptive Analysis on Correlations

Correlations

		Inhibitors	Enablers
Inhibitors	Pearson Correlation	1	.354**
	Sig. (2-tailed)		.003
	N	68	68
Enablers	Pearson Correlation	.354**	1
	Sig. (2-tailed)	.003	
	N	68	68

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 3.16: Correlations

Nonparametric Correlations

			Inhibitors	Enablers
Spearman's rho	Inhibitors	Correlation Coefficient	1.000	.353**
		Sig. (2-tailed)	.	.003
		N	68	68
	Enablers	Correlation Coefficient	.353**	1.000
		Sig. (2-tailed)	.003	.
		N	68	68

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 3.17: Nonparametric Correlations

3.6.2.3 Hypothesis testing

Various hypotheses were tested to determine whether there were statistical significant differences, between groups of respondents, in factor mean scores. Based on the extant literature, the following were hypothesized:

H_1: Interorganizational BIM users would hold collaborative factors to be more significant on average than organizational BIM users.

H_0: $\mu_0 = \mu_1$ **H_a: $\mu_1 > \mu_0$**

Independent Sample Test was performed to determine if there was a statistical significant difference in contractors' perception on the factors based on the level of BIM use (organizational level = 0, interorganizational level = 1). The assumption of homogeneity of variances was tested and found tenable using Levene's test (sig. = .498), which indicated equal variances were assumed. A significant difference (p-value = .022) was found between the two levels with regard to the social factors (organizational variety). Mean for interorganizational BIM users was 4.2147 while that of organizational BIM users was 3.5926. Hence, results supported a hypothesis (**H_1**) that there was a significant difference in contractors' perception of the collaborative factors based on the level of BIM use. Figure 3.18 summarizes results. Other tests had p-value > .05.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Organizational_variety	Equal variances assumed	.463	.498	-2.350	66	.022	-.62210	.26473	-1.15066	-.09354
	Equal variances not assumed			-2.896	12.762	.013	-.62210	.21481	-1.08704	-.15715
Team_BIM_capability	Equal variances assumed	.005	.946	-1.232	66	.222	-.33032	.26802	-.86544	.20480
	Equal variances not assumed			-1.268	10.810	.231	-.33032	.26051	-.90492	.24428
Duty_of_care	Equal variances assumed	.009	.923	-.880	66	.382	-.23588	.26795	-.77085	.29910
	Equal variances not assumed			-.949	11.210	.363	-.23588	.24860	-.78179	.31004
Risk_and_liability	Equal variances assumed	.549	.461	-1.713	66	.091	-.44962	.26244	-.97361	.07436
	Equal variances not assumed			-2.104	12.708	.056	-.44962	.21374	-.91247	.01322
Scope_of_work	Equal variances assumed	2.106	.151	-.174	66	.863	-.04959	.28564	-.61990	.52071
	Equal variances not assumed			-.232	14.086	.820	-.04959	.21415	-.50864	.40945
Data_preservation	Equal variances assumed	.170	.681	-1.181	66	.242	-.32831	.27791	-.88317	.22654
	Equal variances not assumed			-1.348	11.788	.203	-.32831	.24352	-.85997	.20334

Figure 3.18: Independent Samples Test based on BIM Level

A one-way analysis of variance (ANOVA) was performed to determine if there was a statistical significant difference in contractors' perception of the collaborative factors based on the type of primary service offered ($\mathbf{\mu_1}$ = design/build; $\mathbf{\mu_2}$ = construction management; $\mathbf{\mu_3}$ = specialty services; $\mathbf{\mu_4}$= general contracting; $\mathbf{\mu_5}$ = "others").

H_2: There is a statistical significant difference, in factor mean scores, between contractors based on the type of primary service offered to clients.

H_0: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$ **H_a: at least one μ is different**

Results for this test did not show any statistical significant difference between groups (all tests indicated $p > .05$), as shown in Figure 3.19. Post hoc test was, therefore, not necessary. In this test, the hypothesis (**H_2**) was not supported.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Organizational_variety	Between Groups	1.361	4	.340	.568	.687
	Within Groups	37.781	63	.600		
	Total	39.142	67			
Team_BIM_capability	Between Groups	.981	4	.245	.419	.794
	Within Groups	36.893	63	.586		
	Total	37.875	67			
Duty_of_care	Between Groups	.819	4	.205	.352	.842
	Within Groups	36.618	63	.581		
	Total	37.437	67			
Risk_and_liability	Between Groups	1.828	4	.457	.817	.519
	Within Groups	35.248	63	.559		
	Total	37.076	67			
Scope_of_work	Between Groups	.893	4	.223	.342	.849
	Within Groups	41.177	63	.654		
	Total	42.070	67			
Data_preservation	Between Groups	3.410	4	.853	1.442	.231
	Within Groups	37.235	63	.591		
	Total	40.645	67			

Figure 3.19: ANOVA Test based on the Type of Primary Service Offered

ANOVA was also conducted to evaluate whether there was statistical significant difference in contractors' perception on the collaborative factors based on the level of interorganizational interaction ($\boldsymbol{\mu_1}$ = Level 1; $\boldsymbol{\mu_2}$ = Level 2; $\boldsymbol{\mu_3}$ = Level 3; $\boldsymbol{\mu_4}$= Level 4).

The four levels are defined as:

Level 1: Automating generation of documents using 2D plans, and for 3D visualization

Level 2: Conflict or clash detection (includes Level 1)

Level 3: Complex analyses through interdisciplinary models, using model server technologies (includes Level 1 and 2)

Level 4: Supply chain integration (i.e. BIM models shared with other firms in the supply chain) (includes Level 1, 2, and 3).

H_3: There is a statistical significant difference, in factor mean scores, between contractors based on their companies' level of interorganizational interaction.

H_0: $\mu_1 = \mu_2 = \mu_3 = \mu_4$ **H_a: At least one μ is different**

Results indicated a significant difference existed between groups with regard to the social factors (organizational variety), (*p*-value = .02), as shown in Figure 3.20. The dependent variable, level of interaction, included four levels: level 1 (M= 3.48, SD=1.05, n=11), level 2 (M= 4.23, SD=.86, n=16), level 3 (M= 4.3, SD= .60, n=20), and level 4 (M= 4.24, SD=.48, n=21). The ANOVA was significant, F (3, 64) = 3.531, *p*-value =.02 and Levene's test (sig. = .02). Thus, it was inferred that there is a statistical significant difference in contractors' perception of the collaborative factors based on their companies' level of interaction.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Organizational_variety	Between Groups	5.559	3	1.853	3.531	.020
	Within Groups	33.583	64	.525		
	Total	39.142	67			
Team_BIM_capability	Between Groups	2.583	3	.861	1.561	.207
	Within Groups	35.292	64	.551		
	Total	37.875	67			
Duty_of_care	Between Groups	2.142	3	.714	1.295	.284
	Within Groups	35.295	64	.551		
	Total	37.437	67			
Risk_and_liability	Between Groups	1.108	3	.369	.657	.581
	Within Groups	35.968	64	.562		
	Total	37.076	67			
Scope_of_work	Between Groups	.408	3	.136	.209	.890
	Within Groups	41.663	64	.651		
	Total	42.070	67			
Data_preservation	Between Groups	2.552	3	.851	1.429	.242
	Within Groups	38.093	64	.595		
	Total	40.645	67			

Figure 3.20: ANOVA Based on Interorganizational Level of Interaction

Post hoc comparison to evaluating pair wise differences among group means was conducted with the use of Tukey HSD test. Tests revealed a significant pair wise difference between the mean scores of contractors at interaction levels 3 and 1 (mean difference = 0.81515, p=0.02), and between levels 4 and 1 (mean difference = 0.75325, p = 0.03). These results supported a hypothesis (**H_3**) that there is a statistical significant difference on perception of collaborative factors between contractors based on their company's level of interorganizational interaction. No statistically significant difference was found between companies at interaction levels 1 and 2 (p > .05). Post hoc test results are presented in Figure 3.21.

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Interaction	(J) Interaction	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Organizational_variety	1	2	-.74432	.28373	.052	-1.4927	.0041
		3	-.81515*	.27192	.020	-1.5324	-.0979
		4	-.75325*	.26961	.034	-1.4644	-.0421
	2	1	.74432	.28373	.052	-.0041	1.4927
		3	-.07083	.24297	.991	-.7117	.5701
		4	-.00893	.24038	1.000	-.6430	.6252
	3	1	.81515*	.27192	.020	.0979	1.5324
		2	.07083	.24297	.991	-.5701	.7117
		4	.06190	.22633	.993	-.5351	.6589
	4	1	.75325*	.26961	.034	.0421	1.4644
		2	.00893	.24038	1.000	-.6252	.6430
		3	-.06190	.22633	.993	-.6589	.5351

*. The mean difference is significant at the 0.05 level.

Figure 3.21: Tukey HSD-Multiple Comparisons based on the Level of Interorganizational Interaction

ANOVA was also conducted to evaluate whether there was statistical significant difference in contractors' perception on the collaborative factors based on the size of a company (N= 68). Company sized was defined in four categories: μ_1 = Less than 20 employees (small company), μ_2 = 20-99 employees (medium company), μ_3 = 100-500 employees (large company), and μ_4 = more than 500 employees (very large company).

H_4: There is a statistical significant difference, in factor mean scores, between contractors based on company size.

$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4$ **H_a: at least one μ is different**

Results indicated no significant difference existed between groups (*p*-values > .05), as shown in Figure 3.22. Hence, the hypothesis (**H_4**) was not supported.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Organizational_variety	Between Groups	.358	3	.119	.197	.898
	Within Groups	38.784	64	.606		
	Total	39.142	67			
Team_BIM_capability	Between Groups	2.480	3	.827	1.495	.224
	Within Groups	35.394	64	.553		
	Total	37.875	67			
Duty_of_care	Between Groups	1.459	3	.486	.865	.464
	Within Groups	35.978	64	.562		
	Total	37.437	67			
Risk_and_liability	Between Groups	.763	3	.254	.448	.719
	Within Groups	36.313	64	.567		
	Total	37.076	67			
Scope_of_work	Between Groups	1.458	3	.486	.766	.517
	Within Groups	40.612	64	.635		
	Total	42.070	67			
Data_preservation	Between Groups	2.216	3	.739	1.230	.306
	Within Groups	38.429	64	.600		
	Total	40.645	67			

Figure 3.22: Company size-ANOVA

All companies that indicated they offered design/build as their primary service were considered to be design/build set-up companies. The rest were considered to be non-design/build companies. It was therefore hypothesized that:

H_5: Design/build companies would hold collaborative factors to be less significant on average than non-design/build companies.

H_0: $\mu_0 = \mu_1$ **H_a: $\mu_0 < \mu_1$**

There was no statistical significant difference between groups (all tests indicated $p > .05$). Results are presented in Figure 3.23.

ANOVA was also performed to evaluate whether there was statistical significant difference in contractors' perception on the collaborative factors based on the level of BIM experience (N= 68). The four levels of BIM experience were defined as, $\boldsymbol{\mu_1}$ = beginner, $\boldsymbol{\mu_2}$ = intermediate, $\boldsymbol{\mu_3}$ = advanced, and $\boldsymbol{\mu_4}$= expert.

H_6: There is a statistical significant difference, in factor mean scores, between contractors based on the level of BIM experience.

H_0: $\mu_1 = \mu_2 = \mu_3 = \mu_4$ **H_a: at least one μ is different**

Results (Figure 3.24) indicated no statistical significant difference exists between companies' factor mean scores based on the level of BIM experience. Post hoc test was, therefore, not necessary. In this test, the hypothesis (**H_6**) was not supported.

Independent Samples Test: T-Test Groups = DB_vs_nonDB (0,1)

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Organizational_variety	Equal variances assumed	2.054	.157	.647	66	.520	.125	.193	-.261	.510
	Equal variances not assumed			.589	37.727	.559	.125	.212	-.304	.554
Team_BIM_capability	Equal variances assumed	.056	.813	.841	66	.403	.15944	.18951	-.21893	.53781
	Equal variances not assumed			.833	48.777	.409	.15944	.19142	-.22527	.54415
Duty_of_care	Equal variances assumed	2.902	.093	.766	66	.447	.14442	.18858	-.23210	.52094
	Equal variances not assumed			.712	40.091	.481	.14442	.20293	-.26569	.55453
Risk_and_liability	Equal variances assumed	1.139	.290	1.577	66	.120	.292	.185	-.078	.661
	Equal variances not assumed			1.489	42.064	.144	.292	.196	-.104	.687
Scope_of_work	Equal variances assumed	1.653	.203	1.095	66	.277	.218	.199	-.179	.615
	Equal variances not assumed			1.024	40.833	.312	.218	.213	-.212	.648
Data_preservation	Equal variances assumed	2.396	.126	1.613	66	.112	.31225	.19359	-.07427	.69877
	Equal variances not assumed			1.464	37.338	.152	.31225	.21334	-.11989	.74438

Figure 3.23: Independent Samples Test on DB_vs_nonDB

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Organizational_variety	Between Groups	2.652	3	.884	1.550	.210
	Within Groups	36.490	64	.570		
	Total	39.142	67			
Team_BIM_capability	Between Groups	.389	3	.130	.222	.881
	Within Groups	37.485	64	.586		
	Total	37.875	67			
Duty_of_care	Between Groups	.072	3	.024	.041	.989
	Within Groups	37.365	64	.584		
	Total	37.437	67			
Risk_and_liability	Between Groups	1.293	3	.431	.771	.515
	Within Groups	35.783	64	.559		
	Total	37.076	67			
Scope_of_work	Between Groups	.642	3	.214	.330	.803
	Within Groups	41.429	64	.647		
	Total	42.070	67			
Data_preservation	Between Groups	.640	3	.213	.341	.795
	Within Groups	40.005	64	.625		
	Total	40.645	67			

Figure 3.24: ANOVA based on Level of BIM Experience

Cross-tabulation was performed to determine a correlation between interorganizational level of interaction and BIM experience. Based on existing literature, this relationship was hypothesized to be positive.

H_7: There is a positive correlation between companies' level of interorganizational interaction and BIM experience.

H_0: There is no relationship between level of interorganizational interaction and BIM experience.

H_a: Level of interorganizational interaction is positively related to BIM experience.

Results indicated that levels of interorganizational interaction increased with BIM experience. Interaction level 1 involved only companies with beginner and intermediate BIM experience (54.5% and 45.5%, respectively). Interaction level 2 involved companies with beginner, intermediate, and advanced BIM experience, while interaction level 3 only involved companies with intermediate, advanced, and expert BIM experience. Meanwhile, interaction level 4 involved mostly companies with advanced and expert BIM experience.

Pearson Chi-Square test indicated that the relationship between interaction level and BIM experience was significant (*p*-value = 0.000). A hypothesis ($\mathbf{H_7}$) that there is a positive correlation between company's level of interorganizational interaction and BIM experience was, therefore, supported. This outcome was consistent with Taylor and Bernstein (2009) but their study did not utilize a survey methodology. Overall, however, most companies surveyed in this present study, indicated that they interacted at levels 3 and 4 (collaboration and network-based, respectively). This was contrary to Taylor and Bernstein (2009) who found that about 50% of the companies studied had difficulty transitioning beyond coordination (level 2).

A similar test of cross-tabulation indicated a significant correlation between BIM interaction levels and company size. It was hypothesized that:

> **$\mathbf{H_8}$:** There is a positive correlation between companies' level of interorganizational interaction and company size.
>
> **$\mathbf{H_0}$:** There is no relationship between level of interorganizational interaction and company size.
>
> **$\mathbf{H_a}$**: Level of interorganizational interaction is positively related to company size.

Pearson Chi-Square test provided a *p*-value = 0.011. Results supported a hypothesis (**H_8**) that there is a positive correlation between companies' level of interorganizational interaction and company size. Summary of the research hypotheses is provided (Table 3.3).

Table 3.3: Summary of the Research Hypotheses as Detailed Above

Hypothesis	Results
H_1: Interorganizational BIM users would hold collaborative factors to be more significant on average than organizational BIM users.	Supported (*p*-value = .022 for "organizational variety")
H_2: There is a statistical significant difference, in factor mean scores, between contractors, based on the type of primary service offered to clients.	Not supported (*p*-value > .05 for all the six factors)
H_3: There is a statistical significant difference, in factor mean scores, between contractors, based on their companies' level of interorganizational interaction.	Supported (*p*-value =.02 for "organizational variety")
H_4: There is a statistical significant difference, in factor mean scores, between contractors, based on company size.	Not supported (*p*-value > .05 for all the six factors)
H_5: Design/build companies would hold collaborative factors to be less significant on average than non-design/build companies.	Not supported (*p*-value > .05 for all the six factors)

(Table 3.3: Continued)

Hypothesis	Results
H_6: There is a statistical significant difference, in factor mean scores, between contractors, based on the level of BIM experience.	Not supported (*p*-value > .05 for all the six factors)
H_7: There is a positive correlation between companies' level of interorganizational interaction and BIM experience.	Supported (*p*-value = 0.000)
H_8: There is a positive correlation between companies' level of interorganizational interaction and company size.	Supported (*p*-value = 0.011)

3.7 Discussion

The objective of this study was to establish a clear consensus on the critical factors that extend the TOE framework to the topic of interorganizational BIM. The findings, consistent with previous studies and suggestions, revealed that social, interoperability, and legal, factors are important to the interorganizational sharing of BIM. The present study extends these findings by demonstrating that the three collaborative factors are contextual specific (interorganizational), which are inadequate in the classic TOE framework. Moreover, these findings not only extended the TOE framework, but also demonstrated (through grounded theory), that the three factors are in a continuous interaction in practice. Figure 3.9 (page 45) also provided companies' biggest concerns in BIM use, which generally supported the three collaborative factors' influence to the sharing of BIM data at an interorganizational level.

Results indicated that companies utilizing BIM at an interorganizational level have more encounter with the collaborative factors and held higher mean scores (particularly on

organizational variety) on average compared to companies that utilize BIM within organizational boundaries. This was consistent with Ashcraft (2008) who noted that more challenges arise when BIM is shared beyond organizational boundaries. Other studies (Grilo & Jardim-Goncalves, 2010; Mutai, 2009; Oluwole, 2011; Redmond, *et al.*, 2012; Succar, 2009; Thomson & Miner, 2006) presented results that are consistent to these findings but with conceptualization of factors different from the current study. Significant difference between groups was also found based on the level of interorganizational interaction. Results showed that companies at collaboration and network-based levels of interorganizational interaction found the collaborative factors more important and inhibiting in practice than companies at a communication level. Specific differences were particularly on social factors (organizational variety).

Based on cross-tabulation test, results indicated a positive correlation between levels of interaction and BIM experience. These findings were consistent with Taylor and Bernstein (2009) but their study was not based on a survey methodology. Overall, however, majorities (60.3%) of surveyed companies in this present study interacted at higher levels (3 and 4). This was contrary to Taylor and Bernstein (2009) who found that about 50% of the companies studied had difficulty transitioning beyond coordination (level 2).

Based on the ANOVA results, construction stakeholders need to pay attention to the collaborative social factors, where a statistical significant difference was found between companies, as the levels of interorganizational interaction evolve. As a result of the structural mechanisms of project-based organizations, social reconstruction is considered high if groups' constituents change from one project to the next (Stinchcombe, 1968 ; Taylor & Levitt, 2004). Although review of literature found a dearth of research on the social factors, survey results

indicated the three collaborative (social, interoperability, legal) factors are significantly influential within the interorganizational context.

To summarize, this study findings added to the body of knowledge in BIM adoption by confirming the critical influences of social, interoperability, and legal, factors in the sharing of BIM generated data across organizations. More importantly, results not only explored into the key roles of the three collaborative factors within the interorganizational context, but also confirmed that the three factors are inadequate in the TOE framework. By excluding the TOE consistent factors, survey results verified the distinct significance of the collaborative factors to the collaboration and systemic change within the fragment and competitive work environment. As earlier described, this condition is necessary to maximizing adoption of revolutionary technologies, such as BIM, whose interdependence of activities beyond organizational boundaries has proven difficult to adopt to the fullest extent. In addition to the identified factors, the following comments were provided by respondents:

- “We are a huge company that is way behind in BIM. Most of our company doesn't realize what it is or what it could do for us”.
- “We are essentially in the early stages of utilizing BIM. The main impetus for use is knowing that BIM is here to stay and will be utilized now and in the future with increasing importance”.
- “My firm does not directly use BIM but some of our clients do and that is how we are connected to BIM. Detailed quantities of work are hard to get to in the hard bid public building arena. Detailed info (BIM) would allow for better planning of the work”.
- “On design - bid - build projects, the design team needs to have a clear understanding that the BIM model needs to be turned over to the General Contractor -GC to allow

proper BIM coordination among the trades to begin…forcing a GC to develop a 3D model from scratch wastes valuable coordination time, and also results in the potential of too many errors (particularly dimensional errors)".

- "Time scheduled in the project for BIM and clash detection is a challenge…every job wants it done, but little or no time is allowed in the schedule of construction".
- "I have not personally been part of the BIM development/creation process, only managing the process to stay on task & schedule. For the past 3 years, every project I have been a part of has used BIM modeling and it has been a huge part of our success".

Comments provided by respondents indicate that the use of BIM is sporadic and the knowledge of the most influential factors is lacking. The research findings are therefore expected to enhance understanding of the critical influential factors to maximize BIM adoption for best results. Meanwhile, companies that had not adopted BIM at the time of the survey indicated that lack of BIM requirement by clients was their biggest obstacle to adopting BIM. This was consistent with Eastman, *et al.* (2008). Their work noted that many owners do not require new types of deliverables, such as 3D Models, for a fear of limiting the pool of bidders willing to participate in their projects. This fear is linked to the potential increase in project price. Managing challenges related to the identified collaborative factors can help resolve such conflicting opinions and maximize interorganizational BIM adoption.

While many surveyed contractors in the US stated the inapplicability of BIM in civil/road work as their second top most reason for not using BIM, generalization of this specific finding should always be accompanied by the most recent findings. This is mainly because BIM is evolving and its functions, definition of terms, as well as applicable standards, are continuously being developed and improved. In UK, for example, the Uniclass system, that is currently being

improved, can accommodate infrastructure and civil works, in addition to buildings (John, 2014/06/01). These improvements have the potential to influence and change BIM users' perceptions in future.

Non-BIM users indicated that familiarity with computer aided design (CAD) was one of the reasons for not adopting BIM. Literature shows that most companies are currently using 2D technology and claim to have a long, proven track record with the technology (Gilligan & Kunz, 2007). The extant literature also notes that many companies cannot envision a clear business case from using BIM, and have difficulty justifying the return on investment (AGC, 2006). Hence, the industry needs to be clearer on how much of the BIM benefits outweigh the traditional approaches, to maximize adoption.

Meanwhile, a significant number of respondents noted that BIM was not a "tried and true" method. Ashcraft, *et al.* (2006) noted, rather than viewing BIM as a technology, it should be viewed as a new project delivery method with new risks, rewards, and relationships. They added, however, that these new business process models do not yet exist in the market. As a result, project teams struggle to integrate BIM technology into conventional practices. Some of the representative comments provided by non-BIM users included:

- "Given the size of our organization, and the scale of the projects we build, we've always felt that BIM would be over-kill. Additionally, we're of the impression that the learning curve, as well as the costs associated with BIM, would make it less than cost effective".
- "We do not have access to the models. Most design firms that we are working with are not creating models. We do not have the expertise to create them".
- "Cost and lack of qualified employees"
- "No clients have requested BIM utilization".

- “We are civil contractor and are unfamiliar with BIM and any possible benefit from its use”.
- “We are an underground utility contractor that receives civil plans for installation designed by an Engineer…as built for virtually all underground does not exist and our resource is not large enough to house the data for every area of ground that we excavate”.
- “Have seen the program and love how it works, just don't have the personnel to implement”.

3.8 Research Implication and Limitations

The critical factors identified confirmed that collaborative factors are inadequate in the TOE framework. Results presented here confirm that the six factor structure (basic and collaborative) is the most appropriate framework structure for studying technologies that involve interdependency of activities beyond organizational boundaries. Inadequate categorization of these factors limits comprehensive strategies that have the potential to maximize adoptability and benefits of such technologies, particularly BIM. In order to maximize BIM adoption, it was notable that the industry’s focus should be on 1) managing organizational variety to enhance teamwork, 2) acquiring adequate team BIM capability to facilitate seamless sharing of BIM generated data, 3) understanding the scope of work, 4) providing clarity on duty of care of the shared BIM model, 5) protecting companies from BIM risk and liabilities, and 6) providing standard for preserving the shared BIM generated data. Based on the grounded theory (generated CSC framework), it is necessary that these key factors be viewed in an interrelated fashion rather than separation to facilitate collaboration and change in a coordinated fashion within the fragmented and competitive construction environment.

Certain limitations were found in this study. First, the survey focused on contractors, and did not include architects and engineers who are important stakeholders to the sharing of BIM data beyond organizational boundaries. It is therefore advised that the two disciplinary groups be involved in future studies to identify those key collaborative factors that are critical across the three disciplinary groups. Any significant differences that may exist among the three groups should be utilized to further corroborate the current findings. Establishing a clear consensus on the critical factors across disciplinary groups will enhance development of a standard instrument for evaluating effectiveness of interorganizational interaction in BIM adoption. Second, the basic factors fully within the scope of the TOE framework were not tested in this study. Future studies should consider testing the two categorical factors (basic and collaborative) together; to determine specific percentage contributions of each category towards overall BIM projects success.

3.9 Conclusion: Critical Factors for Interorganizational Collaboration and Systemic Change in BIM Adoption

This research examined the key collaborative (social, interoperability, legal) factors to establish a clear consensus on those critical measures for interorganizational collaboration and systemic change in BIM adoption. Principle components analysis identified six factors (organizational variety, team BIM capability, duty of care, risk and liability, scope of work, data preservation) as more important than other influential factors in interorganizational BIM adoption. Respondents' perception of the factors was examined relative to the level of BIM use, the type of primary service offered to clients, company set-up (design/build vs. non-design/build), level of interorganizational interaction, company size, and BIM experience.

Results indicated that companies engaged in BIM data exchange beyond organizational boundaries have more encounter with the collaborative factors and held higher significant scores

of the factors than companies that are not. Hypotheses 1 and 3 were affirmed through statistical analysis. This meant that as companies engage in exchanging BIM data, collaborative factors begin to significantly influence the adoption process. Further, as the levels of interaction evolve (to levels 3 and 4), the focus should be on social factors to enhance teamwork. In addition, statistical results indicated that companies answered the questions similarly, regardless of primary service offered, and whether or not the companies were design/build set-up ($\mathbf{H_2}$ and $\mathbf{H_5}$). Meanwhile, statistical results showed that the level of interorganizational interaction positively correlates with both the BIM experience ($\mathbf{H_7}$), and company size ($\mathbf{H_8}$).

CHAPTER 4: EVALUATION GUIDE FOR INTERORGANIZATIONAL COLLABORATION AND SYSTEMIC CHANGE IN BIM ADOPTION

4.1 Synopsis

Interorganizational collaboration and systemic changes promise best realization of Building Information Modeling (BIM) benefits but a commonly accepted guide for evaluating its effectiveness has not been established. Meanwhile, existing approaches vary between studies. This creates a general misunderstanding in prioritizing decision choices confronting BIM users. The purpose of this study was to validate a more complete guide for evaluating interorganizational BIM adoptability. Key measures for the evaluation guide were identified through grounded theory, and further examined through a survey methodology. Six critical factors; organizational variety, team BIM capability, duty of care, risk and liabilities, scope of work, and data preservation, formed the final instrument. This instrument was tested against three case studies of recent BIM projects among the US contractors. Maximum score was determined by multiplying the highest Likert- scale (5) by factor mean scores. The percentage variance explained by the instrument was multiplied by the maximum score to determine the threshold minimum for a company to be successful. Results were consistent with the survey findings, which further validated the instrument as an efficient measure for evaluating interorganizational BIM adoptability.

4.2 Introduction

The construction industry is being challenged by the inability to fully utilize Building Information Modeling (BIM) technology that has the potential to increase efficiency of projects and, in turn, improve the industry’s declining productivity (Dyer, *et al.*, 2012). Various approaches have been utilized, including motivating critical mass adoption, as well as identifying significant influential factors to guide the adoption process (Khanzode, *et al.*, 2006; Mutai,

2009). Successful case studies to the adoption of BIM have been reported along with various challenges faced in practice (Becerik-Gerber & Rice, 2010; Suermann & Issa, 2009). Meanwhile, most researchers agree that the industry has not best realized the benefits of BIM as a result of interactivity challenges at an interorganizational level. It has been noted that pre-existing ineffective collaborative strategies is one of the reasons the construction industry has not adopted BIM to the fullest extent (Homayouni, *et al.*, 2010); however, no commonly accepted guide has been proposed to evaluate its effectiveness.

BIM has been cited in the literature as a promising technology that improves projects performance through increased efficiency (Azhar, *et al.*, 2008; Becerik-Gerber & Rice, 2010; Becerik & Pollalis, 2006; Khemlani, 2007; Neelamkavil, 2009; Suermann & Issa, 2009; Woo, 2006; Yan & Damian, 2008). Various stakeholders interact when BIM technology is utilized on projects, to effectively implement activities that involve interdependency of activities beyond organizational boundaries. However, the interdependency of activities contradicts the industry' competitive and fragmented work environment. This has proven difficult to adopt BIM to the fullest extent. Literature suggests that as BIM users focus on better management of the identified general influential factors, improvements will occur in effective interorganizational collaboration and systemic change.

To date, there has been no systematic attempt to organize and synthesize the various sets of critical factors for collaboration and systemic change nor have a more complete evaluation guide been proposed. Even though there are long term accepted measures for general technological adoption such as technology-organization-environment (TOE) factors (Tornatzky & Fleischer, 1990), these are particularly focused on a company/organizational level. There is lack of a clear consensus on interorganizational measures related to BIM adoption. In addition,

variations among interorganizational BIM studies and between the studies and the TOE factors, both in terms of categorizing and contextualizing the factors, suggest the TOE framework inadequately address the interorganizational context. In this present study, the development and validation of an evaluation guide for interorganizational BIM adoptability (I_BIMA) is presented. The methodology approach is summarised in the following Figure 4.1.

4.3 Method and Settings

4.3.1 Conceptualization

Conceptualization step involved identifying constructs and items from relevant literature. This was achieved through Formal Grounded Theory (FGT) method. The study determined and compared the factors influencing interorganizational BIM adoption as a function of existing theories. Based on scope of this study/unit of analysis, the classic Technology-Organization-Environment (TOE) theory was utilized as the basis of comparison. An integrated Collaborative Systemic Changes (CSC) framework was synthesized that extended the TOE theory to the topic of interorganizational BIM (Figure 4.2). Three key categorical factors (social, interoperability, legal), novel to the classic TOE framework, were referred to as collaborative factors that continuously overlap the TOE (basic) factors at an interorganizational level. The generated CSC framework theorizes how, in BIM adoption, interorganizational context variables relate to the organizational contextual factors presented in previous studies.

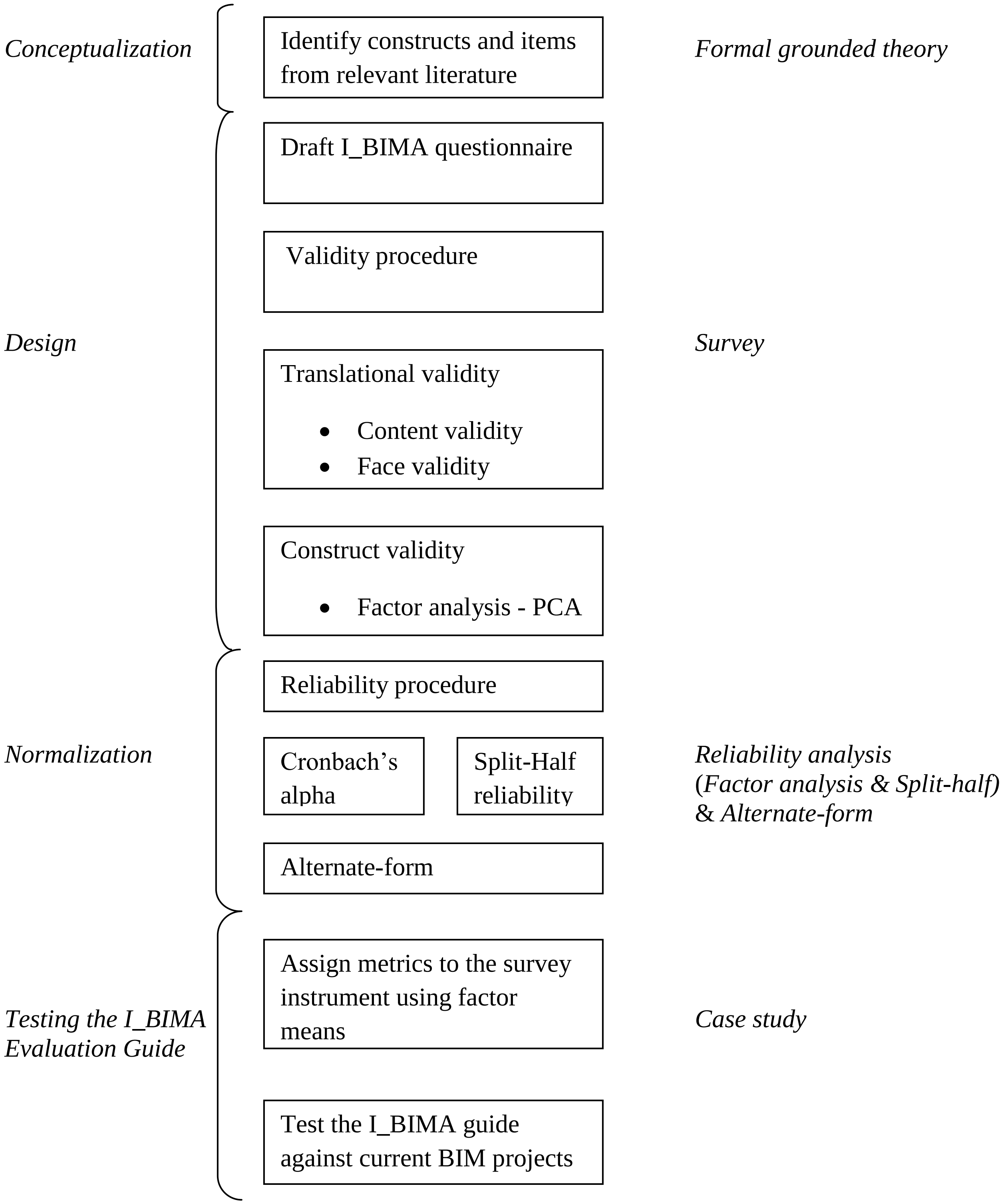

Figure 4.1: Process of Validating and Testing the I_BIMA Evaluation Guide

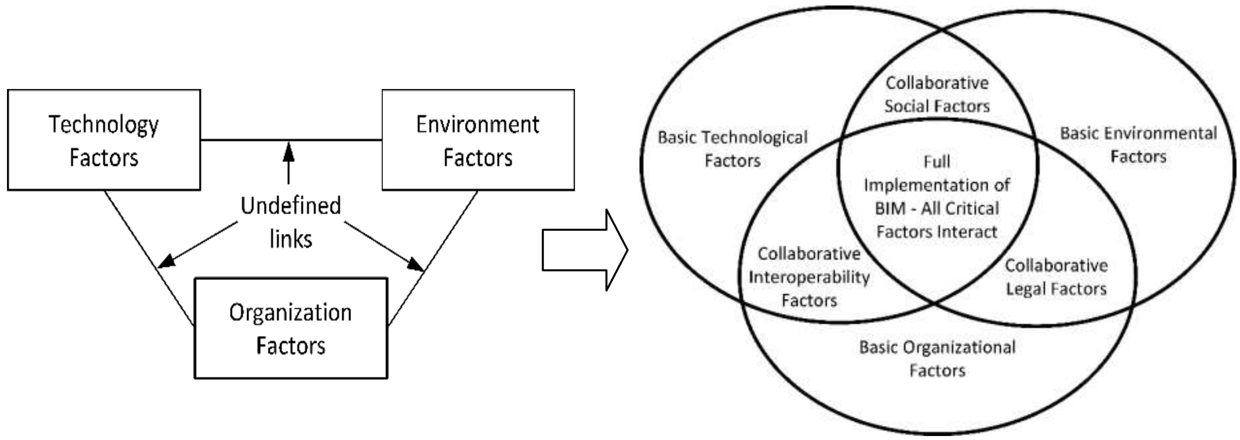

Figure 4.2: Extending the Technology-Organization-Environment Framework for Interorganizational BIM Adoption

Presenting the factors in a contextual specific approach would be useful to both decision makers and researchers. Identifying contextual specific strategies simplifies decision choices by decision makers and enhances their understanding of specific areas that have the potential to maximize BIM benefits. Researchers can use the identified measures to better understand the level of interactive practices necessary for companies to effectively adopt BIM. In addition, researchers can build theories and models that relate the identified critical factors to the companies' overall BIM projects performance. The three collaborative factors represent critical areas of interorganizational interaction and systemic changes where actions must be practiced to best realize the benefits of BIM. Measures of the collaborative factors, however, varied widely and were more numerous than expected-too numerous to embrace and use. Further examination of the collaborative measures was performed, through a survey methodology, to determine those measures that are critical to the interorganizational context.

4.3.2 Design

Measures of the collaborative factors were tested for reliability and validity using perceptual data collected from a random sample of 165 US contractors. Six critical factors (organizational

variety, team BIM capability, duty of care, risk and liabilities, scope of work, and data preservation) were identified as more significant than other influential factors in practice. The identified six critical factors (scale) accounted for 71.089% of the total variance. The survey results demonstrated that reliability and validity of the scale are quite high. Hence, the scale captures most of the important aspects of interorganizational collaboration and systemic changes discussed in today's related research. It was recommended that identified factors (Figure 4.3) be practiced interactively as an interconnected facet rather than isolated. Study results suggested that attempts at either will not be successful without first establishing a comprehensive interactive strategy that supports both collaboration and systemic changes within the interorganizational context.

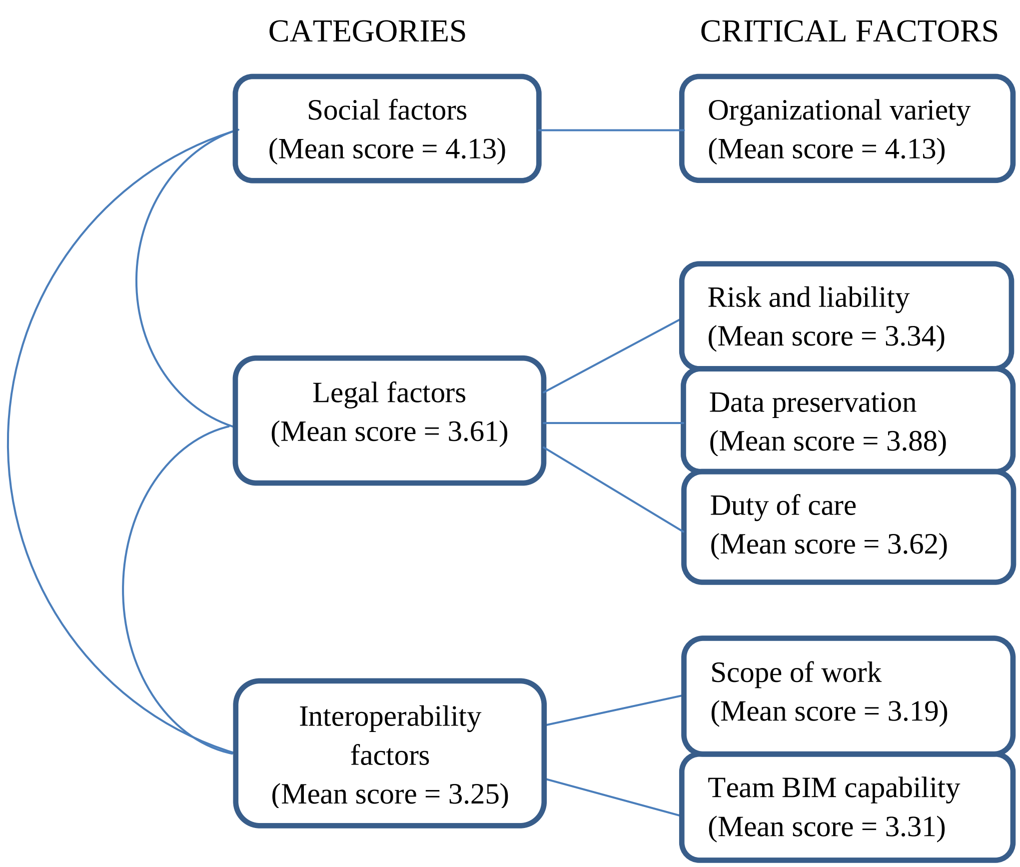

Figure 4.3: Critical Factors for Interorganizational Collaboration and Systemic Change in BIM Adoption

4.3.3 Normalization

In addition to the Cronbach's alpha values (ranging from 0.920 to 0.923), which indicated the scale is very reliable, a split-half analysis (Cronbach, 1951), was performed to further test reliability of scale. Spearman-Brown Coefficient (0.709) indicated the final 25-items instrument is an efficient measure of the interorganizational BIM adoptability (Figure 4.4). Overall, results showed that reliability of scale, based on both tests, is quite high and acceptable.

Cronbach's Alpha	Part 1	Value	.894
		N of Items	13[a]
	Part 2	Value	.899
		N of Items	12[b]
	Total N of Items		25
Correlation Between Forms			.549
Spearman-Brown Coefficient	Equal Length		.709
	Unequal Length		.709
Guttman Split-Half Coefficient			.709

a. The items are: Imp_Clear_w_flow, Imp_Disclaimer, Imp_TeamBIM_exp, Imp_Clear_roles, Imp_Access_contr, Imp_Clear_own, Imp_Conflict_strtgy, Imp_Team_trust, Imp_Transparency, Imp_Clear_deliver, Imp_Data_confidentl, Inh_std_compenst, Inh_BIMrisk.

b. The items are: Inh_Model_security, Inh_Industry_std, Inh_Rigid_bound, Inh_Errors, Inh_Workflow, Inh_Liability_shift, Inh_Change_respons, Inh_Unauthor_use, Inh_Interdp_activt, Inh_Scope_innov, Inh_Change_scope_wk, Inh_Data_loss.

Figure 4.4: Split-Half Reliability Statistics

Alternate-form (enablers and inhibitors questionnaire) method was utilized to test the external reliability of the research instrument. Pearson correlation test was .354, while Spearman's rho was .353. Correlation was found to be significant at the 0.01 level (2-tailed), *p*-value = .003. These measures indicated that the instrument has attained external reliability.

4.4 Ethical Consideration

Ethical clearance for conducting this research was obtained from the Institutional Review Board (IRB) of Louisiana State University (LSU); IRB Approval #8345. Consent was sought from the study participants, in the form of a clearly written explanation of the aims and objectives of the study, prior to answering questions.

4.5 Results

In this specific objective, the study demonstrated utilization of the proposed evaluation guide that includes a comprehensive set of six critical factors for interorganizational collaboration and systemic change in BIM adoption. The identified factors are literature-based, and have been examined for reliability analysis through a survey methodology. The evaluation guide was further validated through empirical research, utilizing quantitative data from three most recent BIM projects.

Three companies were provided with an I_BIMA evaluation guide to assess the evaluation guide based on their most recent BIM projects. The respondents were asked to rate their companies' success on BIM use, based on each of the measurement items. The evaluation guide was measured using a five-point Likert-type scale with anchors ranging from 1 = "very low" to 5 = "very high". To protect their identity, the three companies are referred to as company A, B, and C. The three projects were considered as being similar enough to offer a rational comparison. The companies' revenue in million US dollars were 2,200 (A), 2,002 (B), and 1,300 (C). Companies A and B offered mostly general contracting services, while company C offered mostly design/build services.

The maximum I_BIMA scale score (i.e. mean scores for each factor multiplied by the highest possible Likert scale score a company could get) for the six factors was 107.35 points. A

threshold minimum for determining a company's success or failure on I_BIMA was calculated by multiplying the maximum score by the total amount of variance accounted (71.089%). Specific minimum scores for each factor's ration contribution to the I_BIMA scale was also calculated the same way. This meant that the company's total score must, at the very least, meet the percentage rate of the total variance accounted by the scale, to be considered successful on I_BIMA. Using this approach also helped to recommend specific areas that need improvement, where a company attained scores above the threshold but lower scores on either of the specific factors. A summary of this explanation is provided next, in the form of equations. S = social, I = interoperability, and L = legal, factors.

$$\left(I\_BIMA_{social\_score}\right) = (5 * 4.13) = 20.65$$

$$\left(I\_BIMA_{interoperability\_score}\right) = \{(5 * 3.31) + (5 * 3.19)\} = 32.5$$

$$\left(I\_BIMA_{legal\_score}\right) = \{(5 * 3.62) + (5 * 3.34) + (5 * 3.88)\} = 54.2$$

$$\left(I\_BIMA_{max\ \_total\ score}\right) = (\ 20.65\ S + 32.5\ I + 54.2\ L) = 107.35$$

$$\left(I\_BIMA_{min\_required\ score}\right) = 71\%_{var}\ (20.65\ S + 32.5\ I + 54.2\ L) = 76.2$$

$$\left(I\_BIMA_{min\ \_categorical\ score}\right) = (14.66\ S + 23.1\ I + 38.47\ L) = 76.2$$

From the equations above, the minimum score that a company must attain from the three categories, to be considered successful on I_BIMA are: 14.66 points (Social), 23.1 points (Interoperability) and 38.47 points (Legal), adding up to 76.2 points. Table 4.1 summarizes results of the I_BIMA scores for the three projects.

Table 4.1: I_BIMA Results of Three BIM Projects

Company ID	BIM Experience	Company size	Geographical regional coverage	Company's biggest concern on BIM use	Interaction level	SOCIAL (factor mean score) * (company mean score)	INTEROPERABILITY (factor mean score) * (company mean score)	LEGAL (factor mean score) * (company mean score)	Project cost ($ Mill)	Project time (Months)
A	Intermediate	Very large	South	Legal	Level 1	4.13 * 2.33 (9.62)	3.25 * 4.4 (14.3)	3.61 * 6.75 (24.37)	1	1
B	Advanced	Large	South	Social	Level 3	4.13 * 4.33 (17.9)	3.25 * 7.5 (24.38)	3.61 * 13.17 (47.54)	1	1
C	Advanced	Very large	International	Interoperability	Level 4	4.13 * 4.33 (17.9)	3.25 * 9.3 (30.23)	3.61 * 14.67 (52.96)	100	12
Interpretation of the above company scores										
Company's Required Minimum I_BIMA Score						14.66	23.1	38.47		
Company A (48.29)						Unsuccessful	Un successful	Unsuccessful		
Company B (89.82)						Successful	Successful	Successful		
Company C (101.09)						Successful	Successful	Successful		

4.6 Discussion

The identified critical measures provided a reliable guide for evaluating the effectiveness of interorganizational interaction in BIM projects. The utilization of the evaluation guide was quantitatively demonstrated using the data collected from three companies among the US contractors. The three projects were considered similar enough to provide a logical comparison (Table 4.1). Thirty six (36) companies that voluntarily provided their contacts during the initial survey were contacted. A request was sent for information related to their most recent BIM projects. However, only three companies responded with complete information. The three case study results shade light on specific areas that have the potential to maximize BIM adoption.

Companies A and B both implemented similar BIM projects, in terms of cost ($1 million) and time (1 month). The two companies also operated in the same geographical region (South) and had implemented more than 26 BIM projects, at the time of the study. However, their scores on collaborative (social, interoperability, legal) factors varied significantly. As indicated (Table 4.1), company A scored below the required minimum on all the three factors (unsuccessful), whereas company B scored above the required minimum on all the three factors (successful). Company A had an intermediate level of BIM experience, while interacting at level 1. Meanwhile, company B had an advanced level of BIM experience, while interacting at level 3. Company B was successful (scoring above the required minimum) on all the factors while company A was not. While the two companies differ in terms of BIM experience and the level of interaction, a larger sample is necessary to conclude the impact of the two on the factors scores.

While companies B and C were both successful on the factor scores, they still indicated specific concerns with regard to the collaborative factors. However, their biggest concerns were significantly different; that is, company B (social) and company C (interoperability). Meanwhile,

they both differed from company A (legal) that was unsuccessful on all scores of the collaborative factors. These findings suggest that the three collaborative (social, interoperability, and legal) factors are equally influential to the adoption of BIM at an interorganizational level. The I_BIMA evaluation guide, comprising the six critical factors (presented as challenges on the left) and specific item measures (presented as strategic measures on the right) is presented in Figure 4.5.

4.7 Implication

The 25 –item instrument for interorganizational BIM adoptability (I_BIMA) has undergone extensive evaluation and validation, which represents significant progress toward developing a standard instrument. Further, the study showed that the developed instrument is precise and can easily be utilized in practice. This instrument serves as a starting point for a detailed evaluation of the interorganizational collaboration and systemic change necessary to effectively adopt BIM.

4.8 Limitations and Suggestions

Demonstrating the interorganizational BIM adoptability guide utilized quantitative data from 3 companies with similar projects. Future studies could expand the sample size and compare results to corroborate the findings. The evaluation guide comprised 25-items within the collaborative category. Further research should consider combining the two categories, collaborative and basic, to compare results. Testing the 25-item instrument involved companies of large or very large size. Future studies should expand the sample across company sizes and compare results for potential differences. Involving only design/build companies would be another area of interest to further clarify the reasons why statistical analysis showed no significant differences between design/build and non-design/build companies, despite the argument that their collaboration is made easier as everything is done under one roof.

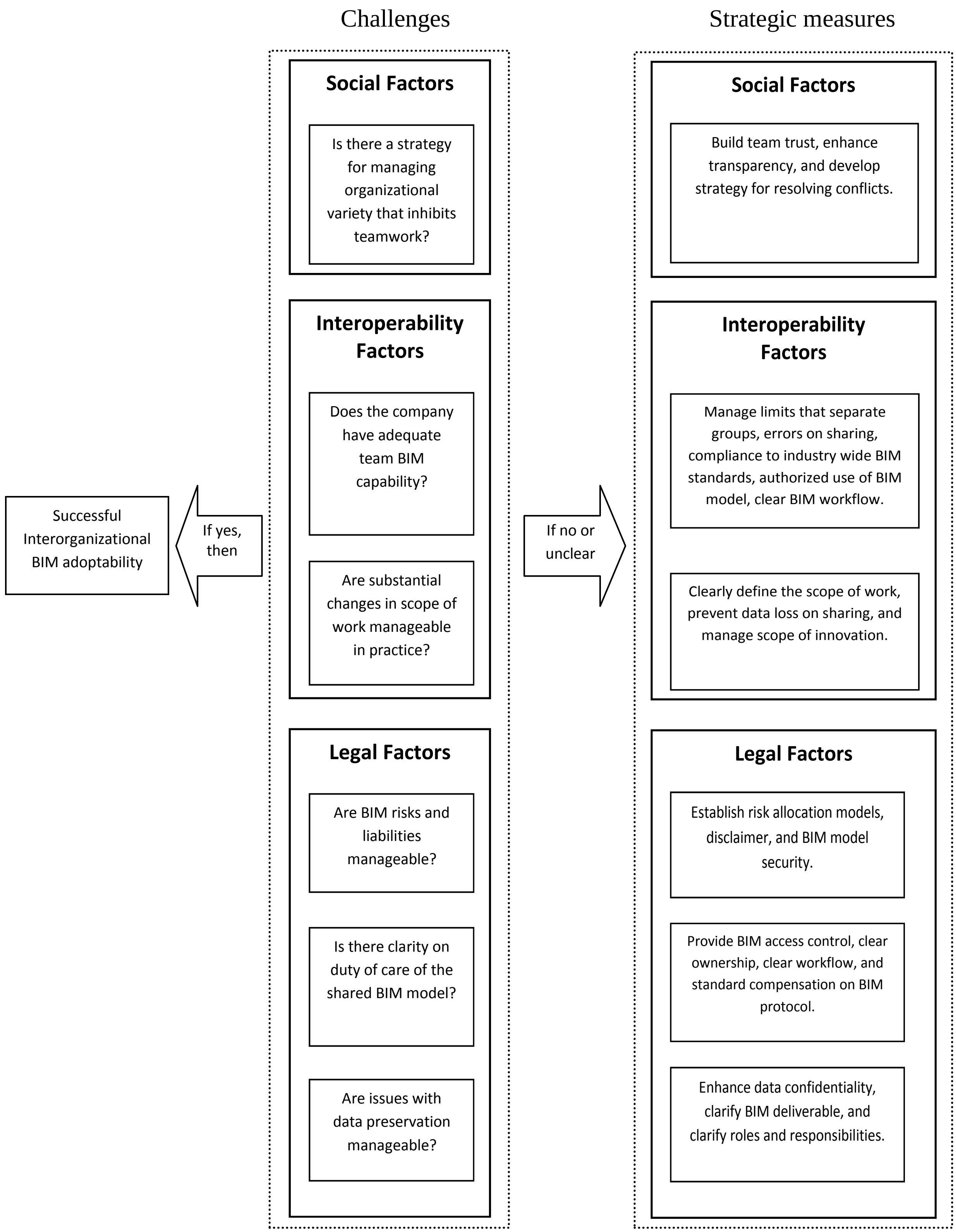

Figure 4.5: Evaluation Guide for Interorganizational BIM Adoptability

Additionally, future research should consider involving other stakeholders (designers) who play an important role in BIM data exchange, to further validate the proposed instrument.

4.9 Conclusion – Evaluation Guide for Interorganizational Collaboration and Systemic Change in BIM Adoption

Different sets of organizational and interorganizational BIM requirements have been offered by different authors. However, no previously published research has developed a comprehensive set of requirements or critical factors that spans the literature. The present research offers a set of six critical factors for collaboration and systemic change, synthesized from various authors. Extant literature on BIM provides little guidance on how to interactively evaluate the proposed critical factors at an interorganizational level. This study successfully developed an instrument that can be used to evaluate interorganizational interactivity to maximize BIM adoption. The measures proposed were empirically based, and shown to be reliable and valid. The reliability coefficients (alphas) ranged from .920 to .923. Split-half reliability test (.709) and Pearson correlation test (.354) also indicated the instrument is reliable. Further, a systematic literature review, through grounded theory, and refinement of the survey by a panel of experts, helped ensure that the measures have the content validity. The correlation coefficients (≥ 0.5) further offered strong evidence of criterion-related validity.

The proposed evaluation guide for I_BIMA permits managers to obtain a better understanding of the level of interaction in practice. It allows researchers to proceed with the task of developing and testing theories of effective interorganizational collaboration and systemic change in a fragmented and competitive work environment. Managers can use this guide to evaluate their companies' interactivity level in practice. These measurements can help decision makers identify those areas with the highest potential to maximize BIM benefits. Also, comparisons of different organizations or divisions can be made to help prioritize interactivity

practices. The findings presented in this study are encouraging but a great deal of further research remains to be done towards proposing a standard instrument for evaluating I_BIMA across disciplines. Future research could replicate the empirical work reported here to corroborate these results. In addition, future studies could involve more items, and larger, more broadly based samples. It is expected that the findings of this study will provide momentum for future research aimed at gaining a better understanding of the collaboration and systemic change necessary to effectively adopt BIM. Overtime, future research will further validate the present findings toward a standard evaluation guide for interorganizational collaboration and systemic change necessary to adopt BIM to the fullest extent.

CHAPTER 5: GENERAL CONCLUSION AND CONTRIBUTION

The lack of an integrated framework that adequately categorizes the factors interdependent beyond organizational boundaries has proven difficult to adopt BIM to the fullest extent in a competitive and fragmented work environment. Based on the thirteen reviewed cases leading to this study, an integrated framework was developed that best allows interorganizational collaboration and systemic change necessary to adopt BIM. Three specific objectives were achieved to solve the research problem. First, the study generated an integrated framework that extended the technology-organization-environment (TOE) theory to the topic of interorganizational BIM. The generated framework adequately categorizes the critical factors by introducing collaborative (social, interoperability, legal) factors, which overlap the basic (TOE) factors at an interorganizational level. Through grounded theory, it was revealed that none of the reviewed cases incorporated all the six factors, basic (technology-organization-environment) and collaborative (social-interoperability-legal); in an integrated framework that also defines the relationship between the two categorical factors. Second, the survey results identified six distinct measures, which established a clear consensus on the critical factors that extend the TOE framework to the topic of interorganizational BIM. Third, using data from three most recent BIM projects, the study demonstrated utilization of the identified factors as an instrument/evaluation guide for assessing success on collaboration and systemic change at an interorganizational level. Success was defined in each category with a specific weighted score value. Ultimately, this score correlated to a company's ability to share BIM data with other organizations and accept changes in a coordinated fashion. This tool was referred to as an evaluation guide for interorganizational BIM adoptability (I_BIMA).

Both the grounded theory and survey results support that the six-factor structure is the most appropriate framework for studying BIM technologies that involve interdependency of activities beyond organizational boundaries. Further, grounded theory results showed that these key factors must be treated in an interrelated fashion, to facilitate comprehensive strategies towards maximizing BIM technologies adoption and implementation.

Overall, users and non-BIM users both acknowledge the potential of BIM to increasing efficiency of projects. However, the rate of BIM adoption (41.2%), survey results, along with the additional comments provided by respondents, indicate BIM utilization is sporadic. It is expected that embracing the six critical factors identified in this study will enhance companies BIM utilization.

Non-BIM users consider the lack of BIM requirement by clients as their biggest obstacle in adopting BIM. Previous research demonstrates that this is linked to the potential increase in project price (Eastman, *et al.*, 2008). Also, many owners do not require new types of deliverables, such as 3D Models, for a fear of limiting the pool of bidders willing to participate in their projects.

Among the strategic measures identified under the legal category (in Figure 4.5), one seems to stand out….it is the "*standard compensation for BIM protocols*". Client should take the lead to establish a BIM requirement while including a provision of standard compensation for BIM protocols. These two items alone could positively influence BIM utilization both by users and non-BIM users alike. However, if these are linked to this study's identification of the critical factors (see Figure 4.3); it is believed the result would have a significant positive impact on the company's ability to effectively use BIM within its operations. Specific conclusions and contributions of this work are provided next:

5.1 From Chapter Two

- This study extended the classic TOE framework to the topic of interorganizational BIM. The extension integrated critical factors identified throughout the literature that are most influential within the interorganizational context.
- Although Chau and Tam (1997) and Nikas, *et al.* (2007) both used and modified the TOE framework, the novelty of this present study is the conceptualization and definition of the collaborative factors as links to the basic TOE factors. The study distinctively represented organizational (i.e. basic factors) and interorganizational (i.e. collaborative factors) contexts in an integrated framework.
- This research introduced and defined three specific practice environments (SPEs) at an interorganizational level (i.e. the intersections of the classic TOE framework) where activities interdependent beyond organizational boundaries significantly affect the process in BIM adoption.
- The SPEs defined in the developed CSC framework better facilitate strategic decisions that enable practitioners to go beyond coordination and collaboration levels, to network-based interaction, than previous strategies that have indicated difficulty transitioning beyond coordination level.
- Based on frequencies, environment and social factors were infrequently cited as critical factors. However, environmental factors have been found to be essential at an organizational level and therefore are inherently present at the interorganizational level. This indicated a current oversight in the interorganizational BIM literature. Similarly, social factors have been found to be of primary importance in BIM adoption, although a dearth of research of these factors exists.

- The lack of existing framework that adequately categorizes all the six factors in an integrated framework (as indicated in Figure 2.2, page 11) showed that the perception of interorganizational BIM adoption factors, as basic and collaborative, in a continuous interaction, is not a theory that exists in the construction industry. However, it is something that must exist to facilitate comprehensive strategies.
- Comparative analysis revealed that identification of collaborative sub-factors within existing literature was more numerous than expected-too numerous to embrace and use. However, these sub-factors were not ontologically categorized, which warranted further research to determine those sub-factors that are most influential.

5.2 From Chapter Three

- Survey results identified six critical factors (organizational variety, team BIM capability, duty of care, risk and liabilities, scope of work, and data preservation), which established a clear consensus, spanning 13 interorganizational BIM literatures.
- The identified critical factors were not within the scope of the classic TOE framework. This confirmed that collaborative factors are inadequate in the TOE framework.
- Hypotheses 1 and 3 were affirmed through statistical analysis. This meant that as companies engage in exchanging BIM data, collaborative factors begin to influence the adoption process significantly.
- As the levels of interorganizational interaction evolve (to levels 3 and 4), companies need to focus on social factors, to enhance teamwork (**H_3**).
- A positive correlation exists between the companies' level of interorganizational interaction and BIM experience **(H_7**). Results also showed a positive correlation between the companies' level of interorganizational interaction and company size (**H_8**). These results suggest there

needs to be an adequate capable team with BIM experience for companies of all sizes to effectively interact with other organizations.

- Results provided an evaluation guide for interorganizational BIM adoptability. The validation process indicated the proposed guide is an efficient measure of the interorganizational collaboration and systemic change necessary to adopt BIM.
- Statistically, there was no significant difference in mean scores between design/build and non-design/build companies. This result suggests that both groups had similar perceptions of the 64 factors (variables) that affect BIM implementation. This outcome was not expected, especially if one argues that, in design/build companies, collaboration is made easier as everything is done under one roof with one large team. Further research is necessary to examine specific case studies to explore specific reasons to these findings.

5.3 From Chapter Four

- Through quantifiable data from most recent BIM projects, utilization of an evaluation guide was demonstrated. The guide provides a more holistic approach that simplifies decision choices confronting BIM users as they interact in practice.
- The steps followed in this study showed that the proposed evaluation guide has undergone extensive evaluation and validation, hence, represents significant progress toward developing a standard instrument.
- This study contributes to a common understanding of the decision criteria most influential to the interorganizational BIM adoption, through development of a comprehensive instrument for evaluating interorganizational challenges.

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APPENDIX A: CONSENT FORM

THE FOLLOWING INFORMATION IS FOR YOUR PROTECTION AND PRIVACY. IF YOU AGREE, PLEASE CLICK TO ACCEPT THE FORM BELOW.

Informed Consent Form (Institutional Review Board Approval number E8345)
Louisiana State University (LSU)

Dear Participant:

We invite you to take part in a research study entitled "Framework for Interorganizational Adoption of BIM. A successful interorganizational sharing of BIM generated data enables the industry to best realize the benefits of BIM. This study attempts to understand what factors affect the sharing of BIM generated data across organizations to determine the strategies that could be taken to maximize its adoptability. Taking part in this study is entirely voluntary. Please take your time making a decision and feel free to discuss it with your friends, family and colleagues. Before agreeing to take part in this research study, it is important that you read the consent form that describes the study. Contact information for the principal investigator for this project is provided in Section 6. Please feel free to contact the investigator directly if you have any questions or concerns.

Section 1. Purpose of the Research
You are being offered the opportunity to take part in this research study because you have the expertise in the field of construction and/or the use of BIM. The purpose of this research study is to understand the factors influencing the interorganizational use of BIM. Your response will facilitate documentation of the current rates of BIM technology adoption, the industry's experience in BIM use, the level of BIM technology adopted, and barriers to the sharing of BIM generated data across organizations, to determine the strategies that could be taken to maximize this level of BIM adoption. If you decide to participate in this study, the survey will take approximately 15 minutes.

Section 2. Procedures
If you agree to take part in this study, it will be conducted in one phase with an online questionnaire. To answer the questions, please click on the link, sent to you via email, containing the URL of the web survey.

Section 3. Discomforts, Risks & Benefits
The risks from participating in this study are not more than would be encountered in everyday life. While there will be no direct cash benefit to participants, the study may yield valuable information regarding the integration of BIM in projects at the interorganizational level, and more profit upon successful management of its challenges. As a token of gratitude, we would like to offer you a copy of the results of this survey. Just fill in your contact information at the end of the survey or email me.

Section 4. Right to Refuse
Taking part in this study is voluntary. You have the right to choose not to take part in this study.

If you do not take part in the study, there will be no penalty. If you choose to take part, you have the right to stop at any time. However, we encourage you to contact the researchers so that we know why you are leaving the study. If there are any new findings during the study that may affect whether you want to continue to take part, you will be told about them.

Section 5. Statement of Confidentiality
Your research records that are reviewed, stored, and analyzed at Louisiana State University will be stored in a secured location. Results of the study may be published, but no names or identifying information will be included in the publication. All individual responses will remain confidential and study findings will be reported in an aggregate form. Subject identity will remain confidential unless disclosure is required by law.
Section 6. Contact Information for Questions or Concerns
You have the right to ask any questions you may have about this research. If you have questions, complaints or concerns or believe you may have developed an injury related to this research, contact Rehema Joseph Monko, Principal Investigator at 225-620-6764, or send email to: rmonko1@tigers.lsu.edu

Section 7. Signature
I have read and clearly understood the informed consent form. I may direct any question that I may have regarding study specifics to the investigator. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Institutional Review Board - IRB #E8345 Approval, (225) 578-8692, irb@lsu.edu, www.lsu.edu/irb. By signing below, you state that you have read and understood the purpose of the study and that you consent to participate.
By accepting this consent form, I agree to voluntarily participate in the study described above and acknowledge the investigator's obligation to provide me with a copy of this consent form.

APPENDIX B: RESEARCH INSTRUMENT

1. **By accepting this consent form, I agree to voluntarily participate in the study described above and acknowledge the investigator's obligation to provide me with a copy of this consent form.**

- accept
- I decline

2. **Which of the following categories best describes your current position within your organization?**

- CAD/BIM manager
- BIM Modeler
- Principal/ Director/ VP (upper management)
- Project Manager
- Project Engineer
- Estimator
- IT Manager
- Other (please specify)

3. **How many employees work at your company?**

- Less than 20 (small company)
- 20-99 (medium company)
- 100-500 (large company)
- More than 500 (very large company)

4. **What primary service does your company offer to your clients?**

- General Contracting
- Design/Build Services
- Construction Management Services
- Specialty Services
- Other (please specify)

5. **Does your organization utilize BIM technology on your projects?**

- ◌ No
- ◌ Yes

6. **How do you use BIM models/projects that are developed within your organization?**

- ◌ BIM models are used ONLY WITHIN my company
- ◌ BIM models are used within my company and SHARED WITH OTHER ORGANIZATIONS OUTSIDE my company

7. **What level has your organization successfully reached in utilizing BIM?**

- ◌ Level 1: Automating generation of documents using 2D plans, and for 3D visualization
- ◌ Level 2: Conflict or clash detection (includes Level 1)
- ◌ Level 3: Complex analyses through interdisciplinary models, using model server technologies (includes Level 1 and 2)
- ◌ Level 4: Supply chain integration (i.e. BIM models shared with other firms in the supply chain) (includes Level 1, 2, and 3)

8. **What is your company's biggest concern in BIM use?**

- ☐ Inability of BIM software/computer systems to exchange data, and interpret the shared data (interoperability issues)
- ☐ Legal status of BIM model and contractual support on BIM protocols
- ☐ Social/cultural influence on collaboration and teamwork

9. HOW IMPORTANT are each of the following items as it relates to your company's BIM use?

	Unimportant	Of little importance	Moderately important	Important	Very important
Re-evaluation of contractual relations					
Charging fees for using BIM					
Establishing risk allocation models					
User authentication for a shared BIM model					
Data encryption/protection					
Standardization of information systems					
Combining trade groups to improve workflow					
Easy and clear delegation of BIM design					
Clear workflow in BIM projects					
Use of emails for exchanging documents					
Compliance to standards and compatibility					
Enhanced collaborative environment					
Protection from unwanted claims/liability					
Training on required new set of skills					
Fast internet connection to manage data transaction					
Adequate team BIM experience					
BIM model access and usability					
Clarity on new roles and responsibilities					

10. Please continue from previous question...

	Unimportant	Of little important	Moderately important	Important	Very important
Access control over a shared BIM model	○	○	○	○	○
Clarity on BIM model ownership	○	○	○	○	○
Interactive communication	○	○	○	○	○
Utilizing BIM with design-build approach	○	○	○	○	○
Use of electronic documents as evidence	○	○	○	○	○
Standardizing business practices	○	○	○	○	○
Clear strategy to resolving BIM conflicts	○	○	○	○	○
Building trust among the project team	○	○	○	○	○
Transparency in collaboration	○	○	○	○	○
Understanding the value of data sharing	○	○	○	○	○
Upgrading information technology for data exchange	○	○	○	○	○
Clarity on required BIM deliverable	○	○	○	○	○
Data confidentiality, integrity, availability	○	○	○	○	○
Standard of preserving the shared data	○	○	○	○	○

11. In which of the following project types do you typically utilize BIM technology?

- Institutional, Government Buildings, Libraries, Prisons etc.
- Commercial Buildings
- Medical Facilities
- Educational (k-12, Universities)
- Sports Facilities
- Residential
- Industrial
- Other (please specify)

12. In which geographical region(s) does your company operate?

- West (WA, OR, CA, MT, ID, NV, AZ, WY, UT, CO, NM)
- South (TX, OK, AR, LA, MS, AL, TN, KY, FL, GA, SC, NC, VA, WV, DE, MD, DC)
- Northeast (PA, NY, NJ, CT, RI, MA, NH, VT, ME)
- Midwest (ND, SD, NE, KS, MO, IA, MN, WI, IL, IN, OH, MI)
- Nationwide
- International

13. Do the following situations HINDER OR OBSTRUCT your company's ability to use BIM?

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Absence of BIM standard contracts	○	○	○	○	○
Non-standard compensation on BIM protocols	○	○	○	○	○
Risk associated with BIM use	○	○	○	○	○
Data misuse	○	○	○	○	○
Security of electronic design/BIM model	○	○	○	○	○
Lack of industry wide BIM standards	○	○	○	○	○
Rigid boundaries separating trade groups	○	○	○	○	○
Errors originating from other contributors to the BIM model	○	○	○	○	○
Lack of clear BIM workflow	○	○	○	○	○
Inadequate interconnectivity	○	○	○	○	○
The shared BIM model is not compatible	○	○	○	○	○
Lack of collaborative/integrated services	○	○	○	○	○
Shift of liability among the project team	○	○	○	○	○
Training and cultural issues	○	○	○	○	○
Insufficient internet platform to host data	○	○	○	○	○
Change in population of contractors from project to project	○	○	○	○	○
Difficulty in organizing BIM model	○	○	○	○	○

14. Please continue from previous question...

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Changes in professional responsibilities	○	○	○	○	○
Unauthorized uses of BIM model	○	○	○	○	○
Issues with intellectual property rights	○	○	○	○	○
Communication breakdown	○	○	○	○	○
Prevalence of design-bid-build method	○	○	○	○	○
Lack of standard electronic contracts	○	○	○	○	○
Lack of standard BIM service framework	○	○	○	○	○
BIM software is not user friendly	○	○	○	○	○
Philosophical differences within the team	○	○	○	○	○
Fear of company information exposure	○	○	○	○	○
Handling of interdependent activities	○	○	○	○	○
Shift in technology/scope of innovation	○	○	○	○	○
Substantial changes to the scope of work	○	○	○	○	○
Data loss on sharing	○	○	○	○	○
Lack of international standard organization-ISO process certificate	○	○	○	○	○

15. In what year was your company founded?

16. What is your company's current work volume/gross revenue ($ in Millions)

17. How would you rate your company's level of experience in using BIM technology?

- Beginner
- Intermediate
- Advanced
- Expert

18. What would be the reason for not implementing BIM?

APPENDIX C: ROTATED COMPONENT MATRIX

Rotated Component Matrix[a]

	Component					
	1	2	3	4	5	6
Inh_Rigid_bound	.765					
Inh_Errors	.718					
Inh_Industry_std	.682					
Inh_Unauthor_use	.639					
Inh_Workflow	.591					
Inh_Interdp_activt						
Imp_Team_trust		.868				
Imp_Transparency		.818				
Imp_Conflict_strtgy		.793				
Imp_TeamBIM_exp						
Imp_Access_contr			.816			
Imp_Clear_own			.720			
Imp_Clear_w_flow			.708			
Inh_std_compenst			.583			
Inh_Liability_shift				.851		
Inh_BIMrisk				.755		
Imp_Disclaimer				.550		
Inh_Model_security				.530		
Inh_Change_scope_wk					.810	
Inh_Data_loss					.690	
Inh_Scope_innov					.569	
Inh_Change_respons						
Imp_Data_confidentl						.699
Imp_Clear_deliver						.653
Imp_Clear_roles						.556

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 22 iterations.

APPENDIX D: TOTAL VARIANCE EXPLAINED

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	9.004	36.015	36.015	3.856	15.424	15.424
2	3.239	12.958	48.973	3.305	13.218	28.642
3	1.797	7.188	56.161	3.086	12.343	40.984
4	1.547	6.186	62.348	2.695	10.779	51.764
5	1.167	4.666	67.014	2.617	10.468	62.232
6	1.019	4.075	71.089	2.214	8.857	71.089
7	.965	3.862	74.950			
8	.807	3.229	78.180			
9	.743	2.972	81.152			
10	.611	2.445	83.596			
11	.536	2.145	85.741			
12	.485	1.939	87.680			
13	.441	1.766	89.446			
14	.365	1.458	90.904			
15	.328	1.312	92.217			
16	.320	1.281	93.497			
17	.270	1.079	94.576			
18	.260	1.041	95.617			
19	.239	.954	96.571			
20	.192	.769	97.340			
21	.178	.710	98.050			
22	.151	.604	98.654			
23	.139	.556	99.211			
24	.107	.426	99.637			
25	.091	.363	100.000			

Extraction Method: Principal Component Analysis.

APPENDIX E: ITEM-TOTAL STATISTICS

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Imp_Clear_w_flow	84.37	174.326	.597	.635	.920
Imp_Disclaimer	84.69	170.426	.554	.702	.921
Imp_TeamBIM_exp	84.37	178.027	.469	.550	.922
Imp_Clear_roles	84.63	171.549	.617	.678	.920
Imp_Access_contr	84.93	174.786	.530	.655	.921
Imp_Clear_own	84.94	165.399	.737	.798	.917
Imp_Conflict_strtgy	84.43	176.756	.432	.623	.923
Imp_Team_trust	84.24	176.541	.493	.788	.922
Imp_Transparency	84.44	177.205	.407	.784	.923
Imp_Clear_deliver	84.44	175.564	.489	.633	.922
Imp_Data_confidentl	84.79	172.315	.553	.705	.921
Inh_std_compenst	85.28	173.458	.610	.584	.920
Inh_BIMrisk	85.24	172.630	.544	.633	.921
Inh_Model_security	85.63	175.967	.470	.594	.922
Inh_Industry_std	84.97	171.760	.571	.595	.920
Inh_Rigid_bound	85.38	169.523	.695	.749	.918
Inh_Errors	84.97	172.417	.511	.635	.922
Inh_Workflow	85.03	170.148	.646	.723	.919
Inh_Liability_shift	85.10	176.392	.449	.643	.922
Inh_Change_respons	85.18	170.476	.668	.726	.919
Inh_Unauthor_use	85.60	175.825	.508	.594	.921
Inh_Interdp_activt	85.43	174.905	.609	.696	.920
Inh_Scope_innov	85.35	174.560	.507	.745	.921
Inh_Change_scope_wk	85.15	174.277	.477	.717	.922
Inh_Data_loss	85.43	173.502	.588	.686	.920

APPENDIX F: RESEARCH VARIABLES (ENABLERS AND INHIBITORS)

	Enablers	**Inhibitors**
1	Re-evaluation of contractual relations	Absence of BIM standard contracts
2	Modification to professional scales of fees	Lack of standard compensation on BIM protocols
3	Establishing risk allocation models	Risk associated with BIM use
4	User authentication for a shared BIM model	Data misuse
5	Data encryption/protection	Security of electronic design/BIM model
6	Standardization of information systems	Lack of industry wide BIM standards
7	Combining trade groups to improve workflow	Rigid boundaries separating trade groups in workflow
8	Easy and clear delegation of BIM design	Errors originating from other contributors to the BIM model
9	Clear workflow in BIM projects	Lack of clear BIM workflow
10	Use of emails for exchanging documents	Inadequate interconnectivity/internet access
11	Compliance to standards and compatibility	The shared BIM model is not compatible
12	Enhanced collaborative environment	Lack of collaborative/integrated services
13	Protection from unwanted claims/liability	Shift of liability among project participants
14	Required new set of skills	Training and cultural issues
15	Fast internet connection to manage data transaction	Insufficient internet platform to host data
16	Inadequate team BIM experience	Change in population of contractors from project to project
17	Ensuring BIM model access and usability	Difficulty in organizing BIM model
18	Clarity on new roles and responsibilities	Changes in professional responsibilities
19	Access control over a shared BIM model	Unauthorized uses of BIM model
20	Clarity on BIM model ownership	Issues with intellectual property rights of BIM model

21	Interactive communication	Communication breakdown
22	Utilizing BIM with design-build approach	Non-collaborative project delivery methods
23	Electronic documents authorized as evidence	Lack of standard electronic contracts
24	Standardizing business practices	Lack of standard BIM service framework
25	Clear strategy to resolving BIM conflicts	BIM software is not user friendly/insufficient user interface
26	Trust among the project team	Psychological issues among the project team
27	Transparency in collaboration and data sharing	Fear of trade or company information exposure
28	Understanding the value of BIM data sharing	Difficulty in handling interdependent activities
29	Upgrading information technology for data exchange	Technology shift/change in scope of innovation
30	Clarity on required BIM deliverable	Substantial changes to the scope of work
31	Features that support confidentiality, integrity, and data availability	Data loss on sharing
32	Standard of preservation of a shared BIM model	Acquiring international standard organization-ISO process certificate

VITA

Rehema Joseph Monko, a native of Singida, Tanzania, received her bachelor's degree in Building Economics (BE) at the University of Dar es Salaam (UDSM)-Tanzania in 2003. Thereafter, she worked with a consulting company on construction estimating and project management. She later joined the graduate school, in 2004, and received a Master in Engineering Management (MEM) degree, in 2006, at the College of Engineering and Technology (CoET) of the UDSM. She also worked on three term-contracts with the Public Procurement Regulatory Authority (PPRA) of Tanzania, on disseminating the Public Procurement Act of 2004 (PPA, 2004) to public officials, between 2006 and 2009. She is an affiliate of Ardhi University- ARU of Tanzania, since 2007. In 2009 she received the Fulbright Scholarship- Junior Staff Development Program award for a PhD in Engineering Science program at Louisiana State University (LSU) in the United States (US). In the Summer of 2011, she was among the panelists in a three day interview of the 2011 Fulbright Scholarship applicants at the US Embassy in Tanzania. In 2011, she received the Schlumberger Foundation- Faculty for the Future (FFTF) Program award to continue fulfillment of her PhD program. She also received an assistantship award by the Bert S. Turner Department of Construction Management at LSU, in 2014, and later, the LSU Graduate School Dissertation Fellowship award, to complete her PhD program. She is a candidate to receive a PhD degree in May 2015, and plans to resume her position at ARU.