

Critical Factors for Interorganizational Collaboration and Systemic Change in BIM Adoption

Rehema J. Monko^{1,*}, Charles W. Berryman², Carol J. Friedland²

¹Ardhi University, Dar es Salaam, Tanzania

²Louisiana State University, Baton Rouge, Louisiana, U.S.

Abstract 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. Measures interrelated beyond organizational boundaries were previously identified, through a meta-analysis of factors and sub-factors, and termed collaborative. The identified measures, however, were numerous and varied between studies. An online survey of 165 US contractors was conducted on the measures, which yielded six critical factors that established a clear consensus on measures spanning 13 interorganizational BIM literatures. The identified critical 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.

Keywords BIM Critical Factors, Interorganizational Context, Collaboration and Systemic Change

1. Introduction

Interorganizational collaboration and systemic change 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 (factors and sub-factors) unclear, requiring further research.

A meta-analysis of factors and sub-factors, introduced two categories of factors, basic and collaborative, that influence BIM adoption. *Basic factors* (technology-organization-environment), are consistent with the classic technology-organization-environment (TOE) theory (Tornatzky & Fleischer, 1990), while *collaborative factors* (interoperability-legal-social) relate to the interdependency of activities beyond organizational boundaries; respectively representing organizational and

interorganizational contexts. Distinct measures for the basic factors fall entirely within the scope of the TOE theory 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. 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.

2. Review of Literature

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

* Corresponding author:

rjmonko1@gmail.com (Rehema J. Monko)

Published online at <http://journal.sapub.org/ijcem>

Copyright © 2017 Scientific & Academic Publishing. All Rights Reserved

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 theory, 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 theory 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 to contribute to a more comprehensive interorganizational BIM strategy. The following; level of BIM use, project delivery method, and levels of interaction in BIM projects, are discussed next in connection with interorganizational BIM usage.

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.

Project delivery method

Depending on the project delivery method, 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 two overlapping categorical factors (i.e. basic and collaborative), that emerged through a meta-analysis of factors and sub-factors assessed in this study, represent best practices for interorganizational collaboration and systemic

change in the construction industry. The overlapping of factors echoes the design/build companies' set-up. It was expected that design/build companies, whose team collaboration is made easier, would find the collaborative factors significantly less inhibiting in practice than non-design/build companies.

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 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 identifies 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 1. Levels of Interorganizational Interaction in BIM Projects

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

3. 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.

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.

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 1 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, 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.

S = Social; I = Interoperability; L = Legal

Collaborative S	• Training and cultural issues (Redmond, <i>et al.</i>, 2012) • Firm culture (Deutsch, 2011) • Communication (Deutsch, 2011) • Trust (Deutsch, 2011) • Working in teams (Deutsch, 2011) • Team communication and interaction (Singh, <i>et al.</i>, 2011)	• Psychological (AGC, 2010) • Communication improvement (Nikas, <i>et al.</i>, 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)
	• Bandwidth (Redmond, <i>et al.</i>, 2012) • Interoperability of BIM software (Redmond, <i>et al.</i>, 2012) • Transparency (Redmond, <i>et al.</i>, 2012) • Drivers for Cloud BIM (Redmond, <i>et al.</i>, 2012) • Standard business practice (Redmond, <i>et al.</i>, 2012) • Technology shift (Redmond, <i>et al.</i>, 2012) • Energy performance analysis/identifying energy usage and demand (Redmond, <i>et al.</i>, 2012) • Using an internet platform to host data for post-occupancy calculations, specifications, and building performance (Redmond, <i>et al.</i>, 2012)	• BIM model organization (Singh, <i>et al.</i>, 2011) • Model access and usability (Singh, <i>et al.</i>, 2011) • User Interface (Singh, <i>et al.</i>, 2011) • Design visualization and navigation (Singh, <i>et al.</i>, 2011) • Procedural flows (Succar, 2009) • Network (Succar, 2009) • Team BIM capability (Mutai, 2009) • Data misuse (Ashcraft, 2008) • Internet connection (Nikas, <i>et al.</i>, 2007) • ISO process certificate (Nikas, <i>et al.</i>, 2007) • % of employee with internet access (Nikas, <i>et al.</i>, 2007) • Usefulness digital transfer of data/information (Nikas, <i>et al.</i>, 2007) • IS standardization (Nikas, <i>et al.</i>, 2007) • Use of email for exchange of documents (Nikas, <i>et al.</i>, 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)
I	• 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) • Access control (Singh, <i>et al.</i>, 2011) • New set of skills required (Oluwole, 2011) • Integrated services (Oluwole, 2011) • Service framework (Oluwole, 2011) • Workflow (Deutsch, 2011) • Number of models (Deutsch, 2011)	

Figure 1. Categorized Factors and Sub-Factors by Factor

- 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)
 - 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)
 - Project delivery method (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) Rigid boundary that separate the impacted trades for a given systemic innovation (Taylor & Levitt, 2004)

Figure 1. Continued

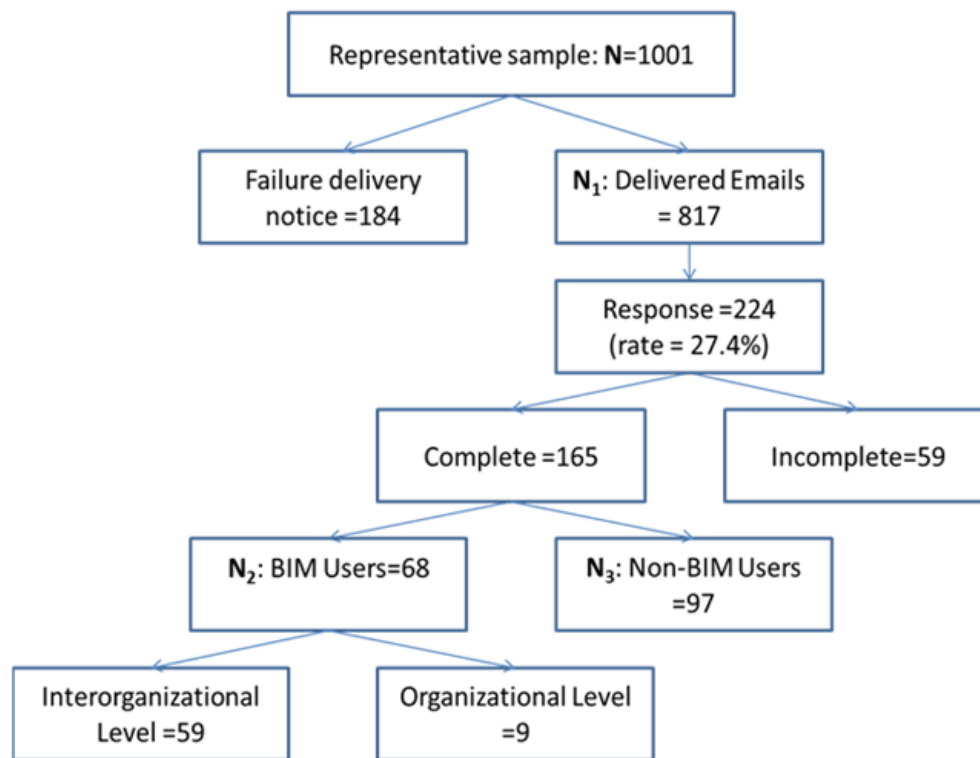


Figure 2. Survey Response

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.

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 2.

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. 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.

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) predominantly held top management positions (31.3%) followed by project managers (23.9%) and CAD/BIM managers (20.9%).

The surveyed contractors came from a variety of company sizes (Figure 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.

Services offered by respondents covered wide geographical regions, including nationwide and international companies. Majorities came from the South region, as indicated in Figure 5. One explanation for a more positive response from the South region could be the location of the researching institution (LSU).

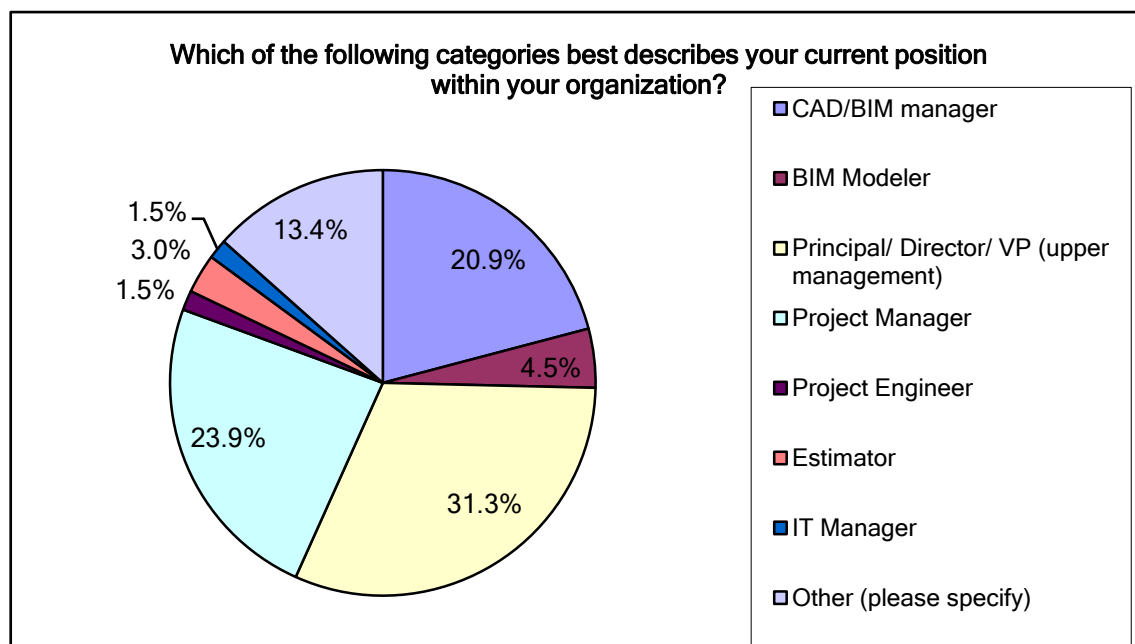


Figure 3. Respondents Categories

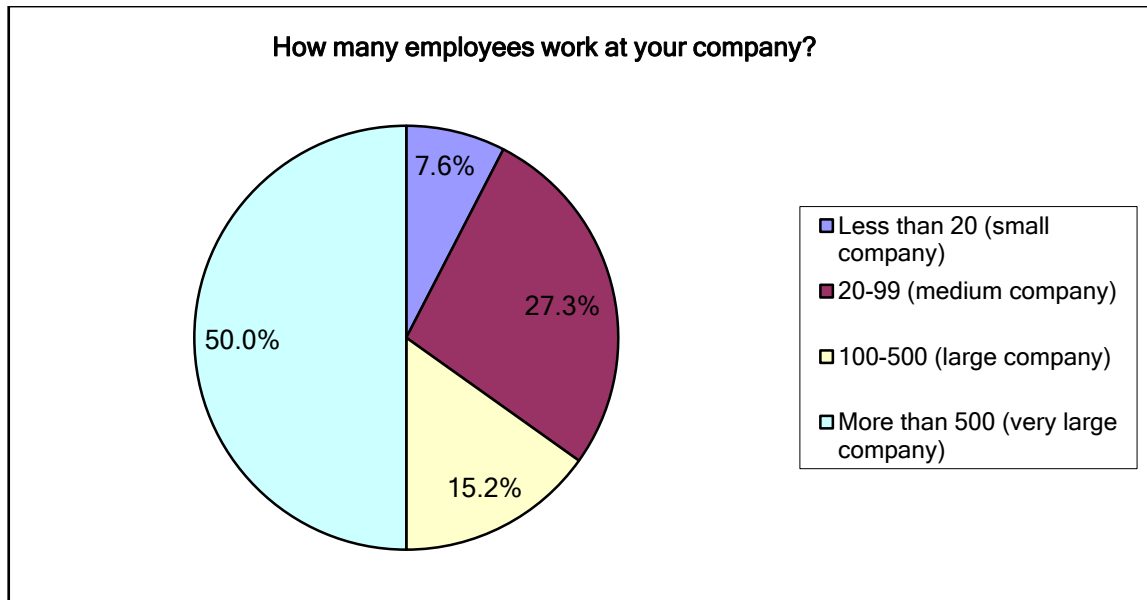


Figure 4. Company Size

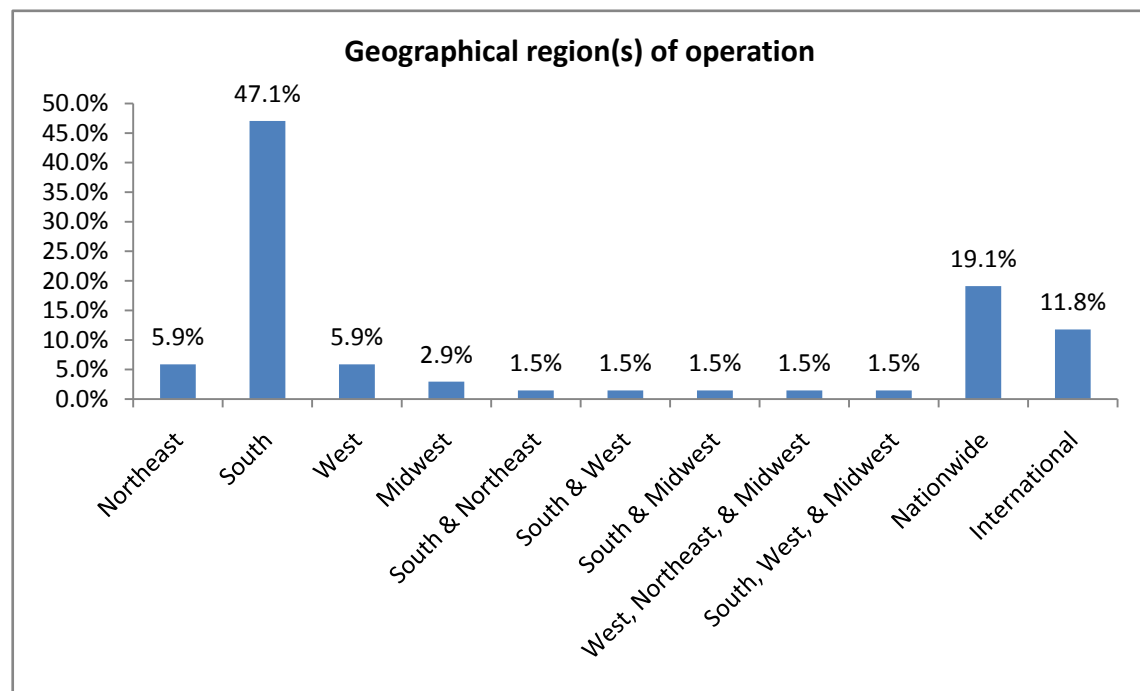


Figure 5. Geographical Region(s) of Operation

Surveyed companies indicated they offered a variety of services (Figure 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 7). BIM was utilized on a variety of project

types (Figure 8) but mostly on commercial construction (63.6%). This was consistent with previous studies (Mutai, 2009; Suermann & Issa, 2009). “Institution, government, and other public 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 9). The four levels were described in terms of BIM functions.

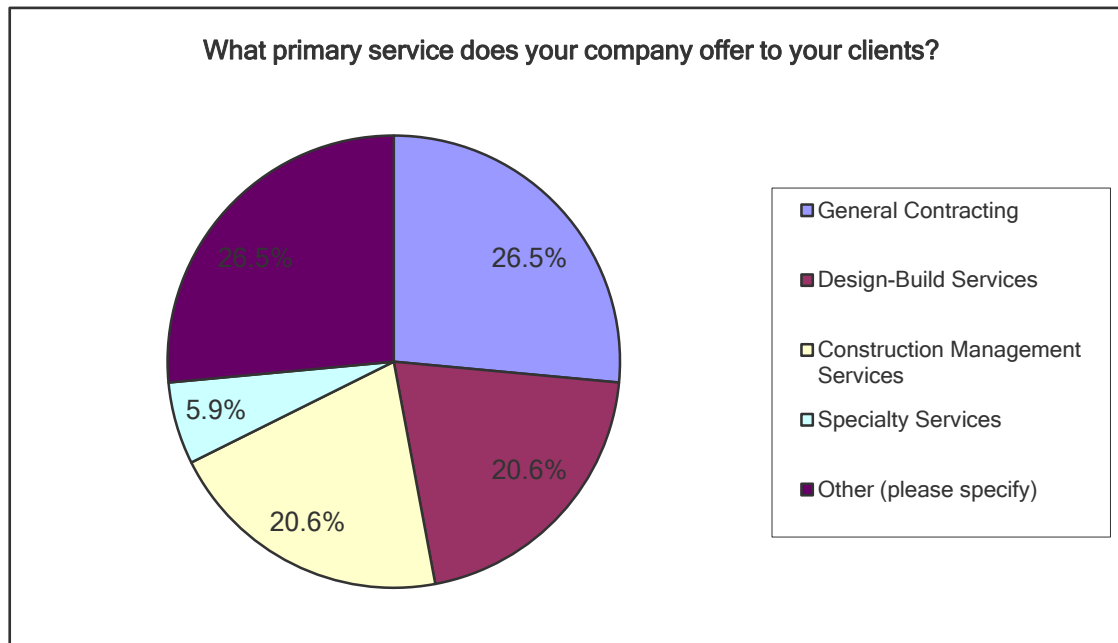


Figure 6. Type of Services Offered to Clients

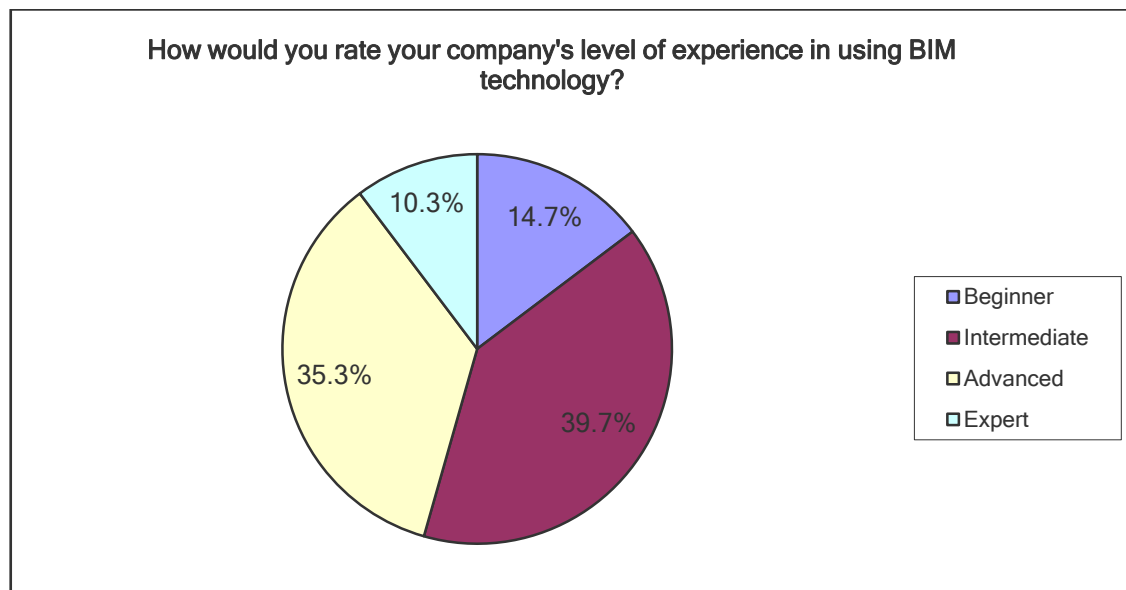


Figure 7. Respondents' Level of Experience in BIM Use

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 through a meta-analysis of factors. 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 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 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 11).

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), whereas 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, 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.

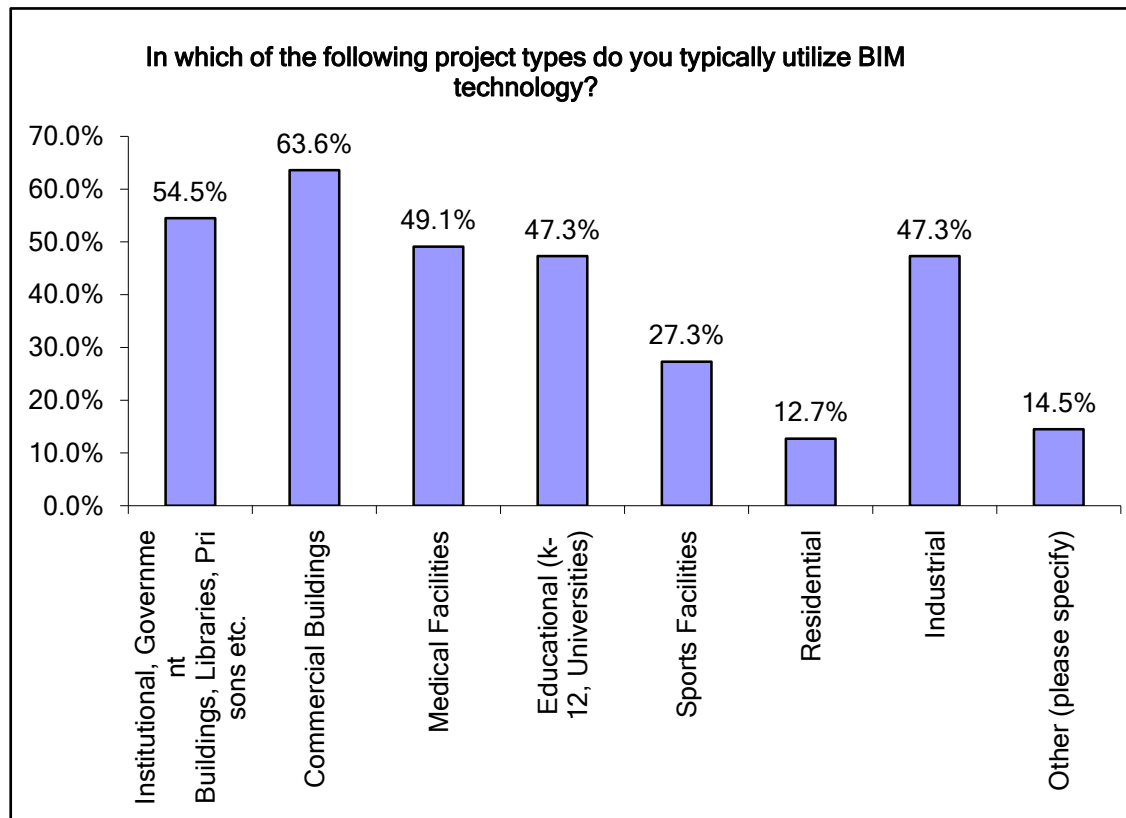


Figure 8. Project Types on which BIM was Utilized

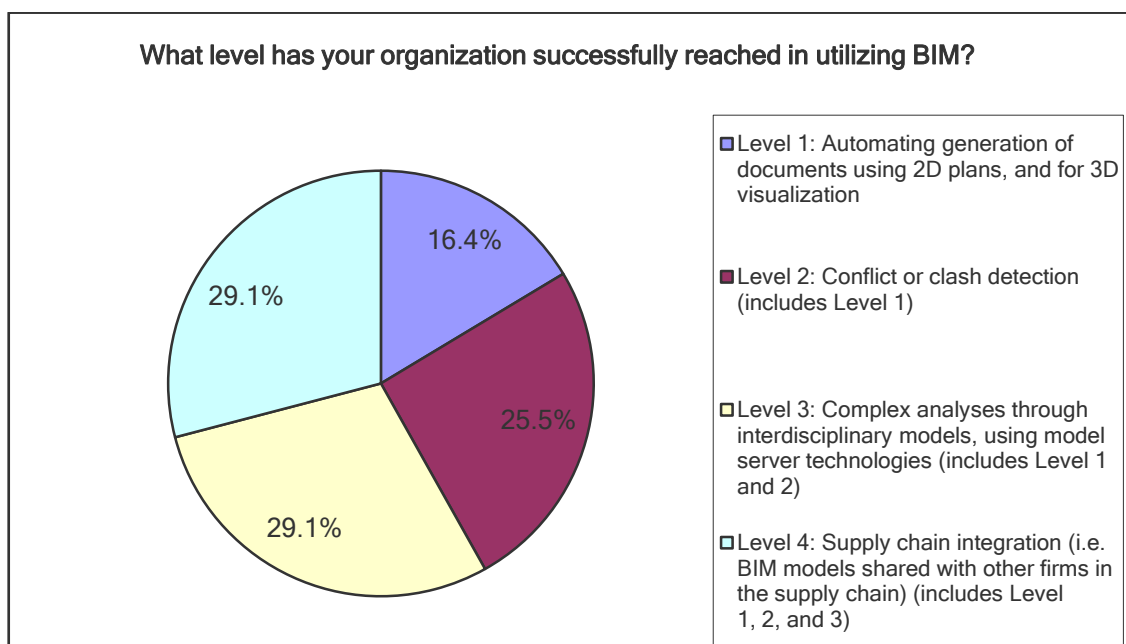


Figure 9. Interaction Levels at an Interorganizational Level

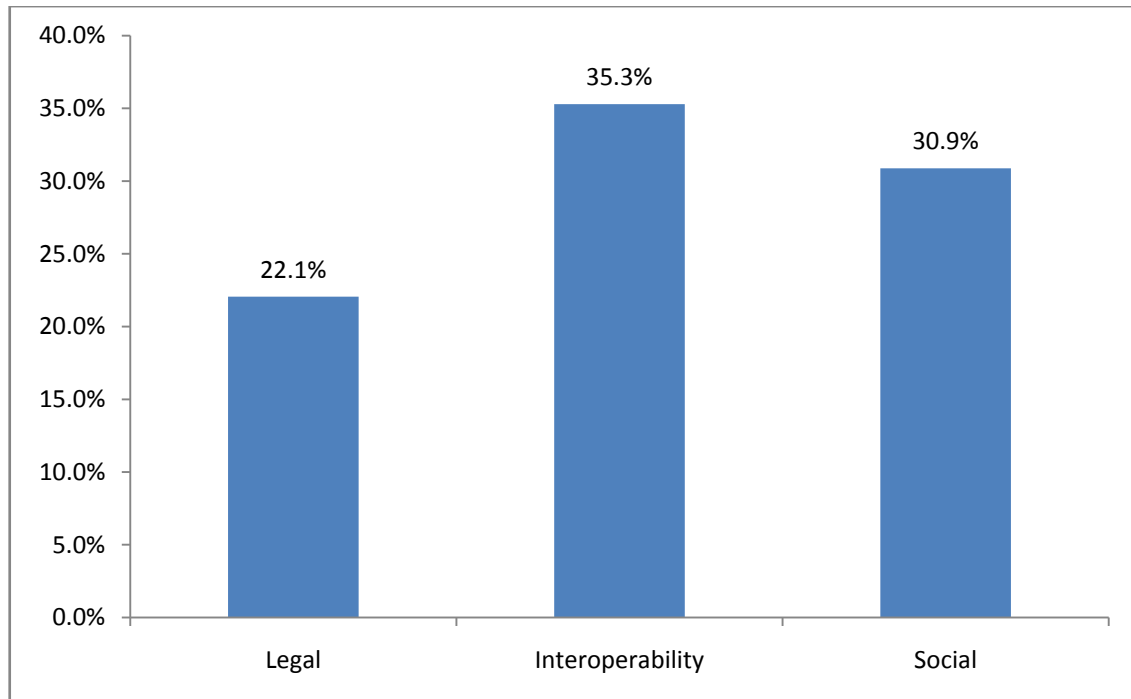


Figure 10. Companies' Biggest Concern in BIM Use

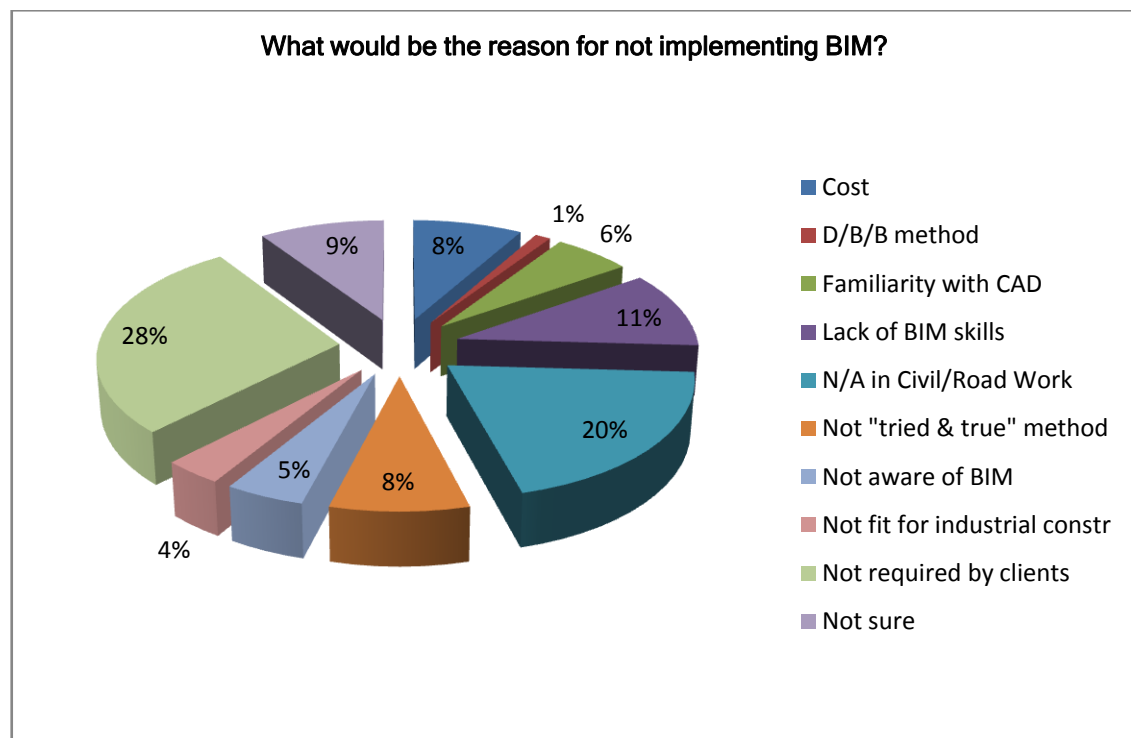


Figure 11. Reasons for not Implementing BIM on Projects

To address the aim of this study, 68 respondents (BIM users), who evaluated the variables, were considered for principal components analysis (PCA) procedure to identify 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 ratio (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. 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 2, along with the specific items describing the factors at correlation loadings of ≥ 0.50 .

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 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 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 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 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 13. Test of Normality of the Transformed Data

Normality test after the data transformation showed that the data were approximately normally distributed. Figure 14 presents a histogram for transformed variables (enablers and inhibitors combined).

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).

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.

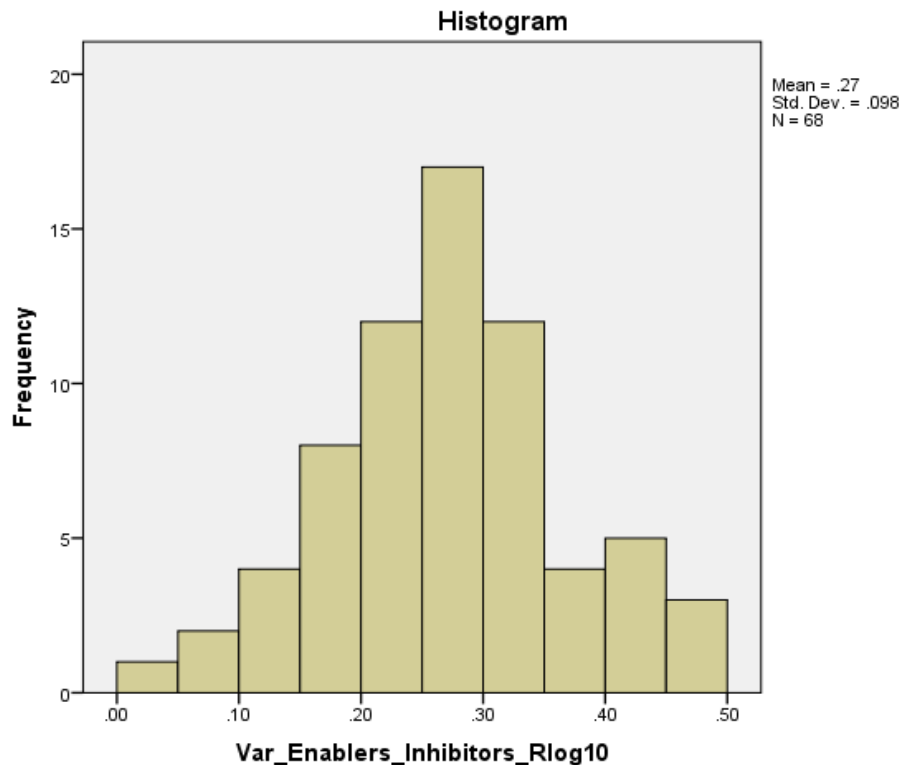


Figure 14. Test of Normality for Transformed Data

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, 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 15). Results, using both Pearson (parametric test-Figure 16), and Spearman (non-parametric test-Figure 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 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 16. Correlations

Nonparametric Correlations

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

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

Figure 17. Nonparametric Correlations

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:

H₁: Interorganizational BIM users would hold collaborative factors to be more significant on average than organizational BIM users.

H₀: $\mu_0 = \mu_1$ **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 (**H₁**) that there was a significant difference in contractors' perception of the collaborative factors based on the level of BIM use. Figure 18 summarizes results. Other tests had p -value > .05.

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 (μ_1 = design/build; μ_2 = construction management; μ_3 = specialty services; μ_4 = general contracting; μ_5 = "others").

H₂: There is a statistical significant difference, in factor mean scores, between contractors based on the type of primary service offered to clients.

H₀: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$ **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 19. Post hoc test was, therefore, not necessary. In this test, the hypothesis (**H₂**) was not supported.

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 (μ_1 = Level 1; μ_2 = Level 2; μ_3 = Level 3; μ_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).

H₃: There is a statistical significant difference, in factor mean scores, between contractors based on their companies' level of interorganizational interaction.

H₀: $\mu_1 = \mu_2 = \mu_3 = \mu_4$ **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 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.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the 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 18. Independent Samples Test based on BIM Level

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 19. ANOVA Test based on the Type of Primary Service Offered

		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 20. ANOVA Based on Interorganizational Level of Interaction

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 21. Tukey HSD-Multiple Comparisons based on the Level of Interorganizational 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 21.

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 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 22. Company size-ANOVA

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

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the 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 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 24. ANOVA based on Level of BIM Experience

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:

H₅: Design/build companies would hold collaborative factors to be less significant on average than non-design/build companies.

H₀: $\mu_0 = \mu_1$ **H_a:** $\mu_0 < \mu_1$

There was no statistical significant difference between groups (all tests indicated $p > .05$). Results are presented in Figure 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, μ_1 = beginner, μ_2 = intermediate, μ_3 = advanced, and μ_4 = expert.

H₆: There is a statistical significant difference, in factor mean scores, between contractors based on the level of BIM experience.

H₀: $\mu_1 = \mu_2 = \mu_3 = \mu_4$ **H_a:** at least one μ is different

Results (Figure 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 (**H₆**) was not supported.

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.

H₇: There is a positive correlation between companies'

level of interorganizational interaction and BIM experience.

H₀: 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 (**H₇**) 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:

H₈: There is a positive correlation between companies'

level of interorganizational interaction and company size.

H₀: There is no relationship between level of interorganizational interaction and company size.

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 (**H₈**) that there is a positive correlation between companies' level of interorganizational interaction and company size. Summary of the research hypotheses is provided (Table 3).

5. Discussion

The objective of this study was to establish a clear consensus on the critical factors influencing interorganizational BIM that are inadequate in the classic TOE theory. 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 theory. Moreover, these findings not only support the extension of the TOE theory, but also demonstrate (through meta-analysis of factors), that the three factors are in a continuous interaction in practice. Figure 10 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.

Table 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)
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)

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 theory. 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”.

Research Implication and Limitations

The critical factors identified in this study confirmed that collaborative factors are inadequate in the TOE theory. Results presented here confirm that the six factor structure (basic and collaborative) is the most appropriate theory 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. Study findings indicate 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 theory 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.

6. Conclusions: 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 (**H₂** and **H₅**). The design/build 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. Meanwhile, statistical results showed that the level of interorganizational interaction positively correlates with both the BIM experience (**H₇**), and company size (**H₈**). Results of this study established a clear consensus of factors, spanning 13 interorganizational BIM literatures.

REFERENCES

- [1] AGC. (2005). Associated General Contractors of America. The Contractor's Guide to BIM, 1st ed. AGC Research Foundation, Las Vegas, NV.
- [2] AGC. (2006). Contractors' Guide to BIM.
- [3] AGC. (2010). *AGC's Building Information Modeling Education Program* (Unit 4, BIM Process, Adoption, and Integration-Participant's Manual, First Edition ed.). Arlington, VA.
- [4] Anastasi, A., & Urbina, S. (1997). Psychology testing..
- [5] Ashcraft, H. W. (2008). Building information modeling: A framework for collaboration. *Constr. Law.*, 28, 5.
- [6] Ashcraft, H., Hanson, B., Marcus, V., Rudy, L. L. P., Hotel, H. R. N., & Spa—Newport, R. I. (2006). Building Information Modeling.
- [7] Azhar, S., Nadeem, A., Mok, J. Y., & Leung, B. H. (2008, August). Building Information Modeling (BIM): A new paradigm for visual interactive modeling and simulation for construction projects. In *Proc., First International Conference on Construction in Developing Countries* (pp. 435-446).

- [8] Baker, J. (2012). The technology–organization–environment framework. In *Information systems theory* (pp. 231-245). Springer New York.
- [9] Becerik-Gerber, B., & Rice, S. (2010). The perceived value of building information modeling in the US building industry. *Journal of Information Technology in Construction (ITcon)*, 15(15), 185-201.
- [10] Becerik, B., & Pollalis, S. N. (2006). Computer aided collaboration in managing construction. *Meridian Systems*.
- [11] Chau, P. Y., & Tam, K. Y. (1997). Factors affecting the adoption of open systems: an exploratory study. *MIS quarterly*, 1-24.
- [12] Ciborra, C. (2000). *From control to drift: the dynamics of corporate information infrastructures*. Oxford University Press on Demand.
- [13] Cramer, D., & Howitt, D. L. (2004). *The Sage dictionary of statistics: a practical resource for students in the social sciences*. Sage.
- [14] Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *psychometrika*, 16(3), 297-334.
- [15] CTI. (2012). The 2012 Construction Technology Integration Report. Retrieved July 3, 2014 from JB Knowledge Technologies, Inc.: <http://jbknowledge.com/2012-construction-technology-integration-report-reveals-lack-of-cloud-adoption-and-need-for-integration-in-construction-industry>.
- [16] Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: a comparison of two theoretical models. *Management science*, 35(8), 982-1003.
- [17] Deutsch, R. (2011). *BIM and integrated design: strategies for architectural practice*. John Wiley & Sons.
- [18] Doane, D. P., & Seward, L. E. (2011). Measuring skewness: a forgotten statistic. *Journal of Statistics Education*, 19(2), 1-18.
- [19] Dyer, B., Goodrum, P. M., & Viele, K. (2011). Effects of omitted variable bias on construction real output and its implications on productivity trends in the united states. *Journal of Construction Engineering and Management*, 138(4), 558-566.
- [20] Eastman, C. M., Teicholz, P., Sacks, R., Liston, K., & Handbook, B. I. M. (2008). A Guide to Building Information Modeling for Owners, Managers, Architects, Engineers, Contractors, and Fabricators.
- [21] Eckblad, Stuart, Jim Bedrick, & Rubel. (2007). *The Possibilities of an Integrated Approach Paper presented at the AIA California Council Change Conference*, June 25 -26, San Francisco.
- [22] Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of management journal*, 50(1), 25-32.
- [23] Fox, S., & Hietanen, J. (2007). Interorganizational use of building information models: potential for automational, informational and transformational effects. *Construction Management and Economics*, 25(3), 289-296.
- [24] Gilligan, B., & Kunz, J. (2007). VDC use in 2007: significant value, dramatic growth, and apparent business opportunity. TR171, 36.
- [25] Glaser BG,; Strauss AL. (1967). *The discovery grounded theory: strategies for qualitative inquiry*.
- [26] Goodhue, D. L., & Thompson, R. L. (1995). Task-technology fit and individual performance. *MIS quarterly*, 213-236.
- [27] Gorsuch, R. L. (1983). Factor analysis. 2nd. Hillsdale, NJ: LEA..
- [28] Grilo, A., & Jardim-Goncalves, R. (2010). Value proposition on interoperability of BIM and collaborative working environments. *Automation in Construction*, 19(5), 522-530.
- [29] Gu, N., & London, K. (2010). Understanding and facilitating BIM adoption in the AEC industry. *Automation in construction*, 19(8), 988-999.
- [30] Homayouni, H., Neff, G., & Dossick, C. S. (2010). Theoretical categories of successful collaboration and BIM implementation within the AEC industry. In *Construction Research Congress 2010: Innovation for Reshaping Construction Practice* (pp. 778-788).
- [31] Huang, C. J., & Bolch, B. W. (1974). On the testing of regression disturbances for normality. *Journal of the American Statistical Association*, 69(346), 330-335.
- [32] Hung, S. Y., Ku, C. Y., & Chang, C. M. (2003). Critical factors of WAP services adoption: an empirical study. *Electronic Commerce Research and Applications*, 2(1), 42-60.
- [33] IBM Corp. (Released 2013). IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.
- [34] John. (2014/06/01). An Update On Uniclass2. Retrieved 03/19/2015, from <http://www.cpic.org.uk/uniclass/>.
- [35] Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika*, 39(1), 31-36.
- [36] Khanzode, A., Fischer, M., Reed, D., & Ballard, G. (2006). A guide to applying the principles of virtual design & construction (VDC) to the lean project delivery process. *CIFE, Stanford University, Palo Alto, CA*.
- [37] Khemlani, L. (2007). Transitioning to BIM. Retrieved October 29, 2012: www.autodesk.com/revit
- [38] Ku, K., & Taiebat, M. (2011). BIM experiences and expectations: the constructors' perspective. *International Journal of Construction Education and Research*, 7(3), 175-197.
- [39] Linderoth, H. C. (2010). Understanding adoption and use of BIM as the creation of actor networks. *Automation in construction*, 19(1), 66-72.
- [40] MacCallum, R. C., Widaman, K. F., Zhang, S., & Hong, S. (1999). Sample size in factor analysis. *Psychological methods*, 4(1), 84.
- [41] Mutai, A. (2009). *Factors influencing the use of building information modeling (BIM) within leading construction firms in the United States of America* (Doctoral dissertation, Indiana State University).
- [42] Neelamkavil, J. (2009, June). Automation in the prefabricated and modular construction industry. In *26th Symposium on Construction Robotics ISARC*.
- [43] Neff, G., Fiore-Silfvast, B., & Dossick, C. S. (2010). A case

- study of the failure of digital communication to cross knowledge boundaries in virtual construction. *Information, Communication & Society*, 13(4), 556-573.
- [44] Nikas, A., Poulymenakou, A., & Kriaris, P. (2007). Investigating antecedents and drivers affecting the adoption of collaboration technologies in the construction industry. *Automation in construction*, 16(5), 632-641.
- [45] Norusis, M. J. (1985). *Advanced Statistics Guide SPSSX*. Chicago: SPSS Inc.
- [46] Nunnally, J. C., & Bernstein, I. (1978). *Psychometric theory*. New York: MacGraw-Hill. _ d. *Intentar embellecer nuestras ciudades y también las*.
- [47] Olatunji, O. A. (2011). A preliminary review on the legal implications of BIM and model ownership. *Journal of Information Technology in Construction (ITcon)*, 16(40), 687-696.
- [48] Polit, D. F., & Beck, C. T. (2004). *Nursing research: Principles and methods*. Lippincott Williams & Wilkins.
- [49] Redmond, A., Hore, A., Alshawi, M., & West, R. (2012). Exploring how information exchanges can be enhanced through Cloud BIM. *Automation in construction*, 24, 175-183.
- [50] Rogers, E. M. (2010). *Diffusion of innovations*. Simon and Schuster.
- [51] Singh, V., Gu, N., & Wang, X. (2011). A theoretical framework of a BIM-based multi-disciplinary collaboration platform. *Automation in construction*, 20(2), 134-144..
- [52] Stinchcombe. (1968). *Constructing social theories* New York: Harcourt Brace and World.
- [53] Strauss, A., & Corbin, J. (1998). *Basics of qualitative research techniques*. Sage publications.
- [54] Succar, B. (2009). Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in construction*, 18(3), 357-375.
- [55] Suddaby, R. (2006). From the editors: What grounded theory is not. *Academy of management journal*, 49(4), 633-642.
- [56] Suermann, P. C., & Issa, R. R. (2009). Evaluating industry perceptions of building information modelling (BIM) impact on construction. *Journal of Information Technology in Construction (ITcon)*, 14(37), 574-594.
- [57] Taylor, J. (2005). Three perspectives on innovation in interorganizational networks: Systemic innovation, boundary object change, and the alignment of innovations and networks. *PhD, Stanford University, Stanford, CA*.
- [58] Taylor, J. E., & Bernstein, P. G. (2009). Paradigm trajectories of building information modeling practice in project networks. *Journal of Management in Engineering*, 25(2), 69-76.
- [59] Taylor, J., & Levitt, R. (2004). Understanding and managing systemic innovation in project-based industries. *Innovations: Project management research*, 83-99.
- [60] Thompson, D. B., & Miner, R. G. (2006). Building information modeling-BIM: Contractual risks are changing with technology. *WWW document* URL <http://www.aepronet.org/ge/no35.html>.
- [61] Tornatzky, L. G., Fleischer, M., & Chakrabarti, A. K. (1990). *Processes of technological innovation*. Lexington Books.
- [62] Velicer, W. F., & Fava, J. L. (1998). Affects of variable and subject sampling on factor pattern recovery. *Psychological methods*, 3(2), 231.
- [63] Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management science*, 46(2), 186-204..
- [64] Markova, M., Aula, A., Lonnqvist, A., & Wigelius, H. (2008). Identifying and measuring the success factors of mobile business services. *International Journal of Knowledge Management Studies*, 2(1), 59-73.
- [65] Wikforss, Ö., & Löfgren, A. (2007). Rethinking communication in construction. *Journal of Information Technology in Construction*, 12, 337-345.
- [66] Wold, S., Esbensen, K., & Geladi, P. (1987). Principal component analysis. *Chemometrics and intelligent laboratory systems*, 2(1-3), 37-52.
- [67] Won, J., Lee, G., Dossick, C., & Messner, J. (2013). Where to focus for successful adoption of building information modeling within organization. *Journal of Construction Engineering and Management*, 139(11), 04013014.
- [68] Woo, J. H. (2006). BIM (building information modeling) and pedagogical challenges. In *Proceedings of the 43rd ASC National Annual Conference* (pp. 12-14).
- [69] Yan, H., & Damian, P. (2008, October). Benefits and barriers of building information modelling. In *12th International conference on computing in civil and building engineering* (Vol. 161).
- [70] Zhu, K., Kraemer, K., & Xu, S. (2003). Electronic business adoption by European firms: a cross-country assessment of the facilitators and inhibitors. *European Journal of Information Systems*, 12(4), 251-268.