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Investigation of Factors and Sub-Factors Influencing Interorganizational Building Information Modeling Adoption

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Abstract This study investigates factors and sub-factors influencing usage of Building Information Modeling (BIM) at an Interorganizational level. A Grounded Meta-Analysis of thirteen case studies was utilized. An often-cited Technology-Organization-Environment (TOE) theory that has demonstrated stability across multiple domains at an organizational level was used as the basis of analysis. The goal was to consistently define the factors outside the basic TOE theory that influence usage of Interorganizational BIM (IBIM). Two categories of factors emerged from the analysis, representing organizational and interorganizational contexts, respectively: *basic factors* (technology-organization-environment), which are consistent with the TOE theory; and *collaborative factors* (interoperability-legal-social), which relate to the interdependency of activities beyond organizational boundaries. Results of this study consistently define the IBIM factors while revealing the inadequacy of the TOE theory to addressing the interorganizational BIM. It is important that IBIM users embrace the collaborative category of factors for best realization benefits. The study results provide the potential to extending the TOE theory to adequately address the interdependency of activities beyond organizational boundaries.

Keywords Grounded Meta-analysis of Factors, Interorganizational BIM, Technology-Organization-Environment Theory

1. Introduction

Through digital representation of facility physical and functional characteristics (Mutai, 2009) using a relational database that offers active access for data use and exchange among stakeholders (Azhar, *et al.*, 2008; Mutai, 2009), BIM is a revolutionary technology that facilitates identification of inefficiencies that reduce productivity. The data exchange and collaboration inherent in BIM necessitate coordinated changes at the interorganizational level for a successful adoption process; however, the lack of a comprehensive interorganizational building information modeling adoption (IBIMA) theory has made the adoption process sporadic, incomplete, and prohibitively shallow (Deutsch, 2011). Interorganizational BIM (IBIM) describes the utilization of BIM technology where a multidisciplinary team of companies is required to collaborate, exchange BIM data, and accept changes in a coordinated fashion. This level of BIM adoption was also described by Fox and Hietanen (2007) as “BIM use across a broad range of companies” that involves the exchange and sharing of computer files between different organizations. Other 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). IBIM is also referred to 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, a comprehensive theory that integrates the key factors for IBIMA is still needed for the industry to maximize adoption (AGC, 2010; Azhar, *et al.*, 2008; Robson, *et al.*, 2014).

Adoption theory is aimed at understanding the choices individuals or organizations make in accepting or rejecting an innovation (Straub, 2009; Venkatesh & Davis, 2000). A particular focus of such understanding is the extent to which the adopted innovation, as described by its unique

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characteristics, is integrated into the appropriate scope or context (Straub, 2009). The interorganizational scope of this study renders 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 scope of analysis. These theories focus on the user and do not consider the influence of technological characteristics, which are central to the adoption of BIM. Tornatzky and Fleischer (1990) provided an organizational-level adoption theory through the Technology-Organization-Environment (TOE) theory. The TOE theory is distinctive from other adoption theories in that it accounts for the influence of technological characteristics (Nikas, *et al.*, 2007). The factors comprising the TOE theory are: 1) *Technology*, 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 theory is an often-cited theory that has demonstrated stability across multiple domains (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 (Baker, 2012; Zhu, *et al.*, 2003). However, being an organizational level theory, the TOE theory does not integrate certain factors that contemporary BIM literature identifies as influential to its use and are related to the interdependency of activities beyond organizational boundaries.

Baker (2012) found that researchers who reference the TOE theory in developing theoretical models 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 IBIM, 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 theory that describes identified factors been generated. The goal of this paper is to consistently define the factors outside the basic TOE theory that influence usage of Interorganizational BIM, through a meta-analysis of factors and sub-factors.

2. Methodology

A meta-analysis of factors and sub-factors was conducted to identify and consistently define the factors outside the TOE theory that influence utilization of interorganizational BIM. The analysis includes comparative analysis of factors from case review and identification of emerging categories of determined relevant measures. The reviewed cases have been selected to represent IBIM, and were examined to elicit factors among IBIM-related studies and between IBIM-related studies and the classic TOE theory. This analysis seeks to disclose varying IBIM adoption theories and identify influential factors within the interorganizational context. Thirteen cases, relevant to IBIM, were reviewed, two of which (Chau & Tam, 1997; Nikas, *et al.*, 2007) used and modified the classic TOE theory. This study analysis drew from the Meta-analysis as well as the Grounded theory techniques. This approach was referred to by Stall-Meadows & Hyle (2010) as “Grounded Meta-Analysis of case studies” or “cross-case research” that follows the procedures based on the Grounded Theory development (Strauss & Corbin, 1990). The study approach is described in the following steps next:

Step 1 - This study focused on contemporary studies or cases on Interorganizational Building Information Modeling (IBIM), or studies likened to IBIM.

Step 2 - The study identified commonalities among factors and sub-factors influencing IBIM utilization. This was done in detail within the text while naming similar or common items through assigning a common letter next to each factor or sub-factor. Identification of commonalities among the factors and sub-factors was done simultaneously with the analysis of the case by case of the thirteen studies involved.

Step 3 - Constant comparative method was done on the factors and sub-factors. Each case was analyzed on the basis of the TOE theory – the organizational level technology adoption theory that has demonstrated stability across multiple domains. This theory also standardized the basis of comparison across thirteen cases involved in the analysis.

Step 4 - Identification of Emerging Categories was clear with the summarized list of factors and sub-factors. The commonality among factors and sub-factors was summarized in Figure 1 and Figure 2 respectively. The two figures clearly show the emerging categories of factors along with groups of sub-factors. It can clearly be seen from the two figures that three more categories, in addition to the basic TOE, emerged that relate to the IBIM usage. The emerging of the three categories at IBIM level factor also revealed the inadequacy of the TOE theory to addressing the IBMI level factors, giving potential to extending the TOE theory to the IBIM level.

3. Comparative Analysis of Factors and Identification of Emerging Categories

In IBIM literature, there are consistencies in both factors and sub-factors (sub-division of factors); however, these have not been distinctly categorized at the same level as the basic TOE factors. Groups of related factors are organized into factor categories. In this study, *basic* factors refer to the TOE theory factors that influence BIM adoption with many sub-factors; however, these basic factors do not fully describe issues that emerge as projects extend beyond organizational boundaries. The factors related to the interdependency of activities beyond organizational boundaries are referred to as *collaborative*. Collaborative factors are defined as those that significantly influence the adoption process, and are related to the interdependence of activities beyond organizational boundaries.

Through factor-pattern analysis (Figure 1, in descending date order, and further categorized into sub-factors in Figure 2), *social*, *interoperability*, and *legal* collaborative factors clearly emerge that necessitate extension of the TOE theory beyond organizational boundaries (i.e., the interorganizational context). *Social* factors are those associated with organizational variety, collaboration concerns, difference in firm culture, and issues toward social reconstruction; *legal* factors deal with legal instruments, laws, regulatory theories, codes and industry standards; and *interoperability* factors are related to the need to pass data between BIM applications across a broad range of companies (e.g. architecture, engineering, and construction – AEC) allowing multiple AEC experts to contribute design and construction input. Basic and collaborative factors are the two categories that emerged from the comparative factor analysis, as further presented in Figures 1 and 2.

When factors from the literature are identical to basic and collaborative factors identified in this research, these factors are presented in italics, with sub-factors, when clearly provided, subsequently listed in plain text. In many cases, factor names with similar intent appear in the literature (e.g. "human factors" fall under the organizational factor in the TOE theory) – in these instances, the original authors' words have been 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 are categorized as sub-factors as indicated in Figure 1. Care has been taken to present the original authors' taxonomy of sub-factors; however, when individual sub-factors are classified under one of the six basic and collaborative factors defined in this study, the first letter of the categorized factor is listed in parentheses after individual sub-factors. In some cases, many issues are discussed in single-factor papers; however, only those clearly presented as sub-factors are listed.

The sub-factors presented in the literature are categorized by identified factors in Figure 2, 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 is also presented in descending date order. The following analysis provides the basis for the comparative factor analysis (Figure 1) and list of sub-factors presented in Figure 2.

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 1. Factor-Patterns and Emerging Categories

Case Review and Analysis

Redmond, *et al.* (2012) interviewed eleven experts regarding "Cloud BIM". According to Chuang, *et al.* (2011), the concept of Cloud-BIM allows a broad range of users from different teams or companies to share a common set of BIM information, which makes it comparable to IBIM. An interview conducted by Redmond, *et al.* (2012) identified the following critical factors for collaborative work environments and faster and more economic information exchange: capability of cloud computing, defined in terms of security/legality (L), bandwidth (I), and education (O); interoperability of BIM software (I); contractual issues, defined in terms of current contracts (L), training and cultural issues (S), vendors (E), and transparency (I); business process defined in terms of drivers for Cloud BIM (I), standard business practice (I), technology shift (I), and design and operation (L); information exchange, defined in terms of energy performance analysis/identifying energy usage and energy demand (I); and Cloud-Based BIM life cycle, defined as the use of an internet platform to host data for post-occupancy calculations, specifications, and building performance (I) (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, defined in terms of BIM model organization (I), model access and usability (I), and user interface (I); design review-related requirements, defined in terms of design visualization and navigation (I), and team communication and interaction (S); data security-related requirements, defined in terms of features supporting confidentiality, availability, and integrity (L), user authentication (L), system security (L), data security (I), access control (I), and encryption (L); and the set-up of BIM-server, its implementation, and requirements to assist its usage, defined in terms of project decision support (O), server administration support (O), help support and training (O), 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 (O), training (O), team BIM capability (I), BIM experience (O), job relevance (O), and internal support (O); *technology*, defined in terms of perceived technology difficulty (T), interoperability (I), technology cost (T); and risk factors (L), defined in terms of scope of work (L), liability (L), and project delivery method (L). Mutai referred to IBIM 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 and hardware (T), network (I); process, including leadership, infrastructure, human resource, product and services (O); and policy, defined in terms of contractual, regulatory (E), and preparatory (E). 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).

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)
	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)
Collabo rative	**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)

Figure 2. Categorized Factors and Sub-Factors by Factor

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) • Access control (Singh, *et al.*, 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)
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 2. Continued

Oluwole (2011) focused primarily on the *legal* factor, defining *legal* limitations of BIM use in terms of duty of care [i.e. model ownership (L), exposure of trade information (L), copyright issues (L), authorization of e-documents (L), and validity and unauthorized uses of models (L)], obligations [i.e. new set of skills required (I), integrated services (I), and service framework (I)], consideration [i.e. standard remuneration (L), new sets of professional responsibilities (L), and addendum to professional scales of fees (L)], jurisdiction [i.e. indefatigability of e-documents as evidence (L), e-contracts (L), disclaimer clauses (L), and errors emanating from other contributors (L)], tools (i.e. interoperability (I), standardization(I), value integration/intrinsic conflicts (I), and commitment to IT innovation and deployment of the same in multidisciplinary context (I)), and cyber security (L) (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 (I), intellectual property (L), loss of data (L), legal status of the model (L), standard of care (L), design delegation (L), and information ownership and preservation (L). The study also defined commercial barriers in terms of lack of immediate benefits accruing to the key adopter (O), and absence of standard contracts (L). 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 theory, they add valuable information to the definition of the legal factor in an integrated theory.

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, defined as the change in population of contractors from project to project (S); degree of interdependence (S), defined as pooled, sequentially, or reciprocal; boundary strength, defined in terms of rigid boundary that separate the impacted trades for a given systemic innovation (L); span, defined in terms of the number of boundaries between trades that are spanned by a given systemic innovation (I); 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 theory 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, defined as internet connection (I), percent of employee with internet access (I), and usefulness digital transfer of data/information (I); IT department quality, defined in terms of existence of separate IT department (T), and training in the last 3 years (O); top management support referred to ISO process certificate (I); and collaborative work practices that was defined in terms of use of email for exchange of documents (I). Significant drivers included organizational drivers, defined as cost reduction (O), IS standardization (I) and communication improvement (S); and organizational characteristics, which includes number of employees (over 100) (O), and turnover category (over 50 M euro) (O). 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 IBIM. 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 theory by Tornatzky and Fleischer (1990). The study interviewed 89 respondents and the following factors were identified significant to open systems adoption: organizational technology, defined in terms of satisfaction with existing systems (T); and characteristics of the "open systems technology" innovation, defined in terms of perceived barriers (T), 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 IBIM. 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: initial 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. Figure 2 presents categorized factors and sub-factors by factor.

Table 1. Summary of Categorical Factors and Sub-factors Frequency from IBIMA Literature

Factors	Basic			Collaborative			Total
	T	O	E	S	I	L	
Factor frequency	6 (15.4%)	7 (17.9%)	2 (5.1%)	5 (12.8%)	10 (25.6%)	9 (23.1%)	39
Sub-factor frequency	9 (8.0%)	17 (15.0%)	3 (2.7%)	10 (8.8%)	37 (32.7%)	37 (32.7%)	113
Total frequency	15 (9.9%)	24 (15.8%)	5 (3.3%)	15 (9.9%)	47 (30.9%)	46 (30.3%)	152

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

Thirty-nine factors were defined in the thirteen reviewed studies relevant to the IBIMA (Figure 1 and Table 1). Basic factors (i.e., TOE) constitute 38.5% of the identified factors (15 of 39). Of these basic factors, technology, organization, and environment were identified with frequencies of 15.4% (6 of 39), 17.9% (7 of 39), and 5.1% (2 of 39), respectively. It is noteworthy that although Succar (2009) identified all three basic factors, that study was not founded in the TOE theory. Conversely, the TOE theory 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) constitute 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 IBIMA.

Figure 2 comprises one hundred thirteen (113) sub-factors, roughly reflecting the frequencies of the six factors presented in Figure 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 with the collaborative (SIL) sub-factors with a total frequency of 74.3% (84 of 113) and respective frequencies of 8.8% (10 of 113), 32.7% (37 of 113), and 32.7% (37 of 113). Table 1 summarizes these findings. While sub-factor frequencies are relevant to development of an IBIMA theory, the sub-factors listed in Figure 2 constitute raw data, and future refinement to develop factor ontology and taxonomy would provide valuable information about distinct sub-factors that are critical for IBIMA.

4. Conclusions

Results of this study enhance understanding of the distinction between organizational and IBIM factors, which is vital to managing challenges within specific adoption contexts. A comparative analysis revealed that collaborative sub-factors within existing IBIM literature are more often identified than basic sub-factors. However, these sub-factors have not been ontologically categorized, warranting further research to determine sub-factors that are most influential (i.e. to identify critical factors). Based on frequencies, environment and social factors are infrequently cited as influential factors; however, environmental factors have been found to be essential at organizational levels and therefore are inherently present at the interorganizational level, indicating a current oversight in the IBIM literature. Similarly, social factors have been found to be of primary importance in BIM adoption, although a dearth of research of these factors exists.

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