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Building information modelling (BIM) framework for practical implementation

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ABSTRACT

Recent advances in building information modelling (BIM) have disseminated the utilization of multi-dimensional (nD) CAD information in the construction industry. Nevertheless, the overall and practical effectiveness of BIM utilization is difficult to justify at this stage. The purpose of this paper is to propose a BIM framework focusing on the issues of practicability for real-world projects. Even though previous efforts in the BIM framework have properly addressed the BIM variables, comprehensive issues in terms of BIM effectiveness need to be further developed. A thorough literature review of computer-integrated construction (CIC) and BIM was performed first in order to interpret the BIM from a global perspective. A comprehensive BIM framework consisting of three dimensions and six categories was then developed to address the variables for theory and implementation. This framework can provide a basis for evaluating promising areas and identifying driving factors for practical BIM effectiveness.

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1. Introduction

Utilizing information systems (IS) in the construction industry has been an issue of great importance in order to enhance the effectiveness of construction projects throughout their life cycle and across different construction business functions. However, the concept of IS in construction is very broad and subjective [17]. Formulating comprehensive frameworks of IS in construction, therefore, would effectively facilitate the strategic utilization of IS.

By definition, a framework is a systematic set of relationship or a conceptual scheme, structure, or system [46]. The purpose of establishing a framework is to guide research efforts, to enhance communications with shared understanding, and to integrated relevant concepts into a descriptive or predictive model [23,33]. Another notion is that a lack of perspective in observing IS not only wastes costly computing resources, but mismanages more expensive ones, human resources.

Computer integrated construction (CIC) and building information modelling (BIM) are the most often used acronyms representing this broad concept of IS in construction. Nevertheless, there have been limited efforts in systematically defining these concepts as a framework for theory and implementation. The purpose of this paper is to provide a comprehensive framework of BIM in order to evaluate promising areas and to identify driving factors for practical applications in real world construction projects.

2. CIC and BIM: reciprocal convergence

In an attempt to develop an IS planning methodology prioritizing construction business value chains, Jung and Gibson [17] defined CIC as "the integration of corporate strategy, management, computer systems, and information technology throughout the project's entire life cycle and across different business functions". In this definition, managerial issues including 'corporate strategy' and 'management' were strongly stressed by utilizing several analytical methodologies developed for assessing the effectiveness of integrated implementation of CIC concepts.

They [17] pointed out the needs for managerial effectiveness of gigantic integration of construction information systems, as technical solutions had been well developed even in the mid-1990s. On the other hand, recent proliferation of BIM has expanded its concept into comprehensive utilization in order to maximize the benefits. These two different approaches indicate a convergence in terms of optimizing the use of IS in the construction industry.

Besides the effectiveness, another frequently investigated sub-issue for CIC and BIM was the integration between graphical data and non-graphical data among many different construction business functions [17,37,42]. The perspectives where construction IS was utilized, namely, the project, organization, or industry level perspectives, were also an issue of research interests.

2.1. Top-down: curtailment in CIC scopes

CIC efforts in the 1990's had generally tried to incorporate entire graphic data and non-graphic data throughout an organization or a project. Three examples of CIC implementations are introduced here in order to interpret the practical implications.

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Most frequently benchmarked case is the integrated company-wide engineering, procurement, and construction (EPC) system for mainly industrial construction projects of a U.S. construction company. Their nD-CAD systems integrating EPC information (design, estimates, cost, schedule, and others) in the early 1990's had achieved the first-mover strategic advantages in the global construction market [16]. The integrity and detail of their data were precise enough to handle job site operations.

A Japanese CIC project [32] exploited a full-scale, on-site automation combining information systems and robotics all through design and construction. Though this effort has been implemented to test further development, three components including integrated design and construction planning system, construction site automation system, and factory automation system were combined through a shared common integrated project database [32]. This case illustrated a future direction of automated CIC implementation.

The third case is a research project, funded by the Korean government, which has developed fully-integrated CIC systems using two real-world projects [9,15]. This full-size effort encompassed the full spectrum of construction business functions, including planning, sales, design, estimating, scheduling, material management, contracting, cost control, quality, safety, human resource management, financing/accounting, general administration, and R&D [17]. CIC systems developed by this project were tested in a high-rise office building and a grand suspension bridge. It is noteworthy that this three million dollar research project fully utilized state-of-the-art technologies coupled with newly researched management methodologies.

These three CIC cases were successful in terms of technical capability and the holistic approach, however, practical effectiveness was not fully proven to be economically feasible [16,32]. Even at this moment, it is still hard to justify the cost-benefits of these types of integrated systems. Lessons learned from early CIC implementations [15,17] indicate that it is difficult to achieve maximum effectiveness with the full-range multi-dimensional (nD) integration. Thus, partial integration based on managerial priorities makes the CIC implementation more viable and effective. Strategic decisions should be formulated in order to facilitate the prioritizing process.

2.2. Bottom-up: expansion in BIM applications

Recent practical BIM proliferation has represented a reverse approach towards achieving this integration in the construction industry. It is recognized that BIM has started to fully utilize 3D graphic data first, and then to expands the usage into an nD environment [3,28,41]. It is encouraging that this expansion is moving towards more engineering analyses and various construction business functions.

Though utilizing 3D CAD systems solely for design practice is becoming highly beneficial, the advent of BIM concepts in recent years actively explores better utilization of 3D models. These efforts can be categorized into two types; one is a passive and the other is an active use of 3D models.

Passive use of 3D models in this paper denotes that 3D models are simply used for further engineering analyses as input information or as visualization. For example, engineering analyses in such areas as structure [4,36,44], energy [38,44], disaster prevention [39] in design phase, construction planning [27], scheduling [10,13,24,35], project control [11,48], safety [7] in construction phase, and even interactive systems [26] in the maintenance phase.

In addition to the passive use, researchers have explored more active utilization of 3D models. An excellent example in the area of automated design is the "geometric reasoner" by Chinowsky and Reinschmidt [8] where "qualitative spatial reasoning" was developed in order to embed the design knowledge into the graphic objects.

Expanding the usage of BIM was further investigated by Taylor and Bernstein [41] who focused on the patterns such as "visualization, coordination, analysis, and supply chain integration as a BIM trajectory". A more comprehensive BIM perspective was recently proposed by Succar [40], encompassing far more variables than those identified in CIC frameworks. Therefore, it can be clearly observed that at this moment there is no significant difference between the concepts of CIC and BIM, except their backgrounds and histories.

2.3. CIC and BIM convergence for practical effectiveness

It is notable that both CIC and BIM researches commonly explore the practical effectiveness. Different approach in CIC and BIM may be suitable depending on the distinct characteristics of an organization or a project. Fully-integrated and sophisticated CIC implementation may effectively support some projects, while a simplified information system may be more appropriate for other projects [16]. However, in general, this reciprocal convergence of CIC and BIM implies the needs and issues of optimizing mechanisms for IS in construction. In this context, the BIM framework proposed in this paper is to provide a basis for this 'optimization'. Variables are explored and organized with a focus on BIM issues while encompassing CIC concerns.

3. BIM framework and variables

A BIM framework should be comprehensive enough to address all relevant BIM issues. However, at the same time, it needs to be concise enough in order to present key issues in a systematic manner. In this context, the BIM framework in this paper focuses on practical implementation with six major variables classified into three dimensions in a hierarchical structure. The three dimensions include 'BIM technology', 'BIM perspective', and 'construction business functions' as depicted in Fig. 1. Among the three dimensions, 'BIM technology' is then further divided into four categories; 'property (D0)', 'relation (R0)', 'standards (S0)', and 'utilization (U0)'.

Based on the definition, the framework can be delineated as that '*practical BIM implementation effectively incorporates BIM technologies in terms of property, relation, standards, and utilization across different construction business functions throughout project, organization, and industry perspectives*'.

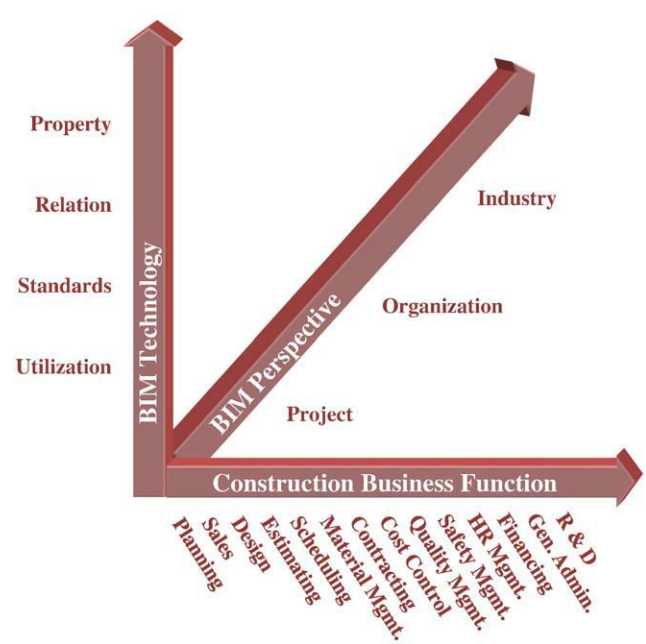

Fig. 1. BIM framework. * Construction business functions defined by Jung & Gibson [17].

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Note that variables in this framework attempt to be fully independent of each other in order to facilitate further analyses and applications. The following discusses each variable within six categories as described in Fig. 2 and Table 1.

3.1. Property (D0)

Property (D0) variables in this study represent the characteristics of BIM objects or data.

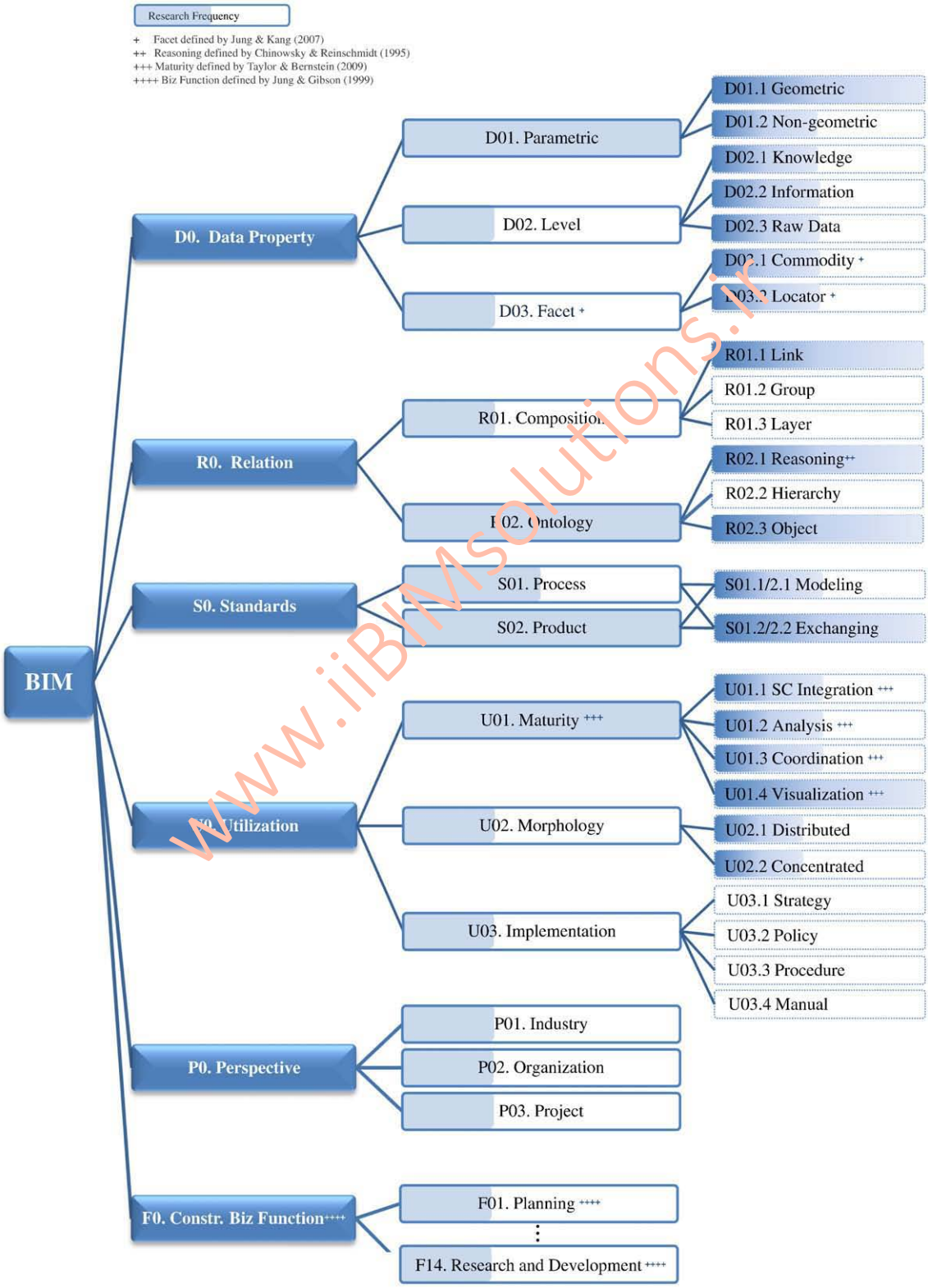

Fig. 2. Variables of BIM framework.

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Table 1
Literature on BIM variables.

Dimension	Category	Variable	Constituent	Chinowsky & Reinschmidt (1995)	McKinney & Fischer (1998)	Jung & Gibson (1999)	Caldas & Soibelman (2003)	Dawood et al. (2003)	Jung & Kang (2007)	Kim & Grobler (2007)	Spearpoint (2007)	Jung et al. (2008)	Tobin (2008)	Succar (2009)	Taylor & Bernstein (2009)
BIM Technology	D0. Data Property	D01. Parametric	D01.1 Geometric	◎	◎			●		◎			◎		
			D01.2 Non-geometric		◎		◎	●							
		D02. Level	D02.1 Knowledge	◎	◎				●					◎	
			D02.2 Information											◎	
			D02.3 Row data											◎	
		D03. Facet +	D03.1 Commodity +					◎	●						
			D03.2Locator +					◎	●						
	R0. Relation	R01. Composition	R01.1 Link	◎	◎		◎								
			R01.2Group												
			R01.3 Layer												
		R02. Ontology	R02.1 Reasoning ++	●	◎					●				◎	
			R02.2 Hierarchy												
			R02.3 Object							◎			◎		
	S0. Standards	S01. Process	S01.1Modeling						◎						
			S01.2Exchange				●								
		S02. Product	S02.1 Modeling								●				
			S02.2 Exchange				◎			◎	●		◎		
	U0. Utilization	U01. Maturity +++	U01.1 SC Integration +++											◎	●
			U01.2 Analysis +++		●						●				●
			U01.3 Coordination +++											◎	●
			U01.4 Visualization +++											◎	●
		U02. Morphology	U02.1 Distributed							◎			●		
			U02.2 Concentrated										●		
		U03. Implementation	U03.1 Strategy			●			◎			●			
			U03.2 Policy			●									
			U03.3 Procedure			◎			◎			●			
			U03.4 Manual			◎			◎						
BIM Perspective	P0. Perspective	P01. Industry										◎			
		P02. Organization				◎									
		P03. Project										◎			
Construction Business Function	F0. Contr. Biz Function	F01. Planning ++++				●									
		⋮				●									
		F14. R & D ++++				●									

Focused ● Covered ◎

+ Facet defined by Jung & Kang (2007)
++ Reasoning defined by Chinowsky & Reinschmidt(1995)
+++ Maturity defined by Taylor & Bernstein (2009)
++++ Biz Function by Jung & Gibson (1999)

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The most often discussed issue in this variable is the parametric (D01 in Fig. 2) property of BIM data, namely geometric (graphic) (D01.1) or non-geometric (non-graphic) (D01.2) properties. Geographic data generally refer to design or engineering drawings. However, graphic representations (D01.1) in this framework are defined to include any non-drawing objects such as working envelopes [2,21] or equipment trajectories [34], due to the fact that these geometric objects are frequently used to enhance the BIM practicability in relevant construction business functions.

The level (D02) of any geometric or non-geometric data can be classified as raw data (D02.3), information (D02.2), or knowledge (D02.1) in an incremental order in terms of property intelligence and accumulation. For example, scheduling data (D02.3) stored in an object can generate progress information (D02.2) by comparing the planned versus actual values. Furthermore, the historical progress information can be automatically manipulated to produce knowledge (D02.1) for future projects [18]. These knowledge applications can be actively generated and utilized by imbedding the information into 3D objects.

The variable of facets (D03) for construction information is well defined by standard classifications such as ISO [12], Uniclass [45], and MasterFormat [29]. For the purpose of simplified and effective BIM applications in construction, this study adopts the definitions of locator (D03.2) and commodity (D03.1) by Jung and Kang [18] as the constituents of the facet variable. Locator (D03.2) indicates the physical breakdown including facility, space, and element facets while commodity (D03.1) handles the work items or materials. The concept of locator (D03.2) and commodity (D03.1) (e.g. main building 1st floor concrete work) facilitates to easily retrieve, analyze, and accumulate BIM raw data (D02.3) with rich information (D02.2) and knowledge (D02.1) [18].

3.2. Relation (R0)

Relation (R0) is defined as a physical or logical interdependency between properties (D0). This relation contains a repository for structures and semantics of properties.

The first variable in the relation (R0) category is the composition (R01), which composes or decomposes the properties (D0). The concepts of link (R01.1), group (R01.2), and layer (R01.3) constitute the composition (R01) variable. Link (R01.1) refers to the interconnection between different properties (D0) [25,47]. Groups (R01.2) and layers (R01.3) are basically utilized to compose these objects. However, these objects can belong to more than one group (R01.2) while they cannot belong to more than one layer (R01.3).

Ontology (R02) in this study focuses on logical interdependency between object properties (D0). Objects (R02.3) can have physical or logical hierarchies (R02.2) with reasoning (R02.1) interpretations. Reasoning is a critical vehicle to automate BIM applications. For the purpose of effectively automated design process, Kim and Grobler [22] proposed a "light-weight knowledge representation" utilizing the variable of ontology. Relating to this knowledge-based automation, Chinowsky and Reinschmidt [8] thoroughly defined "reasoning (R02.1) as temporal, logical, or spatial interrelationship" in a research exploring the "use of qualitative geometric reasoner for integrated design". These researches provided an opportunity to automate 3D design process by linking the objects with integrated knowledge-based reasoning. Practical issues for automated design are still under discussion; nevertheless, artificial intelligence embedded in 3D objects may dramatically contribute to the BIM advancement.

3.3. Standards (S0)

Issues of BIM standards (S0) and interoperability have been widely and largely addressed by many researchers and practitioners [41]. Rigorous efforts including industry foundation classes (IFC), information delivery manual (IDM), and others by several international organizations have also developed various practical details.

Variables within the standards (S0) category in this paper can be classified into two constituents; the process (S01) and product (S02) standards. Previous literature on this issue has generally more focused on the product (S02) standards for modelling (S01.1/S02.1) and exchanging (S01.2/S02.2) BIM properties [6,22,43]. Standardized 'process modelling and exchange' methodologies such as integrated definition (IDEF) language are also widely explored. Caldas and Soibelman [6] exerted the active use of process standards for construction documentations. Some other approaches integrating process (S01) and product (S02) modelling have also been investigated [5,9,15].

Nevertheless, the standards (S0) variables in this study basically stress the intensity and realm of utilizing standards, namely, the perspective (P0) of standards (S0). Vigorous efforts in the area of BIM standards have been developed from industry (P01) perspective (e.g. IFC, IFD, IDM, IDEF, STEP and so on). However, organizational (P02) or project level (P03) BIM standards are also of great importance for practical implementation.

3.4. Utilization (U0)

Utilization (U0) variables consist of maturity (U01), morphology (U02), and implementation (U03). These variables are strongly stressed in this paper in order to facilitate practical implementation by identifying promising areas and driving factors for enhancing BIM effectiveness.

Maturity (U01) indicates the degree of advancement of BIM utilization. In their qualitative and quantitative study examining BIM practice paradigms, Taylor and Bernstein [41] analyzed four phases of BIM advancement; "visualization (U01.4), coordination (U01.3), analysis (U01.2), and supply chain (SC) integration (U01.1)". "BIM experience" and "electronic file sharing" were tested as being affecting factors for this evolving advancement, and it is also found that the companies at the "supply chain integration" gain real savings from "redesigning the process". Maturity (U01) in this paper adopts these four paradigms.

As for advanced 4D-CAD systems, McKinney and Fischer [31] also pointed out an issue of using schedule information in an advanced and active manner; the use of graphic data as part of an automated scheduling process not as part of visualization. This effort well illustrates the analysis (U01.2) phase of BIM maturity. Results from a report [30] by McGraw-Hill Construction, surveying about 300 BIM practitioners in 2008, revealed that the most often used BIM analyses (U01.2) include "quantity take off (57%), scheduling (45%), estimating (44%), energy analysis (38%), project management (35%), structural analysis (32%), LEED/green analysis (32%), storm water analysis (19%), facility management (18%), and vehicle turning analysis (15%)" in that order of frequency. The number in the parenthesis indicates the percentage of respondents who had experiences in that specific analysis task [30].

Morphology (U02) indicates types of physical and logical manipulation of BIM elements or databases. Traditional arrangements of database systems are distributed (U02.1) or concentrated (U02.2). The extended concept of this BIM morphology (U02) was interestingly discussed by Tobin [43] where he tested the effectiveness of a "slice of BIM data" for "atomic BIM".

Finally, the implementation (U03) variable strongly stresses the impact of managerial issues for successful BIM utilization. As previously discussed, strategy (U03.1) and policy (U03.2) direct all activities within an organization, and hence characterize distinct requirements of information systems. Procedures (U03.3) can be interpreted as tools for systemizing construction business functions (e.g. value chain) that provide the most impacting basis for designing IS and BIM interfaces. Regardless of the degree of systemization or standardization, no information system can fully support the users to fill out computerized procedures. In other words, details or decisions should be made before a user types in the lowest level data entry for on-site practice. Well organized manuals (U03.4) reflecting distinct characteristics of an organization or a project [18] can facilitate smooth or automated operations.

3.5. Perspective (P0)

Perspective (P0) variable represents the level of BIM implementation. Three perspectives in this framework include industry level (P01), organizational level (P02), and project level (P03).

For example, as discussed in standards (S0) variable, industry level BIM standards have been actively developed. Organizational or project level BIM standards have somewhat different characteristics in terms of the purpose, format, and details. Though these standards can be based on industry standards, the organizational or project level standards are very deeply related to managerial issues including

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corporate or project strategies (U03.1) or policies (U03.2) based on specific business requirements.

These three different levels of perspective (P0) need to be considered at the same time for a specific BIM implementation. For example, a company (P02) may have its own BIM tools in-house while participating in a project (P03), where many different companies work together as a team sharing common BIM data. For this inter-organizational implementation, industry level (P01) standards facilitate the information exchange. Jung and Gibson [16] illustrated the flexible CIC/BIM requirements for this situation by comparing two different projects. An American EPC company, introduced previously in this paper performed these two mega-projects; one as a design-builder and the other as a construction manager.

Again, the perspective (P0) variable characterizes distinct information systems requirements. Different levels of perspectives also require different information systems assessment (ISA) criteria [16,18,19].

3.6. Construction business functions (F0)

Business functions (F0) well represent the distinct IS requirements of the construction industry [17] and clarify the roles shared by organizations under different project delivery systems (PDS) over the entire project life cycle (PLC) [16,17].

Even though classifications of business functions may differ depending on different research purposes, this paper employs 14 construction business functions defined by Jung and Gibson [17]. These functions include "planning (F01), sales (F02), design (F03), estimating (F04), scheduling (F05), materials management (F06), contracting (F07), cost control (F08), quality management (F09), safety management (F10), human resource management (F11), finance/accounting (F12), general administration (F13), R&D (F14)".

In their research, Jung and Gibson [17] developed a methodology that comprehensively and quantitatively assesses each construction business function in terms of CIC (or BIM) investment and benefits. Based on the assessments, promising business functions for IS development were prioritized by considering corporate strategy, managerial effectiveness, integration efficiency, and information technology effects altogether. Even though case-specific, an evaluation utilizing the proposed methodology revealed that BIM effectiveness could be maximized if a large contractor (P02) started from the integration of design (F03), estimating (F04), scheduling (F05), and cost control (F08) [15,17].

From the industry-level perspective (P01), the degree of informatization also varies depending on each business function. A survey results by Jung et al. [14] that collected responses from 37 construction companies, indicate that scheduling (F05), estimating (F04), and design (F03) are the most demanding areas where the discrepancy between the practitioners' needs versus actual exploitation was found to be significant. Informatization needs for these three functions were identified both for intra-organizational (P02) and inter-organizational (P01) construction information systems [14].

These findings [14–17] encourage the possible and active dissemination of BIM implementation due to the fact that design (F03), estimating (F04), and scheduling (F05) are the core construction business functions bridging the geometric (D01.1) and non-geometric (D01.2) data. This bridging interaction needs to be in an active and mutual manner.

The recent BIM proliferation has mutual synergy effects with increasing adoption of alternative project delivery systems (PDS) including integrated project delivery (IPD) [1]. The construction business function (F0) as a BIM variable is an explicit tool for defining the shared roles and responsibilities in between construction project participants under different PDS. As regards the roles and responsibilities, the business functions assigned to project participants need to be clearly defined in detail in terms of scope, depth, and weight of the construction business functions [20]. Project management information systems (PMIS) including CIC or BIM concepts serve as one of the important tools for clarifying and systemizing these project execution plans, procedures (U03.3), and manuals (U03.4).

4. Implications of BIM framework

As pointed out by several researchers [17,41], CIC or BIM efforts have largely focused on issues of technology. In order to achieve effective BIM implementation, a comprehensive framework can facilitate the identification of promising areas and influencing factors. The BIM framework proposed in this paper supplements practical issues for real-world implementation while encompassing broad issues across different levels of perspective.

The relative density of the shadings rendered in Fig. 2 indicates the areas' relative research frequency in BIM literature. It is inferred that BIM research has concentrated on parametric (D01) issues in data property, ontology (R02) in relation, product (S02) in standards, and maturity (U01) in utilization. Among these areas, relation (R0) issues are well addressed exploring ontology (R02) and reasoning (R02.1) topics, but those are still in a developing stage towards a higher maturity (U01) phase.

Embedding knowledge (D02.1) as a data property (D0) into BIM is an area of great potential. Reasoning (R02.1) has been actively explored for this purpose and is expected to be increasingly developed for practical applications. A possible solution to this knowledge-based reasoning was suggested by Jung and Kang [18], where they developed a knowledge extraction mechanism using highly structured data from a historical database of previous projects. Their mechanism requires well organized facet (D03) information (D02.2) for the purpose of making this mechanism economically feasible. The composition (R01) and ontology (R02) tools may automate this knowledge extraction mechanism by combining geometric (D01.1) and non-geometric (D01.2) parameters for BIM.

As Taylor and Bernstein [41] proved, the generalized BIM maturity (U01) trajectory well describes a possible direction from the industry perspective (P01). However, optimized utilization of BIM in an advanced maturity stage or even in an automated way with embedded knowledge (D02.1) should be thoroughly evaluated in terms of strategy (U03.1) and policy (U03.2), because organization-specific (P02) or project-specific (P03) requirements often make this BIM utilization exceptionally feasible. PDS is also a driving factor in these requirements.

Managerial issues (U03.1) in construction information systems are more influencing than technology issues [17,18]. Strategic advantages and managerial benefits attained from BIM in terms of business process re-engineering (BPR) or process innovation (PI) need to be quantified and clarified. It is encouraging, as in the Korean construction industry case, that many of the top 20 Korean general contractors have performed company-wide extensive BPR/PI projects over the last decade, and BIM has been one of the core PI subjects. Architects and engineering companies in Korea also have started systematic BIM implementation as an official organizational policy (U03.2).

In summary, findings of this paper strongly recommend that the reasoning (R02.1) with embedded knowledge (D02.1) needs to be actively developed in order to maximize the benefits of BIM practice. For these research and development efforts, implementation strategies (U03.1) and policies (U03.2) should be examined and evaluated for successful implementation. It is also important that the proposed framework can be used as evaluation criteria for practical implementation.

5. Conclusions

CIC and BIM literature was intensively reviewed and analyzed in this paper in order to address BIM variables for theory and implementation.

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Even though their development patterns were historically different, the current objectives of CIC and BIM are identical; improving construction effectiveness by better utilization of construction information systems in an integrated way.

This paper defines the proposed framework as that 'practical BIM implementation effectively incorporates BIM technologies in terms of property, relation, standards, and utilization across different construction business functions throughout project, organization, and industry perspectives'.

Comprehensive variables of BIM framework were then discussed within three dimensions (BIM technology, perspective, and construction business functions), and six categories. Issues for practical BIM implementation were stressed throughout this paper. This framework can provide a solid basis for 'evaluating promising areas' and 'identifying driving factors' for practical BIM effectiveness.

As a conclusion, utilization research incorporating the strategy and policy for specific levels of perspective coupled with automated reasoning needs to be strongly encouraged in order to accelerate practical BIM implementation. The authors of this paper believe that knowledge (in property level variable) and reasoning (in ontology variable) are the promising areas for advanced BIM, and cost-effective approaches using structured BIM properties are found to be both feasible and recommended, based on literature and actual industry experience.

A quantitative evaluation methodology based on the proposed framework is under development by the writers. The methodology will be able to quantify the benefits of BIM under different PDS, for different participants, or among fourteen different business functions. The framework is also adapted to complement another framework for automated progress measurement and management (APMM) systems, where the highest BIM utilization is intended.

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