MODEL OF INFORMATION SHARING AND EXCHANGE IN A BUILDING INFORMATION MODELLING SUPPLY CHAIN

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ABSTRACT

The responsibilities of the multi-disciplinary BIM-based project participants has been extended to include compulsory information supply, compulsory information demands, offering of professional inputs, participating in reviews, and participating in cross-referencing. These additional responsibilities appear to be the principles of information sharing and exchange in BIM supply chain and require an in-depth investigation so as to prevent them from constituting barriers to information sharing and exchange among the BIM-based project participants. This paper presents the results of an investigation of the constituents of information sharing and exchange in BIM supply chain, as well as their agreement with the requirements of the BIM process. The investigation has the practical purpose of supporting the body of knowledge in the search for the understanding of the best model of information sharing and exchange on a collaborative BIM project. A two-dimension BIM-enabled information sharing and exchange model on construction projects was developed to define the functional requirements for information sharing and exchange in a BIM supply chain. PRISMA methodology was adopted to construct the dimensions and to identify components for the dimensions. The model is capable of being used as the basis for assessing the process of information sharing and exchange within collaborative working. The findings of the study have numerous implications for research and practice in BIM-enabled project management, especially in the performance assessment of BIM adoption on construction projects.
Keywords: BIM, BIM supply chain members, information sharing and exchange, information quality, information structure.

1 INTRODUCTION

The requirements of building information modelling (BIM) process has heightened the need for Information Sharing and Exchange (ISE) among the building information modelling supply chain members (BIM-SCM) [1]. For instance, in the traditional work process, ISE takes place in the form of drawings and documents (such as Bill of Quantities, cost plan, building specification, and building drawings); while in BIM it is exchanged as a building information models [2]. The implication of this development is that, building information models have become the source of project information. Therefore, it becomes important for building information models to be reliable and dependable because the information they provide is required to inform the building information modelling supply chain members (BIM-SCM), support decision-making, serve as project documentation, and represent the project plans [3]–[5]. In addition to the need for reliability and dependability of building information models, the complexity of construction process and more importantly the BIM process requirements make it important for information to flow smoothly among the BIM-SCM [6], [7]. There are lots of studies describing the importance of ISE among the BIM-SCM [1], [7]–[11].

Although, these studies have established the importance of ISE among the BIM-SCM beyond doubt; but there is no consensus among these studies whether ISE is a benefit or a requirement of BIM process. For example, Cerovsek [8] identified the benefits of ISE in BIM as including improved construction efficiency, productivity, and quality. Azhar et al. [9]

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maintained that ISE among the BIM-SCM will add value, intelligence, and flexibility to the project information. Hooper and Ekholm [7] pointed out that ISE is critical to BIM application on construction projects because it determines the future use of building information models, the level of BIM application on projects, the extent of collaboration and integration among the BIM-SCM, and the development and richness of the federated building information models. Boton and Forgues [1] explained that ISE is an important BIM principle and process that is required for the integration of the project participants and project information. Sacks et al. [10] described ISE as a requirement in BIM because the discipline-specific building information models developed by the BIM-SCM is not sufficient in itself and that the discipline-specific building information models must be shared, transferred, and integrated in order to fulfil the information needs of the members and to develop the federate building information model. Fox and Hietanen [11] stated that ISE is a BIM process requirement because the information content of a building information model becomes more useful for the BIM-SCM and discipline-specific purposes, when it is exchanged, shared, checked, combined, and updated with other building information models. While the debate continues about the position of ISE as either a benefit of BIM or a requirement of BIM process; the importance of ISE in BSC has been established.

However, there is an increasing concern on how to facilitate seamless information flow in the midst of the huge demand for and large supply of information among the BIM-SCM [12]–[14]. This concern has grown in importance because BIM process requires that BIM-SCM author discipline-specific building information models that are void of errors or clashes and that can be integrated [15], [16]. The attending implications of this requirement is that the responsibilities of the BIM-SCM has been extended to include compulsory information supply, compulsory information demands, offering of professional inputs, participating in reviews, and participating in cross-referencing [11]. Failure to undertake these additional responsibilities by the BIM-SCM will pose a threat to the seamless flow of ISE. Furthermore, these additional responsibilities appear to be the principles of ISE in building information modelling supply chain (BSC) and require an in-depth investigation so as to prevent them from constituting barriers to ISE among the BIM-SCM. Previous studies [17]–[19] have focused on the need for ISE in BSC, information required to implement ISE in BIM (the domains, the level of details, and responsible party for each exchange), and benefits of ISE in BIM. None of these studies have explained the constituents of ISE in BSC which is a functional requirement to ensuring the smooth flow of ISE in BSC. Besides, the domain and level of details of information deals with data contained in the information. According to Lillrank [20], data is different from information because it is a codified and symbolic representation of entities, properties, and their states. Another essential point is the conclusion by Hooper and Ekholm [7] and Boton and Forgues [1] that the smooth flow of ISE among the BIM-SCM depends on the sharing and exchange of the expected quality and form of information models. This indicates a need to understand the various dimensions of ISE in BSC. This study seeks to remedy this problem by investigating the constituents of ISE in BSC and establish whether they agree with the requirements of BIM process. The study addresses the void in literature by identifying the dimensions and components of ISE in BSC. Additionally, the study offers some important insights into BIM-based ISE for BIM managers and BIM professionals. The study will support further empirical research on BIM-based ISE.

This paper has been divided into six parts. The first part deals with the introduction of the study. The second part deals with the research framework and background. Research method is presented in the third part. Results are presented in the fourth part; while the fifth part deals with the discussion of the findings. Finally, conclusions, limitations, and suggestions for future research are presented in the sixth part. For the purpose of this study, ISE will refer to the authoring of, supply of, demand for, and review of building information models; as well as the creation of shared building information model repositories with concurrent access by the BIM supply chain (BSC) [11]. BIM supply chain (BSC) will refer to short-term or long-term networks of multi-disciplinary BIM-based project participants such as clients, subcontractors, main contractors, suppliers, and BIM consultants [21], [22]. BIM supply chain members (BIM-SCM) denotes BIM-based project participants as represented by persons or organizations.

2 RESEARCH FRAMEWORK

To understand the concepts, variables, and dimensions of information sharing and exchange (ISE) among the building information modelling supply chain members (BIM-SCM), this study adopts the Social Exchange Theory (SET) modified with BIM-enabled collaborative behaviours in ISE. The SET explains the relational exchange and mutual dependence among a network of actors by postulating that social exchange occurs when the exchange partners have a resource of value to exchange with each other and after they must have conducted an information supply and demand analysis [23], [24]. Among the BIM-SCM, the resources of value to be exchanged is information, but the rationale behind the ISE cannot be understood using SET. Hence, theories on BIM-enabled collaborative behaviours in ISE was employed to support the SET. The postulations by some [7], [25]–[30] reveal the exchange rationale for ISE in BIM process as collaborative behaviours among the network of actors participating in a BIM process. Abanda et al. [16] posit that BIM process fosters a new form of social exchange among the BIM-SCM by creating opportunities for inter-organizational collaboration. Grilo and Jardim-Goncalves [29] theorize that collaborative behaviours are demanded among the BIM-SCM because of the need to develop a clear understanding of information demands and supply in BIM process, develop the capacity to utilize the supplied information, and develop the capacity to meet the information demands. In support, Sacks et al. [30] posit that one of the main objectives of BIM process is the sharing and integration of information across the BSC; and that without a mechanism to ensure collaborative behaviours on the part of the BIM-SCM, this objective may not be achieved. Vidalakis et al. [31] expressed the opinion that the efficiency of the BIM-SCM depends on the information they supplied and demanded from each other. Based on the ideas presented by Hooper and Ekholm [7] and Grilo and Jardim-Goncalves [29], collaborative behaviours in ISE is important because of the need for the interoperability of the various information models that may be created by the BSC and because of the need to ensure that project information is developed in an accessible and smooth manner without omission, errors, or clashes.

Based on these perspectives, the following four foundational principles can be identified for ISE among the BIM-SCM:

- The resources of exchange
- Rules and norms of exchange
- Exchange rationale
- Exchange cycles

A theoretical framework for understanding the concepts, variables, and dimensions of ISE among the BIM-SCM is presented in Fig. 1. As illustrated in Fig. 1, the resources of exchange are information. The rules and norms of exchange are collaborative behaviours as enabled by exchange protocols. According to Hooper and Ekholm [7], the protocols for collaborative behaviours can be summarized as (i) discipline-specific information models must be shared, exchanged, and integrated from time to time (ii) information contents, reference, and authoring tools must be interoperable. The rules and norms of exchange bind the participants together, serve as the guidelines for the exchange process, and form the basis of the exchange rule or principle that participants must abide by. Exchange rationale represents the requirements for smooth flow of exchange. The theoretical framework shows that exchange rationale enables the exchange, facilitates open information workflow, supports decision-making process, speed up workflow, and enables the creation of databases.

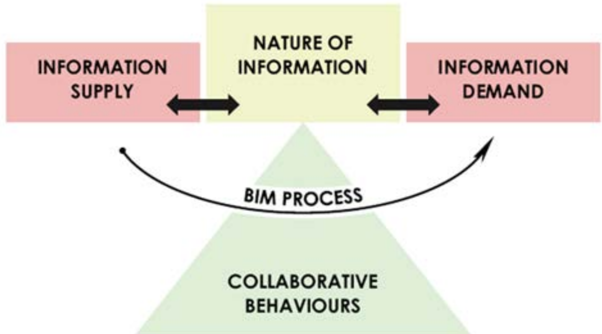

Figure 1: A theoretical framework for understanding information sharing and exchange among the BIM supply chain members.

Founded on this explanation, the exchange rationale describes variables and dimensions of information to be exchanged among the BIM-SCM. The theoretical framework describes this as the nature of ISE among the BIM-SCM. The exchange cycle as portrayed in Fig. 1 illustrates the BIM process which implies that the BIM-SCM must share, exchange, and integrate their information models from time to time and within the BIM process.

The theoretical framework presented in Fig. 1 facilitates the understanding that the main elements that will expedite ISE is the exchange rationale. The theoretical framework has also enabled the identification of the exchange rationale as the nature of information to be shared and exchanged among the BIM-SCM. Grounded on the insights from the theoretical framework, a theoretical model is proposed to explain the dimensions of ISE among the BIM-SCM. The model explains that exchange rationale will ensure that information (resources of exchange) is exchanged in a consistent manner. The model proposes that the nature of information to be shared and exchanged (exchange rationale) determines the dimensions of ISE among the BIM-SCM.

As illustrated in Fig. 2, the model features two dimensions of ISE among the BIM-SCM. These are information quality and information structure. Information quality as a dimension of ISE refers to the value of information for a given use and explains that information will only be suitable for the intended purpose while satisfying expectations [32], [33]. This implies that information quality is important to ISE in reducing uncertainty, supporting decision-making, and meeting the request for information by the BIM-SCM. In BIM process, information quality will enable the BIM-SCM to find the information being shared and exchanged fit for use. As conceptualised in the model, there are 11 requirements for information quality based on theoretical grounding from studies such as Chen and Luo [34] and Logothetis et al. [35]. Information structure, as the other dimension of ISE, describes the specific and consistent way of presenting information so that it fits the context of usage or demand [36], [37]. Specifically, information structure describes the form of the content of an information which makes it easier to accessed, review, and integrate. The model identified nine attributes of information structure that define the aggregation and evaluation of the usefulness of an information according to studies such as Solihin et al. [38] and Nepal et al. [39].

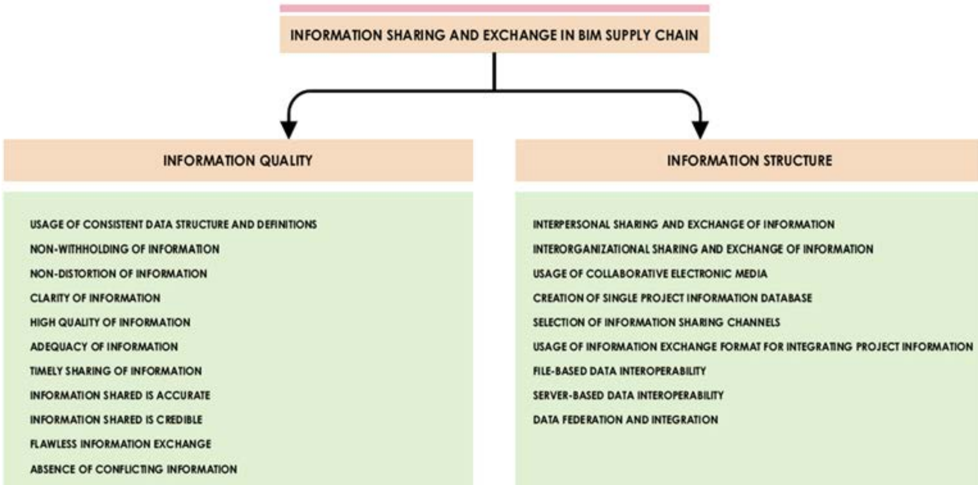

Figure 2: A model of information sharing and exchange in BIM supply chain.

3 RESEARCH METHOD

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method was adopted in this study following [40]. The method was applied in a two-step approach. Firstly, a database was created using a four-step systematic review process (see Fig. 3). Secondly, the data analysis was conducted using meta-analysis. For each database (Scopus, Engineering Village, Ebesco, Google Scholar, and Web of Science), the key search terms were entered individually. The search terms were combined using different combinations as appropriate. Limitations such as years of publication (2002–2019) and English Language were applied. A total of 2,061 articles were identified at this stage. Articles that appear more than once were removed from the database for this study. At this stage 2,014 number of articles remained. The title and abstracts of the remaining articles were screened for relevance to this study. Only the articles that appear to provide information required for the study were included, totalling 903 articles. The eligibility of articles to be included in the final review was done by screening the articles for substantive relevance, context, and content. This stage gives a total of 41 articles.

For the meta-analysis, the following parameters were estimated: frequency of mention, number of studies mentioning the components, sample mean, population mean, and effect size. In determining the validity of the components for inclusion in the model, an effect size of 0.2 and above was taken as an acceptable effect size. Components with effect size of less than 0.2 were considered invalid and not relevant to the dimensions in the model.

4 RESULTS

Table 1 presents the results of the meta-analysis conducted in this study. The meta-analysis investigated the validity of twenty variables as components of ISE among the BIM-SCM.

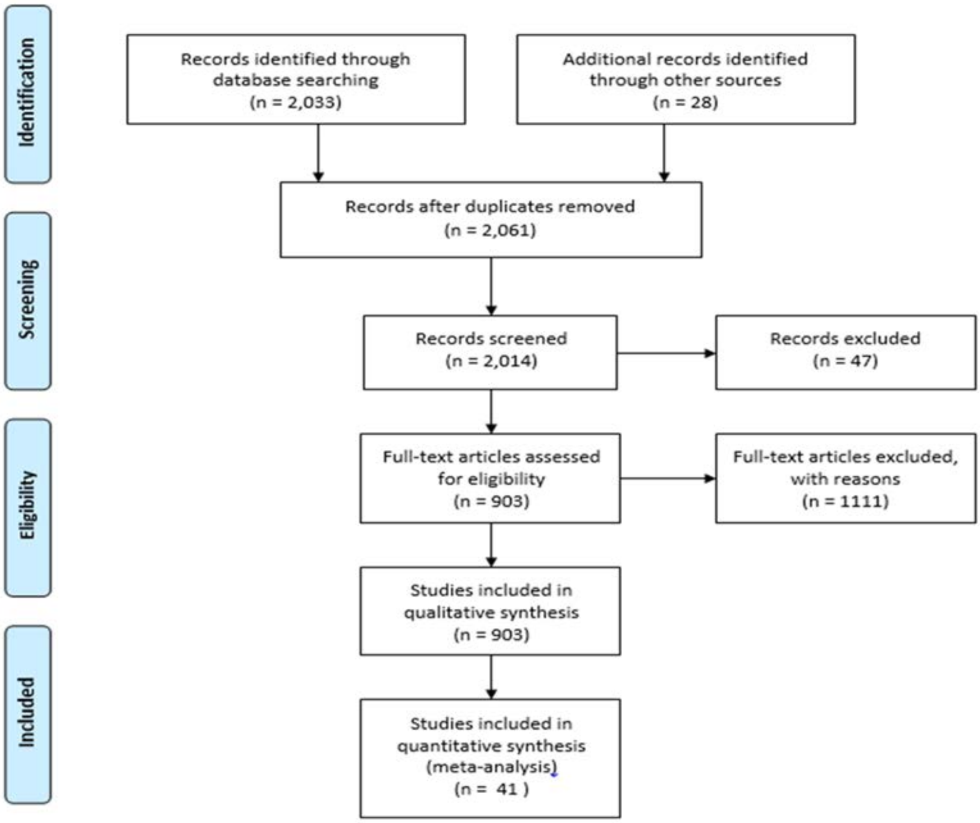

Figure 3: The PRISMA flowchart for the study.

Based on the boundary value of 0.2 for deciding the validity of the variables, all the variables have an effect size greater than 0.2 which qualifies them as components of ISE among the BIM-SCM. Among these variables, selection of information sharing channels has the minimum effect size (d=0.20); while inter-organizational sharing and exchange of information and creation of single project information database have the maximum effect size (d=1.55). These variables (inter-organizational sharing and exchange of information and creation of single project information database) have the highest number of studies mentioning them. Out of the 41 studies used for the meta-analysis, 25 mentioned inter-organizational sharing and exchange of information and creation of single project information database. The evidence from the results suggests that information quality and information structure are essential to ISE among the BIM-SCM.

5 DISCUSSION

Studies by Hooper and Ekholm [7] and Boton and Forgues [1] have noted the importance of understanding the components of ISE because this understanding will support the smooth flow of ISE among the BIM-SCM. As a result this study investigates the constituents of ISE in BSC so as to establish whether they agree with the requirements of BIM process. A theoretical model was developed to aid the understanding of the components of ISE among

Table 1: Meta-analysis estimates of the dimensions and components of ISE.

Components	d	F	N	χ	%
Information Quality					
Usage of consistent data structure and definitions	0.22	2,096	14	2.93	34.15
Non-withholding of information	0.22	5,340	14	2.93	34.15
Non-distortion of information	1.18	1,739	8	5.13	2.43
Clarity of information	0.86	1,862	10	4.10	24.39
High quality of information	0.91	9,189	21	1.95	51.22
Adequacy of information	1.34	992	7	5.86	17.07
Timely sharing of information	0.20	1,457	16	2.56	39.02
Information shared is accurate	0.26	4,369	17	2.41	41.46
Information shared is credible	0.86	838	10	4.10	24.39
Flawless information exchange	0.21	114	3	13.66	7.31
Absence of conflicting information	0.69	496	11	3.73	26.83
Information Structure					
Interpersonal sharing and exchange of information	0.74	445	20	2.05	48.78
Inter-organizational sharing and exchange of information	1.55	436	25	1.64	60.97
Usage of collaborative electronic media	0.22	719	14	2.93	34.15
Creation of single project information database	1.55	4,560	25	1.64	60.77
Selection of information sharing channels	0.20	969	16	2.56	39.02
Usage of information exchange format for integrating project information	1.07	3,838	22	1.86	53.65
File-based data interoperability	0.91	232	21	1.95	51.22
Server-based data interoperability	1.07	105	22	1.86	53.65
Data federation and integration	0.69	601	11	3.73	26.83

D = Cohen's d effect size, F= frequency of mention in the database, N= Number of studies mentioning the components, χ= Sample mean.

the BIM-SCM through the perspectives of SET modified with theory of BIM-enabled collaborative behaviours (see Figs 1 and 2). A meta-analysis of the validity of the twenty variables identified as the components of ISE among the BIM-SCM revealed information quality and information structure as the constituents of ISE. The identification of information quality and information structure as the dimensions of ISE among the BIM-SCM by this study is in agreement with Hooper and Ekholm [7] which maintained that an efficient and smooth flow of ISE will be achieved when information is developed and delivered in the expected quality and form. The expected form stands for information structure and the expected quality represents information quality. Fig. 1 explains that BIM process and collaborative behaviours determine the nature of ISE (information demand and supply) among the BIM-SCM (that is, the dimensions of ISE among the BIM-SCM). The findings of this study reveal information quality and information structure as the dimensions of ISE among the BIM-SCM. This means that the smooth flow of information demand and supply in BIM process depends on the quality and structure of the information.

5.1 Information quality and its association with ISE among the BIM-SCM

The results of this study show that information quality in BIM process consists of non-distortion of information, adequacy of information, high quality of information, usage of consistent data structure and definitions, non-withholding of information, clarity of information, timely sharing of information, accuracy of information, credibility of information, flawless information exchange, and absence of conflicting information. These components are different from those reported for information quality by others [32], [33],

[41]–[43]. For example, Holmes [41] identified the components of information quality to include relevance, accuracy, timeliness, completeness, coherence, format, accessibility, compatibility, security, and validity. The components of information quality as identified in this study, apply only to information quality among the BIM-SCM; hence, they are expected to be different from the components of information quality in other industries and contexts as reported by the past studies. For instance, the components of information quality identified by Holmes [41] apply to ISE among business managers, while the components of information quality identified by Chae et al. [43] applied to ISE among mobile internet users. Therefore, the inconsistencies between components of information quality as found in this study and the reported components of information quality in the other industries (mostly information technology and management) may be due to differences in the type of industry. This line of thought is supported by Li et al. [44] which indicated that information quality is influenced by the type of industry and the type of supply chain. The findings on the components of information quality is in agreement with Nepal et al. [39] conclusions which stated that BIM-SCM must not expend significant amount of time and effort in linking, importing, analysing and interpreting discipline-specific information models.

This confirms that ISE among the BIM-SCM must be devoid of conflicting information, must be timely, and must feature adequate information. Earlier observations by Solihin et al. [38] is also in accord with the components of information quality as found in this study. Solihin et al. [38] maintained that the usage of consistent data structure and definitions is important to the integrity of information models because it ensures consistent structure and elimination of duplicates in geometries and semantics. It is important to recognize the differences between information quality and data quality. While data quality deals with technical feature of information and information models; information quality deals with non-technical features such as credibility, timeliness, clarity, and adequacy of information. According to Westin and Päivärinta [45], information quality is imperative to avoiding information-related construction projects problems such as ambiguity of information, errors, omissions, confusions, conflicts, incomplete information, and waiting for information. Thus, the findings of this study on the components of information quality among the BIM-SCM will help prevent information-related construction projects problems and will enable the understanding of the requirements for smooth flow of ISE among the BIM-SCM.

5.2 Information structure and its association with ISE among the BIM-SCM

Regarding the components of information structure as a dimension of ISE among the BIM-SCM, the meta-analysis results revealed that all the nine variables are valid components of information structure. The most essential components of information structure as shown by the results are inter-organizational sharing and exchange of information, and creation of single project information database. A possible explanation for this might be that inter-organizational sharing and exchange of information is an important requirement to activate and actualize the required collaborative behaviours from the BIM-SCM; while creation of single project information database signifies the outcome of a successful ISE among the BIM-SCM and quintessence of the collaborative behaviours of the BIM-SCM. Server-based data interoperability was found to have a stronger effect size than file-based data interoperability. Kiviniemi et al. [46] supported these findings by indicating that the inter-organizational use of file-based information exchange is superseded by inter-organizational use of server-based information exchange. Other possible explanations for the stronger effect of server-based data interoperability on information structure as compared to that of file-based data interoperability, could be that it enhances collaborative behaviours among the

BIM-SCM; whereas file-based data interoperability merely enables collaborative behaviours among the BIM-SCM.

Thus, the above explanations match the observations of Redmon et al. [28] which indicated that server-based data interoperability enhances collaborative behaviours among the BIM-SCM. In support of data federation and integration as a component of information structure as revealed in this study; Venugopal et al. [47] observed that data federation and integration is important because of the need to re-build the information structure in the receiving application by the receiver of the information. The relevance of the creation of single project information database as found in this study finds support in the conclusion by Fox and Hietanen [11] which indicated that the inter-organizational use of federated building information model depends on the creation of shared building information model repositories with concurrent access. Similarly, Solihin et al. [38] agree with the findings of this study that the usage of collaborative electronic media is a component of information structure; as the study indicated that the usage of collaborative electronic media is important to the consistency of the federated model (data federation and integration) across the BIM supply chain.

6 CONCLUSIONS, IMPLICATIONS, AND FUTURE RESEARCH

Data is a feature of digital information (computer generated information) such as building information models. In BIM process, when information is shared and exchanged among the BIM-SCM, the data contained in the information are also shared and exchanged. Past studies have provided an understanding and requirements of data sharing and exchange through the identification of the levels of details and domain of building information models. The understanding provided by these studies have enhanced integration and collaboration (data sharing and exchange) among the BIM-SCM at the level of inter software technologies and applications. However, there is a lack of understanding of the nature of ISE among the BIM-SCM. The understanding of the nature and requirements of ISE among the BIM-SCM will enhance collaboration among the BIM-SCM at the level of inter-organizational and interpersonal relationships. For this reason, this study investigates the constituents of ISE in BSC and establishes whether the constituents of ISE agree with the requirements of BIM process.

The study identified information quality and information structure as the dimensions or nature and requirements of ISE among the BIM-SCM. The expected components of information quality that will enable a smooth and efficient were identified to include non-distortion of information, adequacy of information, high quality of information, usage of consistent data structure and definitions, non-withholding of information, clarity of information, timely sharing of information, accuracy of information, credibility of information, flawless information exchange, and absence of conflicting information. The components of information structure are interpersonal sharing and exchange of information, inter-organizational sharing and exchange of information, usage of collaborative electronic media, creation of single project information database, selection of information sharing channels, usage of information exchange format for integrating project information, file-based data interoperability, server-based data interoperability, and data federation and integration.

Previously, information quality has been situated in the field of information technology and information management system; but this study has confirmed the uniqueness of the components of information quality in BIM process and by extension in the construction industry. The findings in this study provides a new understanding of ISE protocols (that is, ISE entails sharing and exchange of data together with information) and provides a definition for the functional requirements for ISE. The findings in this study will serve as a base for future case studies on the nature and performance of ISE among the BIM-SCM. Although, the validities of the components of information quality and information structure are based on a meta-analysis estimates, the findings suggest that a smooth and efficient sharing and exchange of information among the BIM-SCM depends on the extent of their collaborative behaviours. This study adds to a growing body of literature on ISE in BIM process; however, the findings are limited by the use of meta-analysis for validation. A case study of ISE among the BIM-SCM will provide a better understanding of the nature and functional requirements for ISE among the BIM-SCM.

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