

Modeling the determinants of BIM-enabled integration and collaboration

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Abstract

Purpose – BIM research to date has in general zeroed in on featuring the significance of BIM-enabled integration and collaboration (BIMIC) rather than giving exact proof of its occurrence. Accordingly, this research quantitatively explored the determinants of BIMIC in South Africa.

Design/methodology/approach – This research conceptualized a four-pillar model of BIM-enabled integration and collaboration. The speculations in the model were examined using SEM-MLE.

Findings – The aftereffects of the SEM-MLE demonstrated that *network communication, knowledge sharing, and transfer, information sharing and exchange* and *trust-based relationships* are critical determinants of BIMIC. The model's prescient power demonstrates an acceptable validity, and the boundary gauges showed that all the hypotheses were measurably huge.

Research limitations/implications – This research gives a hypothetical premise for further investigation of BIMIC by supporting the postulations on the occurrence of collaboration and integrations among the BIM-SCM.

Practical implications – The idea investigated involving SEM in this research gives a holistic view to the BIM managers in arranging BIM-based activities and overseeing BIM cycles and supply chain members. It likewise offers rules and structures for accomplishing and overseeing integration and collaboration among the BIM supply chain members.

Originality/value – Despite 20 years of exploration on the BIM concept and adoption, no idea has been given to clarify the determinants of integration and collaboration as a BIM cycle. The four-pillar model of BIMIC created and tested in this research clarified BIMIC and contributed a new model to the current literature on the BIM process.

Keywords BIM, BIM process, BIM supply chain, Collaboration and integration, Theory of collaboration

Paper type Research paper

1. Introduction

In the construction industry, integration and collaboration have been utilized reciprocally to portray a course of homogenizing the project elements (that is, project documents and project participants). Albeit the two terms are interchangeable, they are likewise unique (Koolwijk *et al.*, 2018). Integration portrays the method involved with planning project components. The primary target of integration is to oversee clashes between the project elements by making the project participants corporate and making the project documents without clashes. Collaboration portrays a helpful cycle wherein project participants cooperate to create an exhaustive project document and deliver projects effectively. The partnership's fundamental



goal is to accomplish a coalition of mastery, assets, reason, information, abilities, experience and priorities of the project participants.

The consequence of the collusion in collaboration is to accomplish a typical reason, cooperation, facilitated or joint endeavors, useful conflict and commitment, direct correspondence, imaginative and inventive solutions and a sense of support. The ramifications are that researchers and specialists can utilize integration and collaboration on the whole to portray the most common way of guaranteeing cooperation and coordination in project elements. In creating project documents, the collaboration will give joint efforts while integration will connect the information and data in the project documents toward making them function as one. For the project participants that will develop the project documents, the collaboration will create teamwork and cooperation, while integration will achieve unity and solidarity (Olugboyege and Windapo, 2019a). This clarification shows that collaboration is to a greater degree a cooperative interaction but has a component of the coordination process due to the joint endeavors that it gives. Integration is for the most part a coordination interaction but becomes inseparable from collaboration since it has a few parts of coordination.

The congruity that integration and collaboration will create between the project elements has been recognized as the answer for the inadequacies and shortcomings of the conventional work process. The imbue of integration and collaboration into the traditional work process will separate the fracture and expert generalizations that have turned into the standard in the construction industry. As of late, Building Information Modeling (BIM) adoption on construction projects has been depicted as giving the chance to infuse the traditional work process with integration and collaboration (Utkucu and Sozer, 2020). It was additionally clarified that imbuing the traditional work process with integration and collaboration through BIM will create a new work cycle known as *the BIM process*.

This indicates that the BIM process or cycle is currently the new integration and collaboration. To illustrate the BIM cycle as the new integration and collaboration and as the fundamental advantage of BIM adoption, AlSehrawy *et al.* (2018) clarified that BIM reception offers the project participants the valuable chance to embed, update, change and separate data, as well as collaborate, trade, convey, support and coordinate information during the BIM process. The clarification for this claim relies on the fact that integration and collaboration represent the ultimate project success factor and the consequence of a productive and compelling BIM process. As the main project success factor, BIM-enabled integration and collaboration (BIMIC) have been posited to streamline the project design, improve communication among the BIM supply chain members, upgrade interoperability and trust advancement and create a non-ill-disposed team-based climate (Baradi *et al.*, 2018).

Genuine conversations about BIMIC have risen up out of China (Guo and Feng, 2019) and Australia (Oraee *et al.*, 2017, 2019; Baradi *et al.*, 2018). In developing and major African nations, BIM-related examinations are as yet examining BIM adoption and implementation. For instance, in South Africa, a considerable amount of literature has been published on BIM adoption and implementation (Olugboyege and Windapo, 2021a, b, c; Okoro *et al.*, 2020; Odubiyi *et al.*, 2019; Knobel *et al.*, 2021). These studies detailed that the early adopters of BIM in South Africa understand its advantages and partake in an upper hand as they work to get and perform new tasks substantially more proficiently. What is yet obscure is the idea of advantages that the adopters of BIM in South Africa are appreciating.

Globally, investigations on BIM adoption and implementation have not investigated BIMIC as an advantage of BIM and the idea of the BIM interaction. This could be an aftereffect of an absence of an unmistakable comprehension of the determinants of BIMIC. Another explanation could be the selective spotlight on the reception of BIM technologies by these investigations. Further investigation of the BIM interaction is fundamental in light of the fact that the BIM cycle and advantages depend on integration and collaboration. Knowing

the nature and level of integration and collaboration in the BIM process will empower the compelling administration of the BIM process. It will likewise permit the expanded execution of the BIM cycle among the BIM adopters. Along these lines, the basic inquiry to be tended to in this study is *what elements decide BIM-enabled integration and collaboration?* Thus, the primary motivation behind this study is to recognize the significant determinants of BIMIC. The other reason for this research is to determine the degree of occurrence of the determinants of BIMIC in South Africa.

The reasoning for this research hinges on the need to comprehend the BIM process. The BIM cycle is significant in light of the fact that it depicts the scope of BIM exercises and gives concentration to accomplishing a fruitful BIM adoption. BIM adoption and examinations have zeroed in essentially on BIM tools and technologies. This is encumbering the appropriate reception of BIM and the acknowledgement of BIM benefits. Without the comprehension of the BIM cycle, its reception in tasks may not happen or might be ill-advised. Without the appropriate adoption of BIM interaction, integration and collaboration may not happen in BIM adoption. However, the effect of BIM adoption on project delivery and the acknowledgement of its advantages significantly rely upon the occurrence of integration and collaboration in BIM adoption.

2. Literature review

The literature on BIMIC is restricted. A large number of the accessible literature has only considered the factors influencing BIMIC (Oraee *et al.*, 2017, 2019; Guo and Feng, 2019), cloud-based BIM-enabled collaboration (Logothetis *et al.*, 2018; Abanda *et al.*, 2018; Naticchia *et al.*, 2020) and collaborative decision-making tools (Wang *et al.*, 2020; Bolshakova *et al.*, 2019; Cidik and Boyd, 2020). Notwithstanding twenty years of examination on the BIM idea and adoption, no concept has been given to clarify the components of BIMIC. The existing research has only conjectured and contended on the occurrence of BIMIC without giving any clarification to the nature of its occurrence. To address this issue, this research conceptualized a four-pillar model of BIMIC. The model as represented in Figure 1 theorized *network communication* (NC), *knowledge sharing and transfer*, *information sharing and exchange* (ISE) and *trust-based relationships* (TBR) to be the determinants of BIMIC.

In light of the above mentioned, it is conjectured that:

- H1. TBR is a significant determinant of integration and collaboration in the BIM process.
- H2. ISE are significant determinants of integration and collaboration in the BIM process.
- H3. NC is a significant determinant of integration and collaboration in the BIM process.
- H4. KST are significant determinants of integration and collaboration in the BIM process.

The four-pillar model is hypothesized in Figure 2 and the conceptual background for the model is given in the accompanying sub-sections:

2.1 Trust-based relationships

TBR among the BIM-SCM (BIM Supply Chain Members) were considered as a form of integration and collaboration because trust is vital for fruitful interactions and dispositions among the project participants (Olugboyega and Windapo, 2019c). Trust has been affirmed to be fundamental for accomplishing adaptability, guaranteeing a smooth progression of information and guaranteeing successful collaboration among the project participants (Neubert *et al.*, 2018). Lin (2019) noticed that trust is a connection that shows a positive view of an aim to act dependably, along these lines causing the turn of events and security of the

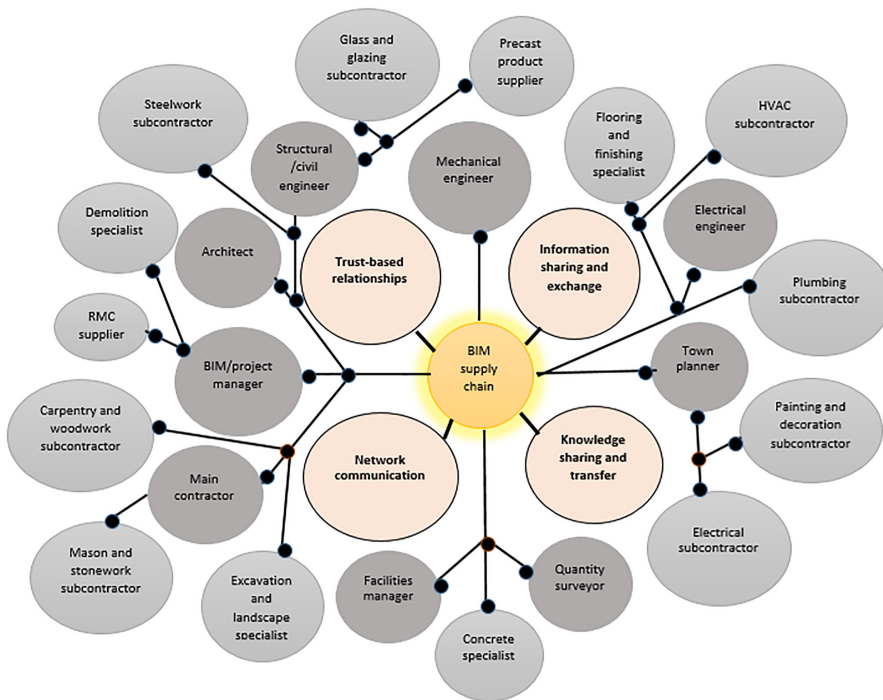


Figure 1.
Four-pillar model of
BIM-enabled
integration and
collaboration

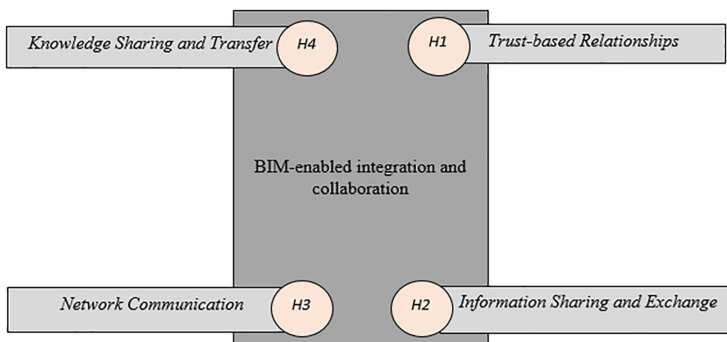


Figure 2.
The hypothesised
model of BIMIC

camaraderie by giving collaboration and fortitude among colleagues. [Wu et al. \(2017\)](#) stressed that trust emphatically affects clashes, expenses and group adequacy. This has prompted the depiction of TBR as an intuitive cycle on which trusting behavior develops because its advancement is impacted by the attributes of construction projects and the nature of relationships in construction projects.

Construction projects are impermanent, special, restricted by time and portrayed by countless members. The nature of relationships in construction projects is to such an extent that the participants need to work with new, old and heterogeneous individuals. The impact of this kind of relationship on trust improvement is critical because there might be no set of

experiences of associations, attitudes and needs among the individuals which are basic to trust advancement. Without trust development, opportunistic behavior, for example, thought process to amplify one's personal circumstance, inability to cooperate, hesitance to really take a look at the lucidity of data, proficient generalizations, helpless correspondence and abuse of information would be pervasive among the project participants. Hence, guaranteeing the shortfall of these behavioral problems according to the collaborative requirements of the BIM process implies that specific helpful practices like dependability, guarantee satisfaction and reasonableness is required from the BIM-SCM. [Talavera \(2013\)](#) guaranteed that cooperative prerequisites of the BIM cycle as appeared in agreeable practices are established on trusting and dependable practices since they allude to the shortfall of conduct issues in that they forestall the BIM-SCM from seeking after private or professional interests and abuse of shared information. This infers that a BIM-SCM is consequently framed in BBCPs (BIM based construction projects) and that the BIM-SCM is relied upon to keep away from the abuse of chances for the compatibility of personal responsibility. In this manner, the BIM-SCM is committed to embracing TBR for direction, correspondence and coordinated effort. This will empower the BIM-SCM to comprehend their individual obligations in the BIM interaction and to see each other's requirements and concerns; consequently ensuring a fruitful construction project delivery.

2.2 Information sharing and exchange

ISE has been distinguished as the reinforcement of collaboration in the BIM supply chain ([Boton and Forgues, 2018](#)). ISE has likewise been distinguished as fundamental for esteemed and informed direction, ongoing transmission and handling of information, enhancement of the inventory network, speed-up of information stream, information coordination and feeling of possession ([Zhao et al., 2018](#)). Specifically, [Boton and Forgues \(2018\)](#) clarified that ISE is a significant BIM standard and interaction that is expected for the integration of the project participants and information. In the BIM process, the BIM-SCM is expected to collaborate on the development of project information to make project information more unsurprising and visualized through rigorous analysis, simulation and modeling.

[Olugboyega and Windapo \(2019b\)](#) noticed that the quintessence of ISE among the BIM-SCM is the making of a federated building information model because it is a common and concentrated data set of coordinated discipline-explicit building information models that must be accomplished by file-based or server-based file linking. This necessity of the BIM process has elevated the requirement for ISE among the BIM-SCM by making building information models the wellspring of project information ([Boton and Forgues, 2018](#)). Notwithstanding the requirement for unwavering quality and steadfastness of building information models, the intricacy of the construction process and more significantly the BIM process prerequisites make it significant for information to flow flawlessly among the BIM-SCM ([Olugboyega and Windapo, 2019b](#)). [Olugboyega and Windapo \(2019b\)](#) further brought up that ISE is basic to BIM application on construction projects since it decides the future utilization of building information models, the degree of BIM application on projects, the degree of collaboration and integration among the BIM-SCM, and the development and richness of the federated building information models. [Boton and Forgues \(2018\)](#) portrayed ISE as a prerequisite in BIM because the discipline-specific building information models developed by the BIM-SCM is not adequate in itself and that the discipline-specific building information models must be shared and incorporated to satisfy the information needs of the individuals and to develop the federate building information model.

Thus, it becomes significant for BIM to be dependable on the grounds the information they give is expected to illuminate the BIM-SCM, support independent direction, fill in as project documentation, and address the project plans.

2.3 Network communications

Communication alludes to the transmission of resources starting with one party then onto the next utilizing shared images and media; and it is fundamental for the productive performance of the project participants because of the distinction in their abilities, capability, interests, and organization structure (Olugboyega and Windapo, 2019a). Olugboyega and Windapo (2019a) expand on this end, expressing that communication is urgent for critical thinking, decision-making, integration and collaboration, understanding, dispute-resolution, project objectives determination and efficient coordination. In the BIM process, communication among the BIM-SCM is about the transmission of project information like data, suppositions, thoughts, abilities, innovation and input. BIM gives structure and control to the communication process and practice; subsequently guaranteeing compelling communication of project information (Olugboyega and Windapo, 2019a). In particular, Wu *et al.* (2017) clarified that the BIM process requires the communication of resources like data, information, and knowledge.

This necessity convolutes the communication cycle and adjusts the idea of communication among the BIM-SCM. In this manner, guaranteeing successful communication of resources among the BIM-SCM implies that the individuals should be interconnected every which way of the chain network. This interconnection is accomplished in the BIM cycle with an electronic collaborative network (e-mail, teleconferencing, mobile phones, Internet, multimedia, virtual reality and intranet) and network structures (contractual relationships, coordination, integration and collaboration requirements). The above portrayals demonstrate an extraordinary type of communication in the method of coordinated and controlled communication among the BIM-SCM that happens through an electronic collaborative network, and network structures. In aggregate, these clarifications portray a pattern of communication among the BIM-SCM that comprises of various communication facets, happens across the project life-cycle, contains blended strategies for transmitting resources, happens at different places simultaneously or the same spot at various times, as well as demonstrates the collaboration and integration prerequisites of BIM process.

Moreover, the BIM interaction requires the planning for communication channels, communication platforms, communication protocols, organized e-meeting, real-time communication and joint problem-solving techniques among the BIM supply chain. This fills in as an appearance of an obviously characterized communication process. As indicated by Olugboyega and Windapo (2019a), the utilization of communication channels like meetings, discussion and communication technologies upgrades communication flow and advances better comprehension among the BIM-SCM. Olugboyega and Windapo (2019a) further affirmed that BIM cycle necessities guarantee the occurrence of overlapping interaction, adaptable conventions and straightforwardness in the communication process. This perception disclosed one more type of communication in the BIM process that happens across plainly characterized channels, stages, conventions, time-space and goals. Altogether, the nature and types of communication among the BIM-SCM address a *NC* and it is characterized by regular communication among the team and groups within the BIM supply chain organizations; as well as across the stages in the project lifecycle. This regular communication should be reciprocated, permit feedback, be multi-layered and occur in real-time.

2.4 Knowledge sharing and transfer

Knowledge addresses intangible assets, technical solutions, experiences, ideas, innovations, expertise, know-how, feedback and inventive approaches that are held by one person or embedded in groups of people. Knowledge might be put away as mental models (that is, tacit knowledge) or put away as manuals, documents or databases (that is explicit knowledge).

Additionally, knowledge might be individual (that is, held by one person) or collective (that is, embedded in groups of people) in nature (Cheng and Fu, 2013). Collective knowledge arises out of collaboration and it is more applicable to the supply chain network. Nonetheless, without the sharing and transfer of knowledge, collective knowledge may not be accomplished.

Knowledge is deemed to be shared and transferred across the supply chain network when ideas, innovations and expertise are leveraged to concentrate on supply chain activities or capture the project objectives (Chen *et al.*, 2014). In the construction industry, KST is fundamental for the successful delivery of construction projects. This is because KST guarantees viability and coordination in project delivery (Cheng and Fu, 2013), support the upper hand among construction organizations, empower the advancement of new abilities and skills among the construction experts and permit project participants to grow their resources pool, deliver value-added services and develop in-depth cooperation (Chen *et al.*, 2014).

KST in the BIM cycle connects with a corresponding course of sharing and exchanging ideas, innovation, expertise, or feedback (Wang and Meng, 2018). The genuine course of KST among BIM-SCM happens through formal and casual conversations, reviews, teamwork, building information models, project databases, project proceedings, insights and comments and reports. This lays out KST as a significant target of integration among the BIM-SCM and as a critical supporter of the proficiency and adequacy of BIM application on construction projects. Albeit, not all construction knowledge goes into the BIM cycle or development of BIM (AlSehrawy *et al.*, 2018); they absolutely affect the BIM interaction and the development of BIM.

This is on the grounds that, in the BIM process, KST are expected to pool all the project support information for project delivery and facilitates the utilization of construction knowledge in the BIM process through the optimization of information collection, interoperability, information flow and information retrieval (Chen *et al.*, 2014). This infers that there is BIM-related knowledge. Additionally, to empower collaborative resource coordination and integration among the BIM-SCM, KST should occur starting with one individual then onto the next (inter-personal KST) or from a workgroup to another (inter-professional, inter-organizational, inter-group and inter-team KST). Studies by AlSehrawy *et al.* (2018) and Lin (2019) offer support for this contention by agreeing that it is a BIM best practice for construction knowledge to be extracted as building information models because BIM-related knowledge is effectively perceived in form of a model and not as text-based illustrations.

3. Research methods

3.1 Research approach and data collection

This research embraces positivism philosophy, deductive approach, and quantitative-based survey method. The eligibility rules for the research participants stipulate that the participants more likely than not created building information models participated in BIM review meetings, possessed BIM knowledge and partook in BIM-enabled collaboration. The complete populace of people meeting these standards comprised 1,871. These individuals were recognized by extracting the contact subtleties of the immediate participants in BIM-based construction projects (BBCPs) from the postings of BIM experts on Linked-In™ and South African BIM clubs. In addition, people able to participate in the research were haphazardly inspected and reached for the study. Questionnaires were sent through e-mail solicitations and web links. The questionnaire was intended to elicit data on the determinants of BIMIC. An aggregate of 975 research participants got the questionnaire. In any case, just 872 of the research participants completed the questionnaires without significant absent and

deficient information. This gives a response rate of 89%. The actual data collection was completed over 13 months. Table 1 sums up the demographic attributes of the research participants for this exploration.

3.2 Constructs and sub-constructs measurement

Four primary constructs (NC – Z_3 , KST – Z_4 , ISE – Z_2 and TBR – Z_1) and nine sub-constructs were recognized from section 2. Z_1 was estimated utilizing three sub-constructs (*positive reputation* – Z_{11} , *positive expectations* – Z_{12} , and *trusting and trustworthy behaviors* – Z_{13}). Two sub-constructs were used to gauge every one of Z_2 (*information quality* – Z_{21} and *information structure* – Z_{22}), Z_3 (*mixed communication* – Z_{31} and *structured communication* – Z_{32}) and Z_4 (*BIM best practices* – Z_{41} and *BIM experiences* – Z_{42}). The items used to measure each of the nine sub-constructs are recorded in Appendix.

3.3 Method of data analysis

Data analysis was completed in two sections. The initial segment managed the analysis of the measurement models and the subsequent part covered the analysis of the structural models. The analysis of the measurement models tested the convergent and discriminant validity (confirmatory factor analysis and average variance extracted), significance (mean item score), internal consistency and structure (factor loading), and reliability (Cronbach's alpha). The structural models were dissected by estimating the model parameters and evaluating the goodness of fit of the models. Structural equation modeling – maximum likelihood estimation (SEM-MLE) utilizing multiple fit indexes.

4. Results

4.1 Validity and internal consistency

Reliability and validity tests were conducted on the measured variables for the sub-constructs to guarantee their sufficiency for SEM. The results in Tables 2 and 3 show that every one of the measured has adequate unwavering quality and legitimacy, as they are huge, exceptionally connected, dependable and have interior consistency. The outcomes additionally demonstrated that the variables have convergent, nomological validity and discriminant validity, contributed to the constructs, and have homogeneity of difference. The results in Tables 2 and 3 demonstrated that the correlations between the variables are above 0.50. This implies that variables validly measure the constructs and that the constructs have a possible linkage. Figure 3 presents the chart of the correlation matrix for the sub-constructs. The chart was plotted in R Correlogram utilizing the R Corrplot package. As displayed in the chart, every one of the circles is blue. This indicates positive inter-correlations among the sub-constructs. The ramifications of these outcomes are that every one of the measured variables is dependable and legitimate for SEM.

4.2 Significant determinants of BIMIC

The profoundly critical variables for the determinants of BIMIC are introduced in Table 4. As displayed in the table, *positive expectations* have the highest number of highly significant variables among the sub-constructs for TBR—the research participants exceptionally rated information quality as a sub-construct for ISE. *Structured communication* and *BIM best practices* were additionally exceptionally appraised by the research participants as sub-constructs for NC and KST, respectively. In light of the number and nature of the profoundly critical variables, it is apparent from Table 4 that BIM-SCM is exceptionally expected to have integrity and BIM competence. They are almost certain to be fit for sharing high-quality and

Answer choices	Response percent
<i>Educational background of the research participants</i>	
Certificate-Diploma with Grade 12	35.17%
Bachelor's Degree	22.49%
Higher Diploma [Technicon/University of Tech]	18.4%
N4-6/NTC4-6/Certificate-diploma with less than Grade 12	25.13%
Master's Degree	10.84%
PhD	1.02%
<i>Designation of research participants</i>	
Director Cadre	73.75%
Management Cadre	19.5%
Technical Officer	8.88%
<i>Services provided</i>	
Main Contractor	38.45%
Subcontractor	29.24%
Supplier	27.26%
Construction Manager	22.2%
Project Manager	17.87%
Consultants	17.33%
Developer/Client	5.6%
Specialist	5.6%
BIM Manager	2.71%
<i>Area of Expertise</i>	
Building and civil engineering construction	48.96%
Building construction	44.63%
Civil engineering	25.42%
Special construction/special works	11.49%
Mechanical engineering works for infrastructure	7.72%
Electrical engineering works for building	7.16%
Mechanical engineering works for building	6.97%
Electrical engineering works for infrastructure	6.78%
<i>Years of experience in the construction industry</i>	
11–15 years	70.75%
16–20 years	19.88%
21 years and above	10.5%
<i>Location of the research participants in South Africa</i>	
KwaZulu-Natal	31.6%
Gauteng	19.39%
Eastern Cape	16.34%
Western Cape	13.29%
Limpopo	6.46%
Free State	5.75%
Mpumalanga	5.75%
Northern Cape	5.21%
North West	4.67%
<i>Category of BIM-based construction projects executed by the research participants</i>	
Ports and Harbor	3.20%
Airports	3.65%
Railways and Tunnels	4.11%
Commercial buildings	20.68%
Industrial buildings	29.22%
Institutional buildings	28.31%
Buildings for domestic use	52.97%
Bridge and Culvert	15.98%
Dams	9.59%
Roads	45.66%

Table 1.
Characteristics of the
research participants

credible information, communicating utilizing BIM tools and protocols, and exhibiting knowledge of BIM processes and workflows.

4.3 Structural model of the degree of occurrence of the determinants of BIMIC in South Africa

The results of the SEM-MLE are presented in Figure 4 and Table 5. All the parameter estimates are significant and showed a robust positive association between Z and Z_1 ($r = 0.97$), Z and Z_2 ($r = 1.47$), Z and Z_3 ($r = 1.24$) and Z and Z_4 ($r = 1.45$). The goodness-of-fit test statistics for the structural equation model are displayed in Figure 4. The Chi-square test statistic is not significant at 0.05, which recommends that the model is acceptable. RMSEA is 0.045 and since it is under 0.05, it indicates a good fit. CFI and TLI are larger than 0.9 which again mirrors a good fit of the model. The prescient force of the structural equation model demonstrates an adequate legitimacy. This proposes the occurrence of *TBR*, *KST*, *ISE* and *NC* among the BIM-SCM in South Africa. The results showed that every one of the hypotheses is statistically significant. Table 6 gives a rundown of the SEM-MLE for the hypotheses. The strength and significance of the relationships between the determinants and sub-constructs of BIMIC give understanding into their occurrence level.

As shown by the results, only Z_{21} ($r = 0.62$, $z = 7.01$) and Z_{42} ($r = 0.52$, $z = 6.33$) have a moderate occurrence level. The greater part of the sub-constructs have a low degree of occurrence [Z_{12} ($r = 0.48$, $z = 6.48$), Z_{13} ($r = 0.17$, $z = 3.40$), Z_{11} ($r = 0.38$, $z = 6.13$), Z_{22} ($r = 0.21$, $z = 5.05$), Z_{31} ($r = 0.44$, $z = 5.74$), Z_{41} ($r = 0.41$, $z = 5.85$)]. This actually intends that there is by and large a low degree of occurrence of the determinants of BIMIC in South Africa, with the exception of information quality (Z_{21}) and BIM experience (Z_{42}) that showed a moderate degree of occurrence.

Table 2.
Validity of the
constructs

	Z_{11}	Z_{42}	Z_{41}	Z_{32}	Z_{31}	Z_{22}	Z_{21}	Z_{12}	Z_{13}
Z_{11}	1								
Z_{42}	0.74	1							
Z_{41}	0.69	0.98	1						
Z_{32}	0.69	0.98	1	1					
Z_{31}	0.69	0.98	1	1	1				
Z_{22}	0.69	0.98	1	1	1	1			
Z_{21}	0.69	0.98	1	1	1	1	1		
Z_{12}	0.69	0.98	1	1	1	1	1	1	
Z_{13}	0.69	0.98	1	1	1	1	1	1	1

Table 3.
Internal consistency of
the constructs

Constructs	Number of significant variables	Factor loading	Cronbach's alpha	Average variance extracted	Maximum shared variance	Average shared variance
Z_{11}	5	0.78	0.74	51.51	2.00	1.56
Z_{12}	17	0.85	0.79	61.03	1.38	1.70
Z_{14}	7	0.81	0.71	55.49	1.38	1.62
Z_{21}	12	0.95	0.94	64.45	1.38	1.90
Z_{22}	12	0.91	0.93	69.32	1.38	1.82
Z_{31}	10	0.96	0.97	55.09	1.38	1.92
Z_{32}	11	0.90	0.95	60.60	1.38	1.80
Z_{41}	19	0.82	0.84	57.10	1.38	1.64
Z_{42}	10	0.78	0.73	63.99	1.48	1.56

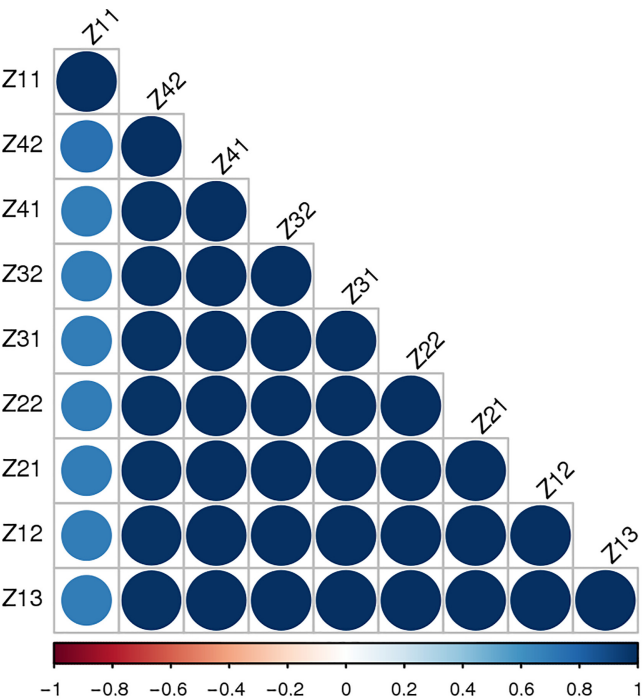


Figure 3.
Correlogram for
visualising the
correlation matrix

5. Discussion of findings

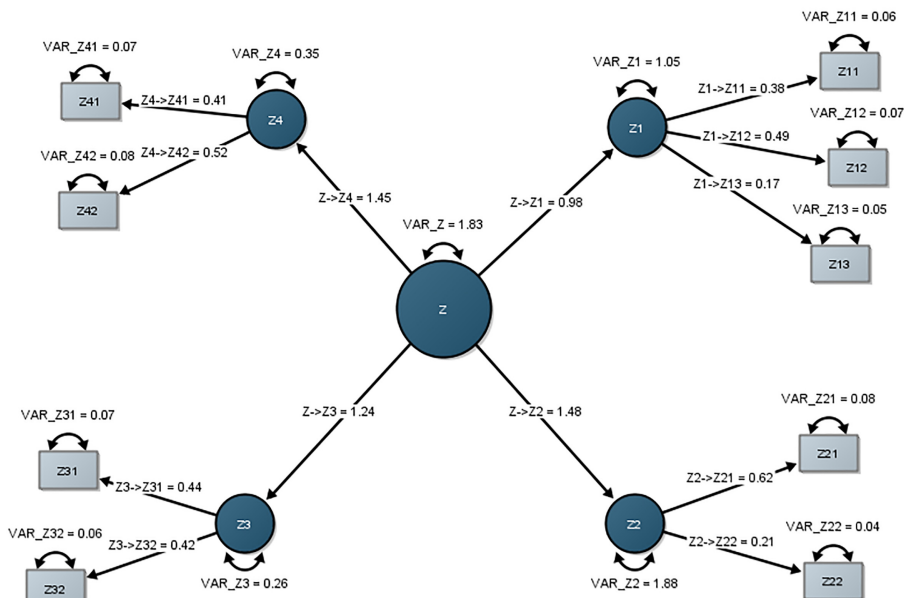
This research set off to distinguish the critical determinants of BIMIC and determine the level of occurrence of the determinants of BIMIC in South Africa. Concerning critical determinants of BIMIC, this research proposed a four-pillar model of BIMIC. Four hypotheses (H1 – H4) were reasoned to test the model. The outcomes approved the four theories (see Table 6) demonstrated that every one of the determinants of BIMIC is significant. It can consequently be proposed that TBR, ISE, NC and KST decide the occurrence of BIMIC in a BIM-based project. As per the discoveries, the main determinant was TBR. This recommends that trust is the most fundamental component in BIMIC. Without trust, BIM-based projects participants might find it hard to uninhibitedly and transparently share information and knowledge. The discoveries of this exploration vary from those in the literature that provide theoretical evidence for BIMIC (Mignone *et al.*, 2016; Oraee *et al.*, 2017, 2019; Guo and Feng, 2019).

Mignone *et al.* (2016) recognized the variables repressing collaboration in BIM-based construction networks (BBCNs). Oraee *et al.* (2017) revealed that there is an absence of information on the accepted procedures for integration and collaboration as a BIM process. The study recommended that future examinations should explore the components of BIM collaboration systems. Guo and Feng (2019) presumed that there is a gap in the literature on BIM-based integration and recommended the development of the concept of integration in BBCNs by future BIM studies. This study has built on the previous studies by theoretically and empirically demonstrating the nature of BIMIC.

Expanding on the model of BIMIC will require a top to bottom contextual analysis of the BIM supply chain and BBCPs. The results got for the subsequent objective uncovered a moderate occurrence level for information quality and BIM experience. Positive reputation and expectations, trusting and trustworthy behavior, information structure, mixed and

Main constructs	Sub-constructs	Highly significant variables (mean score ≥ 3.61)
Trust based relationships (Z1)	Positive reputation (Z11) Positive expectations (Z12)	Consistent integrity (3.66) Problem-solving ability (3.85), competence of personnel (3.84), competence of organizations (3.69), openness in sharing information (3.65)
Information sharing and exchange (Z2)	Trusting and trustworthy behaviors (Z13) Information quality (Z21)	Information shared is credible (3.73), clarity of information (3.67), high quality of information (3.66), information shared is accurate (3.61)
Network communication (Z3)	Information structure (Z22) Mixed communication (Z31)	Communication across the stages in the project lifecycle (3.70), regular interpersonal communication (3.66)
	Structured communication (Z32)	Documentation of communication (3.78), formation of open and formal communication channel (3.76), adoption of common electronic communication platform (3.64), establishment of a secured line of communication (3.61), usage of communication protocol (3.61)
Knowledge sharing and transfer (Z4)	BIM best practices (Z41) BIM experience (Z42)	Valued decision-making (3.75), quick decision-making (3.70), collective decision-making (3.63), interpersonal knowledge sharing (3.61) Understanding of information (3.72), high quality of information (3.65), willingness to share resources (3.61)

Table 4.
Significant variables
for the determinants of
BIM-SCM



Note(s): Chi-Square: 1212.678; RMSEA: 0.045; SRMR: 0.065; CFI: 0.932; TLI: 0.9

Figure 4.
Path diagram for the
structural equation
model of BIM-SCM

Table 5.
Parameter estimation
for the structural
equation model
of BIMIC

Relationship	Estimate	Standard error	Z-value
$Z_1 \rightarrow Z_{12}$	0.48607772446509295	0.07553753913012988	6.434916070375527
$Z_1 \rightarrow Z_{13}$	0.17064093605191658	0.050067567682883896	3.4082130199077336
$Z_1 \rightarrow Z_{11}$	0.38522240708942557	0.06277404724225889	6.136650797785387
$Z_2 \rightarrow Z_{21}$	0.6288452048979266	0.08967904481626945	7.012175544312247
$Z_2 \rightarrow Z_{22}$	0.21056735472885973	0.04162950422806585	5.058127850268731
$Z_3 \rightarrow Z_{31}$	0.44180230867172354	0.0769356153337035	5.74249399001273
$Z_3 \rightarrow Z_{32}$	0.4250327299726955	0.06812876090088671	6.238668138864736
$Z_4 \rightarrow Z_{41}$	0.4128235754006923	0.07053310285706442	5.852905354770521
$Z_4 \rightarrow Z_{42}$	0.5211632714527193	0.08222917410475176	6.337936348342856
$Z \rightarrow Z_1$	0.9792252569856041	NaN	NaN
$Z \rightarrow Z_2$	1.4786505378638806	NaN	NaN
$Z \rightarrow Z_3$	1.2420003540145959	6539.971044947702	1.89909151811012E-4
$Z \rightarrow Z_4$	1.4517946044713361	NaN	NaN

Table 6.
Summary of test
results for the
hypotheses

Hypothesis	Path co-efficient	Result
H1	0.98	Supported
H2	1.48	Supported
H3	1.24	Supported
H4	1.45	Supported

structured communication, and BIM best practices have a low occurrence level. It is evident from the outcomes that collaboration occurs among the participants of BBCPs in South Africa at all phases of BIM processes and in various structures. These structures incorporate *asynchronous collaboration* – collaboration at the same place and at other times, *distributed collaboration* – collaboration at various locations, *synchronous collaboration* – collaboration at the same time and *face-to-face collaboration*.

It tends to be deduced from the discoveries that BIM adoption on construction projects empowered the project participants to trust each other’s critical thinking capacity, skill, assessment and points of view. Apparently, the project participants acted and connected with each other with respectability and trustworthiness because of the BIM interaction necessities. It could likewise be deduced that there was transparency in sharing data, participation and common trade of thoughts on the BBCPs. To a sensible degree, the contention recommends that there is a degree of trust between the project participants. Moreover, BIM adoption on construction projects empowered the project information developed by the project participants to be of high quality. This was uncovered by the sufficiency, believability, clearness, precision and practicality of the information shared among the project participants. The discoveries propose that the project managers or BIM managers chose a committed channel for data sharing for the BBCPs. This work encourages cooperation and combination of both the project information and project participants since utilizing a devoted data sharing channel empowers the sharing of both general and delicate information.

From the results, it tends to be seen that there is a low occurrence of shortfall of contending interests and professional stereotypes among the project participants on the BBCPs. The impact of this is that the project interests probably won’t take essential priority, and the project participants probably won’t have an engaged and clear mentality toward seeking after shared interests. Another amazing finding is the somewhat low occurrence of non-ill-disposed connections and the restricted utilization of both file-based and server-based data

interoperability. The finding proposes the occasion of specific non-cooperative exercises and unsupportive practices among the project participants. The restricted utilization of both file-based and server-based data interoperability could demonstrate that the BIM work processes for the BBCPs were not smooth and successful. It is practically sure that a portion of the building information models created for the BBCPs would have errors, ambiguities and oversights. Similarly, the discoveries show that a portion of the organized e-meetings that occurred on the identified BBCPs was not agenda-driven, open-ended and problem-solving. The finding portrays a low occurrence of two-way interaction and cooperation among the project participants.

5.1 Theoretical implications

Theoretically, this research has given a theory to clarify the components of integration and collaboration as a BIM interaction. The research has conjectured on the idea of integration and collaboration and their occurrence. The propositions of this study have settled the absence of comprehension of the concept of integration and collaboration as a BIM cycle. It has given a theoretical premise to an additional examination of BIMIC. The consequences of this exploration are useful for BIM process management. The examination has given proof supporting the propositions on the occurrence of collaboration and integrations among the BIM-SCM. The proof given by this exploration uncovered new experiences and ideas for the nature and features of BIMIC. Future examinations on theory development for BIMIC will profit from the system provided in this research. The four-pillar model of BIMIC that was created and tested in this research has featured how integration and collaboration shape the BIM process. This theory will expand the comprehension of BIM specialists and experts in other region of the planet on the factors for estimating and arranging the BIM process. The preparation of the BIM execution guide will extraordinarily profit from the propositions in this research. BIM researchers presently have a theory to analyze the BIM process and clarify the basic factors that might hinder the smooth progression of the BIM process.

5.2 Practical implications

This research offers empirically-based insights into the course of integration and collaboration in the BIM supply chain. The idea investigated in this research gives a comprehensive view to the BIM managers in the planning of BBCPs and management of BIM process and supply chain members. It likewise offers rules and systems for accomplishing and overseeing integration and collaboration among the BIM-SCM. The concept is fundamental since knowing the determinants of BIMIC can help specialists and experts in fostering a superior comprehension of the BIM cycle. The exploration has additionally proposed that it will be feasible to assess the various determinants of BIMIC. The discoveries of this exploration fill in as proof for the advantages of BIM adoption and give data on the accepted procedures for BIMIC. The conclusions can support the reception of BIM in projects where integration and collaboration are wanted. Moreover, reasonable strides for decreasing the boundaries to collaboration in the BIM supply chain can be acquired from the highlights of BIMIC distinguished in this exploration.

5.3 Limitations and future studies

One source of shortcoming in this research that might have impacted the finding was the conceptualization of the four-pillar model of BIMIC without inputs from contextual analyses or grounded theory. All things considered, this study has opened up a conversation on the determinants of BIMIC and has given a platform for future examinations. Further work is expected to lay out the degree of BIM adoption at which BIMIC will happen, utilizing a

contextual investigation or subjective grounded hypothesis. Extra exploration on the interrelationships between the components of BIM adoption and determinants of BIMIC is additionally proposed.

6. Conclusion

This research shows that TBR was the main determinant of BIMIC, as consented to by the research participants. The SEM results uncovered a low degree of occurrence of the determinants of BIMIC in South Africa. In light of this outcome, this examination presumes that the low degree of occurrence of the determinants of BIMIC in South Africa might be expected to lack BIM knowledge and a low degree of BIM implementation in South Africa. A ramification of this is the need to increase BIM training and execution in South Africa. BIM experts in South Africa should evaluate their insight into the BIM interaction and standards. This will empower them to show the properties of integration and collaboration while taking an interest in BBCPs. BIM supervisors and project managers should underscore the assessment of BBCPs for the occurrence of integration and collaboration. They should likewise authorize adherence to BIM standards as educated by the embraced BIM convention. Implementing the adherence to BIM standards will guarantee a high occurrence level of BIMIC in BBCPs.

This exploration adds to the body of knowledge by laying out critical determinants of BIMIC. The experimental discoveries in this exploration give extra proof to the occurrence of BIMIC in BBCPs. The research upgrades how we might interpret the nature and strength of occurrence of BIMIC in BBCPs. The principal contribution of this study is that it has given a rare and clear comprehension of how to design BIM process in BBCPs toward accomplishing BIM benefits that accompany integration and collaboration. The significant limitation of this examination is the absence of assets for large-scale data collection. Data collection for an enormous scope would have worked on the generalizability of the exploration discoveries. Moreover, there is a need to examine the BIM convention illuminating the BIM standards on which the BIM processes for BBCPs are based.

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Appendix
See [Table A1](#)

Table A1.
Z₁: Measured variables for trust-based relationships in BIM supply chain

Sub-constructs	Variables
Z ₁₁ – Positive reputation	Consistent integrity, honesty and mutual commitment, display of confidence for each other by supply chain members, mutual rewards and benefits, persistence of relationship after projects
Z ₁₂ – Positive expectations	Problem-solving ability, competence of personnel, competence of organizations, openness in sharing information, mutual exchange of ideas, freedom to state opinions and perspectives, cross-functional cooperation, support for innovation and learning, shared interests and project expectations, conflict resolution, inter-personal relationship, inter-organizational relationship, social interaction between supply chain members, risk sharing, work interaction between supply chain members, compensating for each other's weaknesses, Lack of confrontation and adversarial relationship, exploiting each other's strengths
Z ₁₃ – Trusting and trustworthy behaviors	The emotional interaction between the project team, the absence of competing interests, absence of tribalism, the absence of professional stereotypes, absence of racism, non-misuse of information by supply chain members, the absence of defensive behavior

See [Table A2](#)

Determinants
of BIM-enabled
integration

201

Sub-constructs	Variables
Z ₂₁ – Information quality	Information shared is credible, clarity of information, the high quality of information, information shared is accurate, usage of collaborative electronic media for information sharing, timely sharing of information, adequacy of information, non-withholding of information, usage of consistent data structures and definitions, the absence of conflicting information, non-distortion or manipulation of information, flawless information exchange
Z ₂₂ – Information structure	Selection of information sharing channels, enhanced interpersonal sharing and exchange of information, usage of information exchange format for integrating project information, cross-boundary information sharing/enhanced inter-organizational sharing and exchange of information, usage of information sharing protocols, creation of homogeneous or single project information database, linking and integration of project information/data federation, file-based data interoperability, server-based data interoperability

Table A2.
Z₂: Measured variables
for information sharing
and exchange in BIM
supply chain

See [Table A3](#)

Sub-constructs	Variables
Z ₃₁ – Mixed communication	Communication across the stages in the project life-cycle, regular interpersonal communication, regular team communication, feedback communication, regular inter-group communication, regular inter-organizational communication, positive corporate communication, the multi-directional flow of information, reciprocal flow of information, problem-solving structured e-meeting
Z ₃₂ – Structured communications	Documentation of communication, formation of open and formal communication channels, adoption of common electronic communication platforms, establishment of a secured line of communication, usage of communication protocols, real-time communication, timely communication, flexibility of formalities, adoption of joint problem-solving techniques, agenda-driven structured e-meeting, open-ending structured e-meeting

Table A3.
Z₃: Measured variables
for network
communication in BIM
supply chain

Table A4.
Z₄: Measured variables
for KST among the
BIM-SCM

Sub-constructs	Variables
Z ₄₁ – BIM best practices	Valued decision-making, quick decision-making, collective decision-making, inter-personal knowledge sharing, inter-team knowledge sharing, usage of collaborative electronic media for knowledge sharing, identification of clashes and omission in information models, review of projects after completion, Inter-professional knowledge sharing, database creation and management, Inter-group knowledge sharing, extraction of measurement information from the information models, inter-organizational knowledge sharing, extraction of cost information from information models, extraction of installation information from the information models, extraction of manufacturer’s details from the information models, extraction of fabrication information from the information models, extraction of tendering/bidding information from the information models, extraction of operation and maintenance information from the information models
Z ₄₂ – BIM experiences	Understanding of information, the high quality of information, Willingness to share resources, sharing of knowledge on best practices among the supply chain members, knowledge documentation in the form of the project proceeding, sharing of collaborative experiences among the supply chain members, sharing of project lesson learned among supply chain members, sharing of project reviews among supply chain members, parametric and object-oriented design of information models, sharing of insights among the supply chain members

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