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Reducing Critical Hindrances to Building Information Modeling Implementation: The Case of the Singapore Construction Industry

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Abstract: The Singaporean government has made building information modeling (BIM) implementation mandatory in new building projects with gross floor areas over 5000 m^2, but the implementation is still plagued with hindrances such as lacking project-wide collaboration. The purposes of this study are to identify critical factors hindering BIM implementation in Singapore's construction industry, analyze their interrelationships, and identify strategies for reducing these hindrances. The results from a survey of 87 experts and five post-survey interviews in the Singaporean construction industry identified 21 critical hindrances, among which "need for all key stakeholders to be on board to exchange information" was ranked top. These hindrances were categorized into lack of collaboration and model integration (LCMI), lack of continuous involvement and capabilities (LCIC), and lack of executive vision and training (LEVT). LEVT and LCIC contributed to LCMI; LEVT caused LCIC. The proposed framework implying the key hindrances and their corresponding managerial strategies can help practitioners identify specific adjustments to their BIM implementation activities, which enables to efficiently achieve enhanced BIM implementation. The hindrances identified in this study facilitate overseas BIM implementers to customize their own lists of hindrances.

Keywords: building information modeling (BIM); building project; hindrance; factor analysis; structural equation modeling (SEM); managerial strategies; Singapore

1. Introduction

Building information modeling (BIM) refers to the integration of technological and organizational solutions. The solutions can not only enhance inter-organizational and multidisciplinary collaboration, but also improve the efficiency and quality of the planning, design, construction, and management of buildings [1–5]. Although the value of BIM is now widely recognized compared with the traditional drafting practices, it is not possible to reap the full benefits without awareness, commitment, and capabilities of implementing BIM as well as a realistic view of the adoption status. For example, Chelson [6] found that BIM operators may be typically young and lack enough field knowledge to incorporate new work processes into the project workflow. Khosrowshahi and Arayici [7] revealed that designers and contractors may psychologically contradict the new processes. Forsythe et al. [8] found that firms would start to implement BIM if policymakers already required, specified, or mandated them to do that. Otherwise, it would need many years before BIM is more often used. Juan et al. [9] reported that most firms would use BIM to maintain competitiveness in the market where other firms had already implemented BIM in an earlier time. Thus, both opportunities and risks appeal to exist in BIM implementation.

In the Singapore context, a top-down approach has been used in driving BIM implementation. The Building and Construction Authority (BCA) has been playing a dominant role and made much effort to promote BIM. Among which, the most important regulation was a five-year BIM adoption roadmap. Specifically, all new building projects (both private and public) that have gross floor areas (GFAs) of greater than 20,000 m^2 must submit their architectural plans in BIM format for regulatory approvals since July 2013 and submit their structural and mechanical, electrical, and plumbing (MEP) plans in BIM format since July 2014. Eventually, all new building projects with GFAs of 5000 m^2 and above are mandated to submit their building plans in BIM format, which came into force in July 2015 [10]. In the meantime, the local construction value chain has been encouraged to work collaboratively, with part of implementation cost being subsidized [11]. The local government has also drafted the BIM Particular Conditions to guide the local construction industry to address the procedures of digital data processing, roles and responsibilities, intellectual property rights, each party' extent of reliance on three-dimensional (3D) models, and contractual privity. Consequently, the overall BIM adoption rate had improved from 20% in 2009 to 65% in 2014; such implementation, however, tended to be fragmented BIM uses in individual parties, rather than based on project-wide collaboration [12]. In addition, the building contracts in Singapore are still developed on the basis of the traditional contractual framework that prohibits collective benefits and encourages individualism. When problems occur, such a contractual structure would easily thrust project participants into adversarial positions [13,14]. Overall, most practitioners are conservative to change.

The specific purposes of this study are to (1) identify critical hindrances to BIM implementation in the Singapore construction industry, (2) investigate interrelationships among the hindrances, and (3) identify managerial strategies for reducing these hindrances. Given that the BIM submissions policy in new building projects in Singapore is mandatory, the local practitioners have to be ready for moving towards full BIM implementation and gain an in-depth understanding of what really hinders their BIM implementation and how to reduce such hindrances. Although many studies have investigated BIM implementation in the global construction industry, no studies have been done so far to comprehensively study the hindrances to BIM implementation in Singapore as the present study does. Also, few studies have attempted to investigate the relationships among the critical hindrances and accordingly build a conceptual framework.

The Economic Strategies Committee (ESC) of Singapore has advocated that the local economy, especially labor-intensive industries, should improve work efficiency to maintain competitiveness [15]. Thus, the planning, design, construction, and management of building projects have a critical implication. The managerial strategies identified in this study can help the local industry players eliminate the critical hindrances' negative influence to enhance BIM implementation. Although this study focuses on building projects in Singapore, overseas practitioners may use the identified hindrances to prepare their own hindrances and follow the research method to formulate their strategies. Thus, this study may contribute to the existing literature related to BIM implementation.

2. Literature Review

Through the literature review analyzing 26 previous global studies on BIM implementation, this study has identified 47 hindrances, as shown in Table 1. It should be noted that in the Singapore context, the BCA drives the whole value chain to optimize building designs for off-site manufacture (OSM) which are encouraged in full BIM implementation [11], and intends to develop a BIM guide for Design for Manufacturing and Assembly [12]. Prefabricators can use the precision of geometric data contained in building information models to aid the manufacturing process and assembly of building components on site. Thus, in this study, hindrances related to the integration of BIM and OSM were also identified. Faced with these 47 hindrances, project teams may not implement BIM openly and collaboratively. Lam [12] reported that only 20% of building projects in Singapore had implemented BIM with a relatively high collaboration level. Thus, the local construction industry has been facing many issues: owners cannot see beyond initial cost; designers tend to over-emphasize the BIM e-submissions and lack time to perform design coordination; main contractors can rarely use the designers' models because in most cases such models were not developed in the same way the contractors intend to build the buildings; subcontractors, especially those small- and medium-sized enterprises (SMEs), lack investment for hardware, software, and training; and facility managers are rarely involved upfront and lack BIM uses [12]. Consequently, the contractors may need to re-build the models, taking much time, which in turn hinders the collaboration with the designers.

Table 1. Hindrances to building information modeling (BIM) implementation.

Code	Hindrances to BIM Implementation	References																									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
H01	Executives failing to recognize the value of BIM-based processes and needing training						√			√					√				√			√					√
H02	Concerns over or uninterested in sharing liabilities and financial rewards							√	√	√			√	√						√							
H03	Construction lawyers and insurers lacking understanding of roles/responsibilities in new process				√								√							√							
H04	Lack of skilled employees and need for training them on BIM and off-site manufacture (OSM)			√	√			√	√	√	√	√	√		√	√	√		√		√	√					√
H05	Industry's conservativeness, fear of the unknown, and resistance to change comfortable routines				√			√			√							√	√	√	√						√
H06	Employees still being reluctant to use new technology after being pushed to training programs																		√	√							√
H07	Entrenchment in two-dimensional (2D) drafting and unfamiliarity to use BIM			√				√									√	√	√	√	√	√					√
H08	Financial benefits cannot outweigh implementation and maintenance costs			√						√								√	√		√						
H09	Lack of sufficient evidence to warrant BIM use																		√	√	√	√					√
H10	Liability of BIM such as the liability for common data for subcontractors												√						√		√						
H11	Resistance to changes in corporate culture and structure									√	√								√	√	√	√	√				
H12	Need for all key stakeholders to be on board to exchange information			√		√		√					√	√	√									√	√		
H13	Lack of trust/transparency/communication/partnership and collaboration skills	√	√			√		√				√	√						√	√	√						
H14	BIM operators lacking field knowledge		√									√										√					
H15	Field staff dislike BIM coordination meetings looking at a screen											√															
H16	Lack of consultants' feedbacks on subcontractors' model coordination											√															
H17	Few benefits from BIM go to designers while most to contractors and owners												√														
H18	Lack of legal support from authorities																		√	√		√					√
H19	Lack of owner request or initiative to adopt BIM		√																			√	√				√
H20	Decision-making depending on relationships between project stakeholders		√																	√							
H21	Owners set minimal risk and minimum first cost as crucial selection criteria									√													√				
H22	Poor knowledge of using OSM and assessing its benefits										√																
H23	Requiring higher onsite skills to deal with low tolerance OSM interfaces										√																
H24	OSM relies on suppliers to train contractors to install correctly										√																
H25	Owners' desire for particular structures or finishes when considering OSM										√																
H26	Market protection from traditional suppliers/manufacturers and limited OSM expertise										√																
H27	Contractual relationships among stakeholders and need for new frameworks	√		√		√	√	√						√						√	√		√	√	√	√	
H28	Traditional contracts protect individualism rather than best-for-project thinking	√	√											√													
H29	Lack of effective data interoperability between project stakeholders		√		√			√	√			√	√	√			√				√					√	√
H30	Owners cannot receive low-price bids if requiring three-dimensional models												√														
H31	Firms' unwillingness to invest in training due to initial cost and productivity loss									√			√						√		√						
H32	Assignment of responsibility/risk to constant updating for broadly accessible BIM information									√			√														
H33	Lack of standard contracts to deal with responsibility/risk assignment and BIM ownership							√				√	√							√						√	
H34	BIM model issues (such as ownership and management)			√				√					√													√	
H35	Poor understanding of OSM process and its associated costs										√																
H36	OSM requires design to be fixed early using BIM										√							√									
H37	Seeing design fees of OSM as more expensive than traditional process										√																

Table 1. *Cont.*

Code	**Hindrances to BIM Implementation**	**References**																									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
H38	Difficulty in logistics and stock management of OSM										√														√		
H39	Unclear legislations and qualifications for precasters and inadequate codes for OSM varieties										√																
H40	Interpretations resulted from unclear contract documents																			√							
H41	Using monetary incentive for team collaboration results in blaming rather than resolving issues																			√							
H42	Costly investment in BIM hardware and software solutions			√	√					√	√								√		√	√	√				√
H43	Interoperability issues such as software selection and insufficient standards			√									√				√			√							√
H44	Need for increasingly specialized software for specialized functions												√						√			√					√
H45	Difficulty in multi-discipline and construction-level integration												√								√						
H46	Technical needs for multiuser model access in multi-discipline integration							√					√						√								
H47	Firms cannot make most use of Industrial Foundation Classes (IFC) and use proprietary formats												√										√				√

Note: 1 = American Institute of Architects and American Institute of Architects, California Council (AIA and AIACC) [16]; 2 = AIA and AIACC [17]; 3 = Aranda-Mena et al. [18]; 4 = Arayici et al. [19]; 5 = Autodesk [20]; 6 = Autodesk [21]; 7 = Azhar et al. [22]; 8 = Bernstein and Pittman [23]; 9 = Bernstein et al. [24]; 10 = Blismas and Wakefield [25]; 11 = Chelson [6]; 12 = Eastman et al. [26]; 13 = Fischer et al. [13]; 14 = Fischer [27]; 15 = Fox and Hietanen [28]; 16 = Gao and Fischer [29]; 17 = Gibb and Isack [30]; 18 = Juan et al. [9]; 19 = Kent and Becerik-Gerber [31]; 20 = Khosrowshahi and Arayici [7]; 21 = Kiani et al. [32]; 22 = Kunz and Fischer [33]; 23 = McFarlane and Stehle [34]; 24 = Ross et al. [35]; 25 = Sattineni and Mead [36]; 26 = Zahrizan et al. [37].

However, instead of studying all the 47 hindrances holistically, each of the 26 previous studies tended to only explore part of the hindrances. More importantly, little is known about how the hindrances may influence BIM implementation in the Singapore context. For example, Khosrowshahi and Arayici [7] identified the hindrances to BIM implementation at high maturity levels for the contractors in the United Kingdom, but failed to investigate the factors for other roles in the construction value chain. Zahrizan et al. [37] identified the factors hindering BIM diffusion in the Malaysian construction industry with respects to culture, people, technology, and government's recognition, but rarely studied BIM work processes and the key role of the local government regarding its active participation to specify BIM use and its financial support such as defraying a proportion of training and consultancy costs. Juan et al. [9] explored the hindrances affecting the Taiwan construction industry to be ready to adopt BIM, but was limited to the architectural firms. Although Oo [38] investigated some hindrances to move towards the new work processes in Singapore, its main focus was on the architectural discipline and the identification of driving factors rather than the hindrances. This present study would fill this gap by identifying the critical hindrances that significantly influenced BIM implementation in Singapore and analyzing the influence mechanisms among these hindrances, extending the relevant literature.

3. Method and Data Presentation

Figure 1 presents the research methodology. The literature search indicated that the use of questionnaire survey technique was appropriate in collecting professional views on critical factors in previous construction management studies [39,40]. Thus, a questionnaire survey was performed to investigate the 47 hindrances' influence on BIM implementation in the Singapore construction industry. The questionnaire was designed on the basis of the above literature review and refined according to the comments from five BIM experts who were interviewed face-to-face in a pilot study. All the experts, who were working for large firms and possessed at least three years' experience in implementing BIM in Singapore, were selected to pretest the questionnaire. The final questionnaire collected general information of respondents, and requested them to rate each hindrance's influence on BIM implementation. The ratings should be made regarding one of their ongoing or recently-completed building projects. A five-point Likert scale (1 = very insignificant; 2 = insignificant; 3 = neutral; 4 = significant; 5 = very significant) was used. Miller [41] found that a human usually can hold "seven plus or minus two" objects in working memory. In a one-dimensional absolute-judgment task, a person is presented with a number of stimuli and responds to each stimulus with a corresponding response. Performance is nearly perfect up to five or six stimuli but declines as the number is increased. Thus, to make it convenient for the respondents to judge, the five-point scale was adopted in this paper, which has been widely used in previous studies related to construction management [42–45].

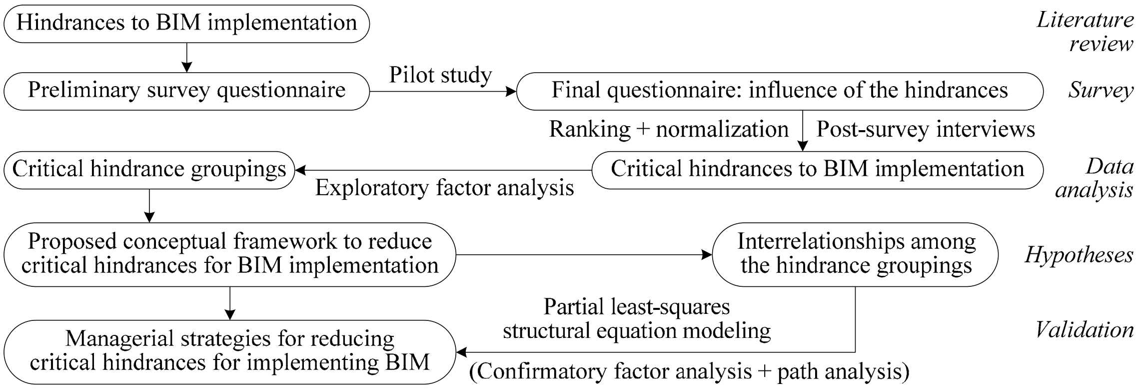

Figure 1. Research methodology.

The population was comprised of all the organizations that were operating in the Singapore construction industry. The sampling frame consisted of the BCA, the Urban Redevelopment Authority, the Housing and Development Board (HDB), the building developers registered with the Real Estate Developers' Association of Singapore, the architectural consultancy firms registered with the Singapore Institute of Architects, the structural and MEP consultancy firms registered with the Association of Consulting Engineers Singapore, the contractors registered with the BCA, and the facility management firms registered with the Association of Property and Facility Managers. Among the contractors, it was considered logical to select only the large ones because they tend to have adequate resources for BIM implementation. Since there was a sampling frame, a probability sample should be adopted. Simple random sampling was used in the data collection because each organization was as likely to be drawn as the others. Finally, the questionnaires were sent to 692 organizations via emails or handed to them personally. It was considered appropriate that 87 completed questionnaires were received based on willingness to participate in this study [46]. The response rate of 12.57% was acceptable because it fell within the general response rate of 10–15% for Singapore surveys [39]. The profile of the 87 respondents is shown in Table 2. The 14 organizations in the "others" category included the BCA, the HDB, developers, precasters, and other consultancy firms such as multidisciplinary consultancy firms and a BIM consultancy firm. Thus, the responding organizations could represent major BIM implementers in the local construction value chain. Moreover, because BIM implementation had been mandated in Singapore since July 2015, it was reasonable that under half (42.53%) had over three years' BIM implementation experience.

Table 2. Profile of respondents and their organizations.

Characteristics	Categorization	N	%	Characteristics	Categorization	N	%
	Respondents				*Organizations*		
Discipline	Government agent	2	2.3	Main business	Architectural firm	18	20.7
	Developer	5	5.7		Structural engineering firm	6	6.9
	Architect	21	24.1		MEP engineering firm	13	14.9
	Structural designer	9	10.3		General construction firm	30	34.5
	MEP designer	9	10.3		Trade construction firm	3	3.4
	General contractor	28	32.2		Facility management firm	3	3.4
	Subcontractor	6	6.9		Others	14	16.1
	Supplier/Manufacturer	2	2.3				
	Facility manager	5	5.7				
Work experience	5–10 years	39	44.8	Years of BIM implementation	0	9	10.3
	11–15 years	10	11.5		1–3	41	47.1
	16–20 years	8	9.2		4–5	22	25.3
	21–25 years	9	10.3		6–10	13	14.9
	>25 years	21	24.1		>10	2	2.3

In addition, after the survey was performed, five BIM experts who had participated in the survey and were experienced in BIM implementation in the Singapore construction industry were contacted for personal interviews. During which, they were presented with the results obtained from the survey. They commented that the findings were in agreement with what they expected. These professionals were also invited to explain the results which would be discussed in the following sections.

4. Results and Discussion

4.1. Ranking of Hindrances to BIM Implementation

The Cronbach's alpha coefficient was 0.974, much higher than the threshold of 0.70 [47]. Thus, the data collected in this study had high reliability. The ranking of the 47 hindrances to BIM implementation in the Singapore construction industry was shown in Table 3. A few methods were adopted to identify the critical factors when Likert scale data were collected in previous studies, but none of them was established as a standardized method. The threshold value was also not determined. Magal et al. [48] recognized all the factors that were deemed critical in previous studies. No cutoff point was established in this said study. Shen and Liu [49] set a cutoff value of 4 because it represented "significant" in the five-point scale in this study. Nitithamyong and Skibniewski [50] used the middle value of the Likert scale as the threshold. Xu et al. [51] and Zhao et al. [43] chose the factors with normalized values of 0.50 and above as the critical factors. Won et al. [52] selected the factors with mean values exceeding the total mean value of the data as the critical factors.

Table 3. Ranking of hindrances to BIM implementation.

Code	Mean	Rank	Normalization *	Code	Mean	Rank	Normalization *	Code	Mean	Rank	Normalization *
H01	3.644	8	0.782	H17	3.161	46	0.018	H33	3.540	13	0.618
H02	3.494	20	0.545	H18	3.184	45	0.055	H34	3.529	14	0.600
H03	3.241	41	0.145	H19	3.414	26	0.418	H35	3.506	19	0.564
H04	3.690	3	0.855	H20	3.264	40	0.182	H36	3.494	20	0.545
H05	3.678	5	0.836	H21	3.345	34	0.309	H37	3.448	22	0.473
H06	3.414	26	0.418	H22	3.333	35	0.291	H38	3.402	30	0.400
H07	3.690	3	0.855	H23	3.402	30	0.400	H39	3.241	41	0.145
H08	3.368	33	0.345	H24	3.241	41	0.145	H40	3.391	32	0.382
H09	3.529	14	0.600	H25	3.149	47	0.000	H41	3.218	44	0.109
H10	3.310	37	0.255	H26	3.414	26	0.418	H42	3.667	6	0.818
H11	3.414	26	0.418	H27	3.713	2	0.891	H43	3.517	17	0.582
H12	3.782	1	1.000	H28	3.655	7	0.800	H44	3.425	23	0.436
H13	3.310	37	0.255	H29	3.425	23	0.436	H45	3.529	14	0.600
H14	3.621	10	0.745	H30	3.299	39	0.236	H46	3.644	8	0.782
H15	3.425	23	0.436	H31	3.621	10	0.745	H47	3.563	12	0.655
H16	3.322	36	0.273	H32	3.517	17	0.582	–	–	–	–

Note: Total mean value = 3.451. * Normalized value = (mean − minimum mean)/(maximum mean − minimum mean). Hindrances with normalized values less than 0.50 would not be considered as critical hindrances.

In this study, the mean scores of the 47 hindrances to BIM implementation in Singapore were normalized, as shown in Table 3. The hindrances that obtained normalized values of 0.50 or above were recognized as critical ones. The results implied that out of the 47 factors, 21 were critical in hindering BIM implementation in building projects in Singapore. Besides, all the mean scores (3.494 and above) of the 21 critical hindrances exceeded 3.451 which was the total mean value of all the 47 hindrances. However, the 22nd hindrance (H37) obtained a mean score (3.448) below this total mean value. Thus, the results of applying the "comparing mean scores with the total mean value" method supported the normalization method which was adopted in this study. Among the critical hindrances, "need for all key stakeholders to be on board to exchange information" (H12) was ranked top. This result echoed El Asmar et al. [53], which found that early involvement of the contractors to share expertise and information upfront is key to creating optimal design models early in a building project. In the post-survey interviews, the experts mentioned that in Singapore downstream parties were generally not involved upfront, and also suggested that BIM implementation would be efficient if the entire team (the owner, the designers, the contractors, and the facility manager) could actively participate from the beginning of the design stage. Indeed, lots of details need to be developed by specialist contractors who, however, usually used the traditional approach in design detailing. Based on the ranking of the critical hindrances in Table 3, the practitioners would have a clear knowledge of the areas of activities of BIM implementation deserving more attention, and establish resources allocation priorities accordingly.

4.2. Underlying Hindrance Groupings

In this study, exploratory factor analysis (EFA) was conducted to obtain a manageable set of hindrance groupings. Such groupings should well represent the 21 critical hindrances to BIM implementation. The appropriateness of performing EFA with the data collected in this study was assessed. The Kaiser-Meyer-Olkin value was 0.911, suggesting that the critical hindrances had a high common variance. The value of the test statistic (chi-square) for Bartlett's sphericity was 1265.756, with a p-value of 0.000, indicating that sufficient correlations existed among the hindrances to proceed with EFA. Thus, the data were appropriate for EFA. The EFA process was terminated after meeting its widely-used threshold values: (1) 0.60 for cumulative percentage of variance (CPV), indicating that all the extracted hindrance groupings together should explain at least 60% of the variance of all the critical hindrances; (2) 0.50 for communalities of all the critical hindrances; and (3) ±0.40 for factor loadings of all the hindrances to be significant [54,55]. The communality of a critical hindrance presents the total amount of variance that this critical hindrance shares with the rest critical hindrances, and the factor loadings of a critical hindrance refer to the correlation between this hindrance and the hindrance groupings.

EFA was conducted using the software IBM SPSS Statistics 20 and the results indicated a well-defined three-factor structure, as shown in Table 4. The CPV explained from the three extracted groupings was 64.070%. Additionally, all the factor loadings of the hindrances were above 0.40 and the communalities above 0.50, indicating a robust EFA. The hindrance groupings were named as "lack of collaboration and model integration", "lack of continuous involvement and capabilities", and "lack of executive vision and training", respectively.

Table 4. Results of exploratory factor analysis (EFA) on critical hindrances to BIM implementation.

Code	**Hindrances to BIM Implementation**	**Communality**	**Hindrance Grouping**		
			1	**2**	**3**
	Grouping 1: Lack of Collaboration and Model Integration (LCMI)				
H34	BIM model issues (such as ownership and management)	0.757	0.948	—	—
H09	Lack of sufficient evidence to warrant BIM use	0.515	0.707	—	—
H36	OSM requires design to be fixed early using BIM	0.701	0.707	—	—
H45	Difficulty in multi-discipline and construction-level integration	0.512	0.657	—	—
H35	Poor understanding of OSM process and its associated costs	0.712	0.646	—	—
H46	Technical needs for multiuser model access in multi-discipline integration	0.587	0.545	—	—
H33	Lack of standard contracts to deal with responsibility/risk assignment and BIM ownership	0.727	0.524	—	—
H27	Contractual relationships among stakeholders and need for new frameworks	0.649	0.516	—	—
H28	Traditional contracts protect individualism rather than best-for-project thinking	0.574	0.463	—	—
H43	Interoperability issues such as software selection and insufficient standards	0.594	0.431	—	—
	Grouping 2: Lack of Continuous Involvement and Capabilities (LCIC)				
H12	Need for all key stakeholders to be on board to exchange information	0.673	—	0.780	—
H07	Entrenchment in 2D drafting and unfamiliarity to use BIM	0.712	—	0.760	—
H14	BIM operators lacking field knowledge	0.676	—	0.739	—
H42	Costly investment in BIM hardware and software solutions	0.630	—	0.652	—
H32	Assignment of responsibility/risk to constant updating for broadly accessible BIM information	0.568	—	0.600	—
H31	Firms' unwillingness to invest in training due to initial cost and productivity loss	0.555	—	0.557	—

Table 4. *Cont.*

Code	Hindrances to BIM Implementation	Communality	Hindrance Grouping		
			1	**2**	**3**
	Groping 3: Lack of Executive Vision and Training (LEVT)				
H01	Executives failing to recognize the value of BIM-based processes and needing training	0.758	—	—	0.814
H04	Lack of skilled employees and need for training them on BIM and OSM	0.725	—	—	0.770
H02	Concerns over or uninterested in sharing liabilities and financial rewards	0.537	—	—	0.654
H05	Industry's conservativeness, fear of the unknown, and resistance to change comfortable routines	0.699	—	—	0.620
H47	Firms cannot make most use of IFC and use proprietary formats	0.596	—	—	0.554
	Eigenvalue		11.142	1.256	1.057
	Variance (%)		53.059	5.979	5.033
	CPV (%)		53.059	59.038	64.070

4.2.1. Lack of Collaboration and Model Integration

This critical hindrance grouping accounted for about 53% of the total variance of the 21 critical hindrances and included 10 hindrances. All the 10 hindrances could be related to the collaboration and model integration of BIM implementation in the building project. The widely-accepted definition of BIM proposed by the National Institute of Building Sciences (NIBS) stated that "a basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder" [56]. The hindrance with the highest factor loading was "BIM model issues (such as ownership and management)" (H34). Even BIM technology has been used by the designers and possibly the contractors, the technological process has been suffering from physical and information fragmentation in different stages of the project. The creation, integration, and use of digital design models would potentially raise many liability issues because little collaboration was built within the typical project team [12], such as the anxiety about providing wrong information by the designers [26] and about offering advice by the contractors. The professionals involved in the post-survey interviews observed that due to potential liabilities, the team members do not fully exchange data. For instance, as the principal role in the Singapore context, the architect may change the design frequently without informing other designers and the contractors, hindering the creation of a composite design and construction model, whereby, all the parties can work on it. Such issues urged the roles and responsibilities in the model management process to be established in standard contracts. Even so, the liabilities may not be solved without trust-based collaboration and proper risk sharing among the key stakeholders. As mentioned earlier, the building contracts in Singapore are still developed on the basis of the adversarial contractual system, leading to individualism and isolated working environment. Thus, three critical hindrances (H27, H28, and H33) that described the fragmented contractual relationships were related to the trust-based collaboration needed for BIM implementation among the team.

"Lack of sufficient evidence to warrant BIM use" (H09) obtained the second highest loading. The post-survey interviewees highlighted that due to the lack of project-wide collaboration, BIM implementation appeared to remain in an early stage in Singapore; it is unrealistic to expect that in the short term, the project team can fully reap the benefits that BIM implementation brings. The lonely BIM adoption among the major stakeholders could also be attributed to the poor understanding of collaboration and data integration. Thus, "poor understanding of off-site manufacture (OSM) process and its associated costs" (H35) was also included in this grouping.

To implement BIM along with OSM, the digital models should be fixed early and fit for off-site fabrication and on-site assembly (H36), because any changes would be costly after the fabrication commences [25]. However, design environments were difficult for multi-disciplinary integration at the construction level (H45) [7] due to "interoperability issues such as software selection and insufficient standards" (H43) [37]. In addition, the multi-discipline model integration also requires "technical expertise, protocols, and infrastructure for multiuser model access" (H46) [9,22]. The post-survey interviewees also suggested that in Singapore different parties tended to use various software or software versions, creating a difficulty in integrating digital models across disciplines.

4.2.2. Lack of Continuous Involvement and Capabilities

This grouping explained about 6% of the total information of the 21 critical hindrances and included six of them. Among these, two significant hindrances (H12 and H32) were closely related to the continuous involvement of the major stakeholders. "Need for all key stakeholders to be on board to exchange information" (H12) obtained the highest factor loading. The early and continuous involvement of the owner and the key designers and contractors from early design through project completion has been advocated for BIM implementation [53]. This would pave the way for the project-wide collaboration in the subsequent stages of the project. Another high-loading hindrance was "assignment of responsibility/risk to constant updating for broadly accessible BIM information" (H32). In the collaborative project team, the processes of creating digital models in the design stage and using, updating, and managing the models in the construction and operations and maintenance stages would assign liabilities to different participants as the project proceeds.

Four significant hindrances (H07, H14, H31, and H42) were associated with relevant capabilities that are necessary for successful implementation of BIM. As recommended by the BIM Project Execution Planning Guide, the capabilities of each party can be defined as resources (personnel, tools and their training, and information technology support), competencies, and experience [57]. The second highest factor loading hindrance "entrenchment in two-dimensional (2D) drafting and unfamiliarity to use BIM" (H07) revealed that in Singapore many firms lacked competencies and experience to use BIM [32]. For example, the upfront BIM operators tend to lack enough field knowledge to know what they are modeling and its constraint in the actual construction (H14); consequently, the digital models may not be developed correctly. In addition, capital investment should also be included in the resources [42]. Thus, "firms' unwillingness to invest in training" (H31) and "costly investment in BIM hardware and software solutions" (H42) could also be related to the capabilities of the participants. Compared with the biggest firms in Singapore that can make most use of BIM, a huge number of SMEs face adoption challenges such as lacking the capital investment to build up BIM competencies [8]. The experts involved in the post-survey interviews also stressed the importance of the BIM implementers' financial capabilities, especially for the SMEs and foreign firms based in Singapore.

4.2.3. Lack of Executive Vision and Training

This hindrance grouping represented about 5% of the total variance and included five hindrances. "Executives failing to recognize the value of BIM-based processes and needing training" (H01), "concerns over or uninterested in sharing liabilities and financial rewards" (H02), and "industry's conservativeness, fear of the unknown, and resistance to change comfortable routines" (H05) were associated with the lack of executive vision among firms, resulting in negative mindsets and behaviors. In particular, H01 achieved the highest factor loading, which described that the executives may not commit on the new working method. In the Singapore context, they tended not to see BIM implementation as mainstream activity but as additional workload. This value proposition established the conservative and unsupportive culture of most firms (H05), hindering BIM implementation in Singapore. This finding was consistent with Khosrowshahi and Arayici [7] which found inadequate marginal utility to be realized by using BIM. Another high-loading hindrance was H02. It was unrealistic to expect the major stakeholders to be willing to share both liabilities and rewards, although such sharing would help build transparency, trust, and collaboration within the team.

In addition to the need for training the executives (H01), "lack of skilled employees and need for training them on BIM and OSM" (H04) was also related to training. Very often the employees tended to be reluctant to adopt the new technology and participate in the new workflow [37], while the post-survey interviewees highlighted the concern about the executives' willingness to train their employees in Singapore. One example of such reluctance is that many firms could not take advantage of the commonly-used data exchange format (Industrial Foundation Classes, IFC), and still use proprietary formats (H47) which would not enable smooth data exchange with other parties.

4.3. Conceptual Framework and Validation

The conceptual framework was constructed to depict the critical hindrances to BIM implementation and the hypothetical influence paths among the hindrances groupings (Figure 2). Three hypotheses were involved in the framework:

Hypothesis 1. *Lack of executive vision and training positively contributes to lack of continuous involvement and capabilities.*

Hypothesis 2. *Lack of continuous involvement and capabilities positively contributes to lack of collaboration and model integration; and*

Hypothesis 3. *Lack of executive vision and training positively contributes to lack of collaboration and model integration.*

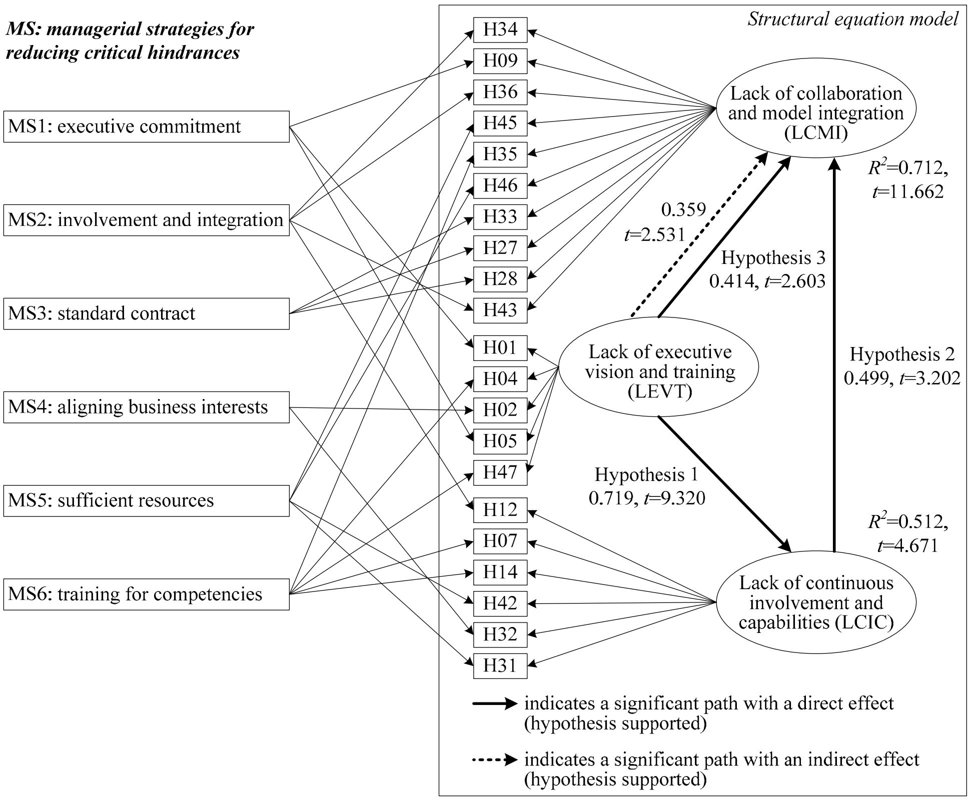

Figure 2. Conceptual framework to reduce critical hindrances for BIM implementation.

Structural equation modeling (SEM) has been recognized as a good technique in terms of relationship analysis among variables [42,58]. A SEM model includes structural and measurement models. The measurement model presents the relationships between measured variables (the critical hindrances) and latent variables or constructs (the hindrance groupings), and the structural one specifies the relationships among the three hindrance groupings. Two types of SEM are commonly-used: covariance-based SEM (CB-SEM) and partial least-squares structural equation modeling (PLS-SEM). Compared with CB-SEM, PLS-SEM: (1) ensures a good statistical power when the sample size is small [59]; (2) can deal with non-normal data sets [60,61]; and (3) can identify key driving constructs [62]. In this study, PLS-SEM was used as the sample size (87) tended to be inadequate for CB-SEM, and this study primarily aimed to investigate the intergroup relationships and driving hindrance groupings. In addition, this approach was widely used in project management research conducted both in Singapore [42,58] and globally [63,64].

SEM can efficiently fit the data and the SEM model. This was because confirmatory factor analysis (CFA) and path modeling analysis were simultaneously conducted. CFA was performed to test whether the 21 critical hindrances could represent well the three hindrance groupings. Furthermore, to check whether the path coefficients (related to hypotheses) were statistically significant, the bootstrapping technique [65] was applied in this study. Hair et al. [62] suggested that 5000 bootstrap subsamples should be used, which were randomly drawn from the 87 data sets.

The PLS-SEM analysis results required the following interpretations: (1) reliability and validity testing; and (2) relationships assessment according to the path coefficients obtained from the analysis. The reliability and validity of the measurement model should be assessed using the indicators and their thresholds: (1) 0.70 for the Cronbach's alpha coefficients [47]; (2) 0.55 for the factor loadings of the measured variables [66]; (3) 0.50 for the average variances extracted (AVEs) of the latent variables [67]; and (4) 0.70 for composite reliability (CR) scores [62]. In addition, discriminant validity should be assessed to test a construct's distinction from others. Two traditional methods were widely used in previous studies: (1) the Fornell-Larcker criterion that the square root of the AVE of each construct should exceed the correlation between this construct and any other constructs [67]; and (2) the cross-loading assessment that a measured variable's factor loading on its respective construct should be greater than its cross-loadings [68].

However, Henseler et al. [69] found that the two traditional assessment methods are not reliable in terms of detecting the lack of discriminant validity in PLS-SEM. This is because such methods would result in an unacceptably low sensitivity, especially in the situation that the AVE is low. Instead, this said study proposed that heterotrait-monotrait ratio of correlations (HTMT) should be a new approach. The HTMT is the average of the heterotrait-heteromethod correlations (the correlations of the measured variables across the constructs that measure different phenomena). The HTMT can be used in two ways: (1) being a criterion; or (2) being a statistical test. If the value of the HTMT is higher than a predefined cutoff point (0.85 or 0.90), this suggests that the SEM model lacks discriminant validity. Henseler et al. [69] suggested that 0.90 is more suitable (referred to $\text{HTMT}_{0.90}$) when the sample size is around 100 and the AVE values are not high. Alternatively, the HTMT can form the foundation of a statistical discriminant validity test. The bootstrapping procedure allows that confidence intervals for the HTMT can be constructed to test the null hypothesis (H0: $\text{HTMT} \geq 1.0$) against the alternative hypothesis (H1: $\text{HTMT} < 1.0$). If 1.0 (held in the H0) falls within a confidence interval, it can be concluded that the SEM model lacks sufficient discriminant validity; conversely, if 1.0 does not fall within the range of the interval, one may conclude that two constructs are empirically distinct.

Tables 5 and 6 show the results of CFA which was conducted using the software SmartPLS 3. As indicated in Table 5, all the factor loadings were greater than 0.55, which were significant at the 0.05 level (critical t-value = 1.96). Besides, all the values of the Cronbach's alpha, AVE, and CR exceeded their respective cutoff values. Meanwhile, it could be seen from Table 6 that the p-values for the HTMT tests among the three hindrance groupings were below 0.05, and that the HTMT values were smaller than 0.90. Therefore, both the HTMT test and the $\text{HTMT}_{0.90}$ criterion indicated that the SEM model met the requirements of the discriminant validity. Thus, the measurement model was reliable and valid for the structural path modeling. In addition, the absolute model fit statistics that were available in the PLS-SEM outputs were acceptable. Standardized root mean residual was 0.066, below 0.10 which, as recommended by Hair et al. [55], was the cutoff point, and the Chi-Square value (320.029) was large. Furthermore, the bootstrapping results in Figure 2 suggested that all the path coefficients (0.719, 0.449, and 0.414, respectively) for the three hypotheses were positive, with the p-values of 0.000. The coefficients of determination (R^2) for lack of collaboration and model integration and lack of continuous involvement and capabilities were 0.712 (with t-value at 11.662 and p-value at 0.000) and 0.512 (with t-value at 4.671 and p-value at 0.000), respectively. Hence, these statistics validated the conceptual framework (Figure 2). The subsequent sections will discuss this framework's rationale.

Table 5. Validity and reliability evaluation of measurement model.

Grouping	Hindrance Code	Factor Loading	p-Value	AVE	Cronbach's Alpha	CR
LCMI	H34	0.813	0.000 *	0.618	0.931	0.942
	H09	0.680	0.000 *			
	H36	0.848	0.000 *			
	H45	0.706	0.000 *			
	H35	0.849	0.000 *			
	H46	0.766	0.000 *			
	H33	0.850	0.000 *			
	H27	0.798	0.000 *			
	H28	0.770	0.000 *			
	H43	0.762	0.000 *			
LCIC	H12	0.798	0.000 *	0.622	0.878	0.908
	H07	0.825	0.000 *			
	H14	0.833	0.000 *			
	H42	0.803	0.000 *			
	H32	0.711	0.000 *			
	H31	0.757	0.000 *			
LEVT	H01	0.866	0.000 *	0.624	0.848	0.892
	H04	0.847	0.000 *			
	H02	0.756	0.000 *			
	H05	0.732	0.000 *			
	H47	0.739	0.000 *			

Note: LCMI = Lack of collaboration and model integration; LCIC = Lack of continuous involvement and capabilities; LEVT = Lack of executive vision and training. * The loading was significant at the 0.05 level (two-tailed).

Table 6. Discriminant validity of hindrance groupings.

HTMT	Original Sample	Sample Mean	t-Value	p-Value
LEVT→LCIC	0.829	0.831	9.797	0.000
LCIC→LCMI	0.879	0.880	10.937	0.000
LEVT→LCMI	0.866	0.866	19.653	0.000

Note: LCMI = Lack of collaboration and model integration; LCIC = Lack of continuous involvement and capabilities; LEVT = Lack of executive vision and training.

4.3.1. Hypothesis 1

This hypothesis that the lack of executive vision and training positively contributes to the lack of continuous involvement and capabilities was supported by the PLS-SEM analysis results. BIM implementation requires not only sufficient resources such as costly infrastructure, but also competent and experienced personnel that can be trained or engaged from the market [57]. Insufficiency of any kind of the capabilities would hinder BIM implementation. This tallies with the post-survey interviews that in practice the practitioners in Singapore should be provided with training and education programs as well as technical support for BIM adoption. This is because they may not be knowledgeable and experienced about a higher level of BIM implementation. In most cases, the executives can determine the allocation of the capital investment to purchase and upgrade the infrastructure, and the sponsorship of training programs [42]. However, the post-survey interviewees also reported that the management of many firms in Singapore tend to keep things under control as they previously did, because compared with the relatively straightforward implementation cost, the benefits of BIM implementation tend not to be so concrete. Thus, without the executive support (H01), training sessions could not be arranged (H04 and H47), and a higher resource allocation priority could not be obtained, leading to the lack of the capabilities among the major stakeholders (H07, H14, H31, and H42).

In addition, the continuous involvement of the major stakeholders is crucial to BIM implementation [53]. Nonetheless, the professionals involved in the post-survey interviews pointed out that in the Singapore context, the downstream parties are often vary of providing professional advice in the design modeling due to potential liabilities, and the upfront parties are cautious about providing design information in the later stages. The stakeholders are unaware of or unwilling to internally waive the liabilities in the project team (H02), and tend to be reluctant to change their customized ways of working and blaming (H05). Nothing is more critical to BIM implementation than a supportive project culture, which depends largely on the project leadership team. Thus, the lack of executive vision and mission would hinder the continuous involvement of the key stakeholders (H12) and the constant model updates (H32).

4.3.2. Hypothesis 2

The hypothesis that the lack of continuous involvement and capabilities positively contributes to the lack of collaboration and model integration was supported. Collaboration is the precondition to BIM implementation because the major stakeholders need to communicate and exchange information with others to complete their scopes of work. The early and active involvement of the downstream stakeholders is critical to building trust and sharing knowledge with others, which facilitates the project-wide collaboration needed for multidisciplinary model integration [53]. Thus, the lack of continuous stakeholder participation (H12) prevents the team from working collaboratively (H27). On the other hand, the collaboration between the design team and the construction team will not intrinsically lead to a blending of disciplines [16]. In the Singapore context, even in the construction phase, there was generally insufficient collaboration between the design consultants and the contractors. The communication between the designers and site managers was weak. Under the current contractual framework of Singapore, the relationships tend to be adversarial. The constant updating and management of broadly accessible digital information would potentially subject the designers and the contractors to increased liabilities as the project proceeds [26]. Therefore, the lack of proper assignment of responsibilities and allocation of risks (H32) would point to the need for collective risk management and model management (H28, H33, and H34). In addition, plenty of resources upfront are also needed to create and fix the model early (H36). Thus, the lack of capital resources (H31 and H42) creates a difficulty in the model integration (H43, H45, and H46). Moreover, the staff may unconsciously evaluate whether their knowledge, skills, and experience are good enough to enable them to be involved in the BIM-based work practices. If they regard themselves as less competent and experienced individuals in working with BIM (H07 and H14) or have not yet learnt about similar success stories, they would not actively use BIM (H09). Because of human nature, the negative mindset and passive behavior may in turn keep their inertia to continuously learn about relevant processes (H35). This would result in fragmented or discipline-specific BIM implementation, rather than project-wide collaboration and multidisciplinary design modeling and integration. In the post-survey interviews, the experts also emphasized the importance of building a high level of capabilities in the project team, as experienced and skilled personnel that can lead BIM modeling teams are still lacking in the current market in Singapore.

4.3.3. Hypothesis 3

This hypothesis that the lack of the executive vision and training positively contributes to the lack of collaboration and model integration was also supported. It is worth noting that when faced with change, people would possibly react in their accustomed and comfortable ways as well as be biased against the reality [70]. The executives may be unwilling to change (H01) when they have long been psychologically entrenched in the traditional drafting practices [7] and cannot see the value of BIM in increasing inter-organizational collaboration and improving work efficiency [1]. It has been verified in numerical studies and projects that BIM implementation can facilitate information integration across the lifecycle, and close collaboration among the participants [71,72]. People may still bias or ignore the reality (H09) and be reluctant to learn the new working method (H35). The post-survey interviewees also highlighted that although the executives of many firms in Singapore change to use 3D tools, the leadership style appeals to continue to keep a 2D mindset (H05). Additionally, without the pre-agreed liabilities and rewards sharing arrangements (H02), the downstream parties, if involved upfront, would work financially at risk (H28 and H33) and lack motivation and enthusiasm to work collaboratively with others (H27). Some stakeholders may take advantage of information asymmetry at the cost of other stakeholders. They think that the efforts spent in collaborating with others toward a "win–win situation" would discourage them from optimizing the benefits they could have obtained [8]. Consequently, the project-wide transparency and collaboration cannot be built; the construction and operations expertise cannot be incorporated into the upfront design modeling and multi-disciplinary coordination (H36), and potential liability issues would inevitably be raised in the dynamic model management in different phases (H34). Furthermore, if the IFC data exchange format is not used by all the parties (H47), the cross-enterprise design integration would be difficult (H43 and H45). Besides the interoperability standards and guidelines, local experimentation and continuous learning play a central role in BIM implementation [1]. Thus, the lack of training programs (H04) hinders the continuous improvement of the skill sets (H46) required by the model integration and management throughout the project.

4.4. Managerial Strategies

To reduce the 21 critical hindrances to BIM implementation, six managerial strategies (Figure 2) have been proposed based on the data analysis results. These strategies can not only help the leadership teams of building projects in Singapore to reduce possible hindrances in their BIM implementation practices, but also provide insights for the local government to refer to when rolling out new regulations related to BIM implementation.

Executive commitment (MS1). The planning, design, construction, and operations and maintenance processes have been increasingly relying on the information models [26]. The executives of the primary project participants should recognize the inevitable change to adapt to the information-oriented project delivery and continually commit on BIM diffusion which will probably be stunted if the participants cannot implement their part of BIM (H01 and H09). With the tone of changing at the top, the employees who carry out day-to-day work on the shop floor must change their passive mindsets and behaviors (H05). Moreover, the willingness of implementing BIM is also affected by the Singapore government's policies, competitor motivation, financial incentives, and technical support [9]. The post-survey interviewees recommended that in addition to the existing government mandate and support in Singapore, incentives such as additional GFA for the owner and a series of objective performance milestones for the designers and contractors need to be formulated.

Involvement and integration (MS2). The participants should be early involved and physically collocated to build trust and collaboration as the BIM adoption in Singapore tended to be firm-based. Specifically, the key contractors, manufacturers, and facility management team downstream can contribute their knowledge and experience in the digital design modeling upfront (H12), which enables to fix the design early and build constructability in the design (H36). Otherwise, problems may occur in the subsequent stages where design changes would be costly. The close collaboration and frequent communication upfront may help address the interoperability issues such as by using predetermined software or software versions and interoperability standards (H43). This can align fragmented BIM adoptions in different participants by integrating their discipline-specific models. Furthermore, these preparatory work would also serve as the basis of collaboratively managing the digital model in the later stages (H34).

Standard contract (MS3). An updated version of the BIM Particular Conditions in Singapore should be developed as the standard contract (H33) to incorporate the BIM work processes into the local contractual framework because the current version was partly completed [73]. As mentioned earlier, currently, the design processes may not be collaborative because the design team and the construction team in Singapore tend to individually create different models. The new multi-party contract should be set by the local government and incentivize the participants to openly share data, which helps improve the contractual relationships (H27) among these primary participants because they can act as a collaborative team (H28). Besides, the flow of information can also be ensured in the model management. In addition, the owner should set relevant contractual requirements on BIM when building the project team. Otherwise, the service providers' motivation and willingness of implementing BIM in practice would be affected [33].

Aligning business interests (MS4). Sharing business interests should be agreed on by all the key stakeholders (H02) in the contract. This will build the necessary trust and the continuous collaboration among the participants [53]. All the participants should have a clear understanding of the opportunities, risks, and responsibilities when incorporating BIM work practices into the project workflow in Singapore. Sharing risks (H32) forces them to be responsible for the project rather than shifting risks or blaming their partners, whereas sharing rewards drives the team to think and behave in a best-for-project manner. These avoid the downstream parties from working at risk upfront. Furthermore, the individual corporate goals are bound with the project outcomes. It is worth noting that individual parties can leverage BIM only when it is successfully implemented in the project.

Sufficient resources (MS5). The management should allocate sufficient resources which are not limited to the skilled personnel, tools (H45 and H46), and information technology support, but also the capital investment (H31 and H42). For example, BIM software have been constantly improving to enable the cross-discipline integration at the construction level. The post-survey interviewees, however, reported that the hardware in many firms in Singapore cannot support the advanced software applications efficiently. In addition to the local government's subsidies, the primary participants should also invest in improving their infrastructure. It should be noted that BIM implementation may span many years; those who achieve enhanced BIM implementation will gain a competitive advantage when bidding for building projects in future, which in turn helps convince them to guarantee the sufficiency of the resources [74].

Training for competencies (MS6). Apart from the awareness and willingness to implement BIM, technical knowledge and ability is also needed [8]. Training programs should be provided to build the staff's competencies (H04, H07, H14, H35, and H47) and thus reduce their anxieties about their qualifications for being involved in the new project workflow in Singapore. Once the project team is built, the owner may provide trainings to the service providers on how to use new software applications, reinvent workflow, assign responsibilities, and collaborate with others using interoperability tools like IFC. For instance, it is imperative in practice to maintain integrity across design models, because changes are made to the different models by their respective disciplines. Both manual updates using IFC and smart automated transactions in BIM servers require specialized expertise. In addition, the major stakeholders should also arrange constant in-house training and education programs to help their staff adapt to new policies and work rules and procedures.

5. Conclusions and Recommendations

This study has examined the hindrances to BIM implementation in building projects in Singapore and explored the interrelationships among these hindrances. The analysis results from the questionnaire survey and the post-survey interviews implied that 21 out of the 47 hindrances were deemed critical. If everything is important, nothing is manageable. The top-ranked hindrances represented the most important areas of activities of BIM implementation. Since resources are usually limited in a project, the project leadership team should allocate resources for such areas rather than all the key areas. Additionally, the 21 critical factors hindering BIM implementation were grouped into three categories:

lack of collaboration and model integration, lack of continuous involvement and capabilities, and lack of executive vision and training, which were confirmed by CFA. Furthermore, these hindrance groupings and the intergroup relationships formed a conceptual framework. This framework could depict the key hindrances of BIM implementation in the Singapore construction industry. According to the path modeling analysis results, the lack of executive vision and training and the lack of continuous involvement and capabilities contribute to the lack of collaboration and model integration, and that the lack of executive vision and training results in the lack of continuous involvement and capabilities. Thus, the key areas described by the hindrances in the driving hindrance grouping "lack of executive vision and training" should also have top management priority. According to the ranking of and the relationships among the critical hindrances, six managerial strategies are proposed for project teams to overcome these hindrances.

There are limitations to the conclusions. First, the critical factors hindering BIM implementation might not be exhaustive. These factors might not be continuously true as time passes. Second, the data analyzed in this study were collected from the BIM implementers in Singapore, which may restrict the interpretation and generalization of the analysis results.

Nonetheless, the managerial strategies proposed in this study are not only applicable in the project teams in Singapore, but also hold true in overseas building project teams. This is because: (1) overseas project teams may also use the hindrances to BIM implementation identified in this study and follow the methodology used in this study to customize their own lists of hindrances, with minor adjustments. Similar to Singapore, other countries are also encouraging, specifying, or mandating BIM uses in publicly-funded building and construction projects by issuing a variety of BIM policies and standards [75,76]. Other countries such as the United States, the United Kingdom, and Australia also only have gone a step further to include elements of relational contracting which stress on shared rewards and responsibilities to break out of the conservative industry culture; (2) the governments that have not made much effort to incentivize BIM implementation can refer to these managerial strategies to purposefully and efficiently formulate and roll out their plans and policies. They may conditionally mandate BIM uses in their construction and building projects, establish national data exchange standards for enhanced multidisciplinary model integration, and provide technical support such as by defraying a proportion of the capital investments in software purchase, subscription, updating, and training; and (3) the proposed conceptual framework indicating the groupings of the critical hindrances as well as the intergroup cause-effect relationships is novel and can help the BIM implementers identify specific adjustments to their BIM implementation activities for efficiently enhancing BIM implementation. Thus, the main findings of this study contribute to the scholarship in terms of BIM implementation.

Reducing the critical hindrances to BIM implementation requires the project team, including the executives and employees of the major stakeholders, to change the accustomed work practices. Thus, with support from the conceptual framework constituted and validated in this study, future publications would propose an extended change framework for the project organization to systematically guide the primary participants and their staff to change.

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