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RESEARCH ARTICLE

Identifying factors for incorporating spatial data into BIM using the Delphi method

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Abstract

Construction industry players are now realising the need to implement Building Information Modeling (BIM) at the preconstruction planning stage to allow spatial data of the site to be incorporated into BIM. Incorporating spatial data in BIM as early as possible in the building lifecycle poses a new challenge to industry players, particularly to the consultants who collect and provide these data. The aim of this study is to identify important factors through a consensus opinion of industry experts for incorporating spatial data into BIM at the preconstruction planning stage. Three rounds of the Delphi method were employed to obtain a consensus among twenty construction industry experts, selected through purposeful sampling. The findings revealed seven consolidated factors, with Technology, Client Demand, and Added Value as the top three, followed by Regulations, Skilled Staff, Management Commitment and Data Management. Experts were significantly in agreement with each other, as indicated by the Kendall's W Coefficient (= 0.6505) significant at $<$ 0.005. The findings highlight the requirements for utilising spatial data in BIM at the preconstruction planning stage and help the respective professional bodies to identify the prerequisites for BIM application and subsequently, improve the existing training for the professional development of their members.

Keywords

Spatial data; building information modeling; preconstruction planning; Delphi method; construction industry

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Introduction

The construction industry is challenged to adopt Building Information Modeling (BIM) to improve its performance and to achieve sustainability in the industry (Arayici et al., 2011). Also known as n-Dimensional (n-D) Modeling or Virtual Prototyping Technology (Azhar et al., 2015), BIM refers to a digital presentation that integrates various sets processes, technologies and players in a building or facility lifecycle, aimed at increasing productivity and improving performance (Thomson, 2016, Liao et al., 2017). The visualisation in a 3D model under BIM improves understanding of the proposed project (Liao et al., 2017).

Practitioners are now realising the need to implement BIM as early as possible to allow the spatial data of the site where the building or facility is going to be constructed to be utilised and incorporated into BIM. Clearly, the building lifecycle starts with preconstruction planning, followed by the design stage (Karan et al., 2015). Examples of spatial data collected during surveying work are data on topography, terrain and site obstacles for neighbouring buildings, overhead powerlines, and underground pipelines. These data, which are absent in the current BIM models, are valuable for determining the position of a building or facility on the site, the building height, width and length, and the main building materials of the external structures (Peckiene and Ustinovičius, 2017, Ma and Ren, 2017). In fact, if spatial data is included into BIM, it will permit architects to utilise the climatic data at the design stage, for incorporating natural ventilation (Hjelseth and Thiis, 2008), natural lighting (Vijay K. Bansal, 2009) and projections of energy demand in their designs (Strzalka et al., 2011).By generating spatial data that are compatible with BIM, incorrect interpretations of survey data during the design phase can be reduced (Chris Houghton et al., 2013). Also, the integration of spatial data and BIM can help in site planning for temporary structures, which could reduce accidents on construction sites (Kumar and Cheng, 2015). When applied at the earliest stage of the building lifecycle, BIM can address the problems of delay, cost escalation, construction site safety and disputes among project members (Azhar et al., 2015). The discussion thus far underscores the importance of incorporating spatial data into BIM at the preconstruction planning stage.

Despite an increase in research interest in BIM, very little is devoted to incorporating spatial data into BIM technology during the preconstruction planning stage. Most published research on BIM focuses on its application along the construction supply chain (Clark and Gray, 2014, Baik, 2017), the advantages of BIM (Ralf Becker, 2018, Chong et al., 2017), the drivers and barriers to general BIM application (Oo, 2014, Yaakob et al., 2016), the development of BIM tools (Santos et al., 2017), the narrow application of BIM, such as in heritage buildings (Baik, 2017), facilities management (Kasprzak and Dubler, 2015), costing or 5D BIM (Stanley and Thurnell, 2014), formwork design (Singh et al., 2017) and on simulation studies using BIM information (Santos et al., 2017). In other words, there is a lack of research on BIM application at the preconstruction planning stage and on the incorporation of spatial data into BIM.

There are several softwares available for BIM application such as Tekla, Navisworks, and Autodesk Revit, to name a few. The industry foundation classes (IFC) in BIM which provide details on building components, elements, materials and their interrelationships, were established to ensure interoperability (Amirebrahimi et al., 2016). Spatial data added to a building information model can provide a detailed description of the building and site where the building is located (Karan et al., 2015). However, some of the spatial data could not be incorporated into BIM (Kim et al., 2014). This applies to the 2D maps or digital maps that have a geographic reference system, i.e., latitude, longitude and elevation coordinates of an object. To address the complexity, factors for successful inclusion of spatial data into BIM should be investigated.

As with the adoption of any innovation or new technology, previous studies have established that construction firms face a host of difficulties due to limitations such as the unique social, economic and technological contexts of developing countries (Bui et al., 2016). Adoption of new technology or processes remains challenging in the construction industry (Nor'Aini Yusof, 2017), which is known to be lagging behind in adopting new ideas, technologies and processes. Therefore, it would not be surprising if BIM technology received a slow response from the industry players (Rogers et al., 2015, Liao et al., 2017). At the same time, innovations in the construction industry are not all the same, and each innovation has different influencing factors and outcomes (Lai et al., 2016). Kamal et al. (2016) showed that some firm characteristics have different impacts on a firm's adoption of innovation. In Peru, for example, migration from traditional tools to BIM-compatible models was not an easy task because the players, including clients, architects, key suppliers, and constructors, were not ready for a high level of coordination and synergy (Murguia et al., 2017). Thus, previous research points to an important area of investigation, which is the need for incorporating spatial data into BIM, which the present study seeks to address.

The main objective of this study is to obtain agreement among construction industry experts on the factors that are seen as important by the experts for successful inclusion of spatial data into BIM at the preconstruction planning stage. At the end of the paper, a framework that consists of consensus factors for BIM-spatial will be proposed. The study contributes to our knowledge in two ways: first, in terms of theoretical contribution, the findings will provide further understanding of the potentials of BIM, particularly by advancing Clark and Gray (2014) and Park and Kim (2016) work by identifying additional factors besides the technology factor, through consensus opinion of the industry experts, that are prerequisite to extend BIM beyond its current usage to cover the preconstruction planning stage, and second, in terms of practical contribution, the findings will provide helpful guide to construction industry players who are involved at the preconstruction planning stage of how to prepare themselves to enable BIM application.

Literature review

Introduced by Professor Charles M. Eastman in 1970, the first application of BIM was in the USA in 2000 (Latiffi et al., 2013). The original focus of BIM was at the planning and design phase, intended for modeling physical aspects of buildings. Later on, BIM progressed from 3D to 4D and 5D modeling to incorporate the scheduling and costing of the construction process (Clark and Gray, 2014; Stanley and Thurnell, 2014). BIM application is not only for new buildings, but can also be expanded for existing buildings such as to retrofit them for sustainability – using BIM as a tool to achieve thermal comfort, the overall well-being of occupants, and to address the issues of carbon footprint and waste generation in existing buildings (Backes et al., 2014). BIM was later expanded to 6D and 7D modeling for sustainability and operations-maintenance, respectively (Oo, 2014), and, in fact, attempts have been made to identify how BIM can be applied to integrate and achieve all three sustainable pillars-social, economic and environmental sustainability (Chong et al., 2017). Due to BIM's benefits of improving efficiency and productivity, it has been widely used in developed countries such as the USA, Australia, Hong Kong, Denmark, Norway, Finland and Singapore (Latiffi et al., 2016).

In most developing countries, BIM application is still in the early stages (Ishak, 2017, Latiffi et al., 2016; Murguia et al., 2017). In Malaysia, where the current study is carried out, the idea to implement BIM was first mooted in 2007 by the Department of Public Works (PWD), and in 2013, the PWD launched the BIM roadmap (Keat, 2013). BIM application can be seen in the integration of digital models with geometric and parametric information, where Autodesk is used as BIM's platform software (Ashhar, 2017). Areas of BIM application are project visualisation, refining project design, identifying design collision, quantity take-off, post-occupancy and maintenance (Rogers et al., 2015). At the moment, BIM implementation in Malaysia does not cover the preconstruction planning stage, and the consultants who are responsible for collecting spatial data (i.e., land surveyors, site engineers, geologists) are not included in the BIM committee (Adimin and Rashid, 2016).

Incorporating spatial data in BIM at the preconstruction planning stage poses a new challenge to consultants who collect and provide these data, that is, the surveyors and geospatial consultants. These consultants need to acquire new knowledge and skills beyond their traditional core areas (Yeong and Ragananthini, 2017; Landpoint, nd), in other words, the use of computer-aided design (CAD) is no longer sufficient. A new authoring software - Survey Information Model that is able to create Digital Terrain Models (DTMs), Triangulated Irregular Networks strings and point clouds is now used to allow survey data to be imported into BIM (Chris Houghton et al., 2013). However, experience from developed countries revealed that mismatch issues still exist and hamper the migration process (Chris Houghton et al., 2013).

As previously mentioned, some studies have attempted to address the integration between spatial data and the BIM issue, but these studies have limited their focus on a specific topic: BIM and geographic information system (GIS) integration. Examples of these BIM-GIS studies are Ma and Ren (2017) who proposed four items, namely, application object, application phase, integrated pattern and platform, while Park and Kim (2016) stressed on technology advancement to overcome the rigid requirements of BIM application. Liu et al. (2017), on the other hand, suggested that surveying consultants adopt a change towards more flexible and cooperative attitudes. Apart from GIS, it should be noted that spatial data also exist in other systems, such as CAD and computer-aided mapping (CAM), where the requirements may differ. This gap points out the need for another study to investigate the factors for successful integration of spatial data into BIM.

A host of other studies identified factors for general BIM or new technology adoption. Four readiness criteria, namely, Process, Management, Technology, and People Readiness were identified for BIM adoption at the design stage (Haron, 2013). Organisational factors such as organisational culture, forward planning, and economic factors including the cost of software and hardware were identified as important for their role in persuading firms to embrace BIM (Lee and Yu, 2017). Free, easy-to-learn, flexible and up-to-date tools were seen to encourage unsophisticated users to embrace new technologies (Nilsiam and Pearce, 2017, Mele and Poli, 2017). Technological support refers to the existence of a common data environment and effective data sharing tools among the BIM team members, made available by a technology provider or research institute can facilitate adoption of the new technology (Alreshidi et al., 2017, Liao et al., 2017). In contrast, the inability of the current technology used by industry players to keep pace with the advancement of new technology has been cited as the reason for slow advancement from old to new technology (Alshammari et al., 2018). Legal support and incentives from the government were identified as necessary factors to encourage industry players to adopt a new technology (Yusof et al., 2010; Yusof et al., 2012). Legal support refers to the legal protection that the players may receive concerning the issues of data ownership, intellectual property rights and miscommunication (Alreshidi et al., 2017). Other legal issues, such as data credibility and the liability for inaccurate data, should also be addressed to encourage adoption of new technology (Juhász et al., 2016). Government incentives can be defined as the additional help from the government in the form of financial incentives to create a favorable environment for adopting the new technology (Yusof et al., 2012). Pressure from stakeholders resulting from increased awareness about the importance and benefits of the new technology may affect readiness to adopt BIM (Rogers et al., 2015).

Although valuable in their own right, these findings revealed the general factors that influence the application of new technology application along the building lifecycle stages. However, these findings are unable to provide feasible guidance for incorporating spatial data into BIM. In order to work towards this latter goal, as a first step, those factors that will enable spatial data to be included in BIM technology should be first identified. At the moment, there is no agreement among scholars about those factors; therefore, it is crucial to seek consensus from industry experts on which factors are prerequisite for incorporating spatial data into BIM. Next, the methodology of the study will be elaborated.

Methodology

The study employed qualitative research methodology, i.e., expert interviews were conducted using the Delphi method to obtain consensus from a panel of construction industry experts in Malaysia through several rounds of interview sessions. The data were analysed using content analysis and descriptive statistics. The Delphi method was employed for the following reasons: (a) there is a lack of studies that have identified the factors necessary for the successful integration of spatial data into BIM at the preconstruction planning stage in developing countries; (b) the required information and knowledge can be obtained from the industry experts; (c) the Delphi method allows industry experts to introduce new factors that are relevant to the study; (d) the Delphi method allows the primary purpose of our study to be examined in detail; and (e) a collective decision made by several individuals who were selected by the Delphi method is less likely to be wrong compared to a decision made by a single individual (Hasson et al., 2000, Livesey, 2016).

An individual deemed to be an expert is generally considered to be more experienced, more proficient, and more significant in the work environment (Okoli and Pawlowski, 2004). Since the aim of this study is to seek consensus on factors for incorporating spatial data into BIM at the preconstruction planning stage from individuals with specific experience and knowledge, purposive sampling was used to select the individuals that will serve as the Delphi panel of experts. The experts must have a minimum of 5 years of working experience in the construction industry, must be currently working in a construction-related organisation and should reflect a high level of knowledge and working experience of the study context. To ensure a balanced view, representatives of construction professionals from public and private clients, consulting firms (architectural, engineering, quantity surveying, land surveyors, property management) and contractors were selected. Twenty-five industry experts were contacted by e-mail to obtain their agreement to participate in the study. Twenty-two experts agreed to participate, but only twenty experts participated in all three rounds of the interview sessions. Two experts who had initially agreed to participate did not reply to several attempts to arrange for the first-round face to face interview and hence were excluded from the Delphi method.

Following the suggestion by Xia and Chan (2012), three rounds of interview were conducted separately with each expert; Round 1 - the exploration and identification process, Round 2 - the narrowing down or categorising process, and Round 3 - the ranking process. The results of each round were fed into the subsequent round, ensuring that decisions were made through the informed consensus of industry experts. Figure 1 depicts the study's process of data collection using the Delphi method.

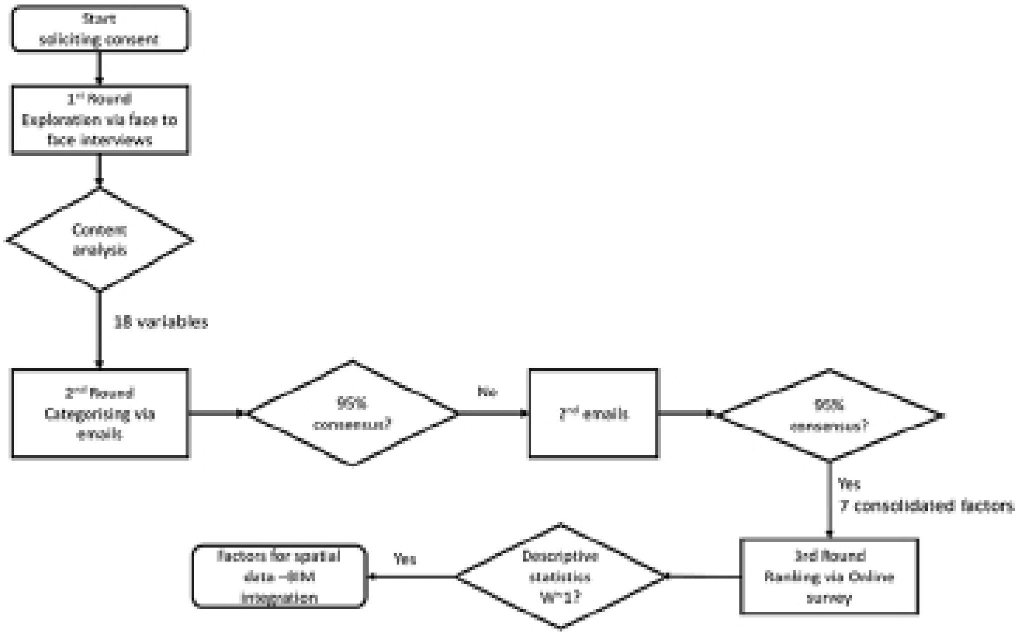

Figure 1 The study's process of data collection using the Delphi method

The first round of interviews was conducted face-to-face at a place and time convenient for the experts. The reasons for conducting the first round interviews face-to-face were to explain the aim of the study, to collect in-depth information about the variables proposed by the experts, and to gain their trust so that they would participate in the subsequent rounds. On average, each interview took 20 minutes. The second round of the Delphi method conducted via two rounds of e-mails requested the experts to categorise eighteen variables identified in the previous round into smaller categories identified by the experts themselves. The first round of emails resulted in nine factors. Subsequently, the second round of emails was sent to obtain at least 95% consensus among the experts, and this resulted in the final seven agreed upon consolidated factors. The third round of the Delphi method was conducted via an online survey where the experts were asked to rank the seven consolidated factors from 1= not at all important to 7= extremely important.

The whole process of the Delphi method took ten weeks to complete. Content analysis was used to analyse the interview data obtained in the first round and descriptive statistics were used to analyse the data received in the third round. The outcome was a consensus of factors that are important for successful inclusion of spatial data in BIM.

Results

Twenty experts participated in the three rounds of the Delphi method. Forty percent of the experts were consultants (three were architects, two were land surveyors and one each was engineer, quantity surveyor and maintenance manager), 25% were private developers, 20% were government departments and 15% were contractors. Twenty percent of the experts had more than 15 years of experience in the industry, 45% had between 10 to 15 years of experience, and 35% had between 5 to 9 years of experience. Forty-five percent of the experts were BIM users with BIM experience ranging from 4 to 8 years. Table 1 depicts the profile of the experts who participated in the Delphi method.

Table 1 Respondent profiles

Expert ID	Type of Firm	Position	Experience (yrs)	BIM user?	BIM experience (yrs)
E1	Contractor	Managing Director	12	No	
E2	Government department	General manager	18	No	
E3	Government department	Project manager	15	Yes	5
E4	Private property developer	Owner	20	No	
E5	Consultant	Architect	11	Yes	7
E6	Consultant	Land surveyor	25	No	
E7	Consultant	Land surveyor	21	No	
E8	Private property developer	Project manager	12	No	
E9	Consultant	Architect	7	Yes	8
E10	Contractor	Engineer	10	Yes	4
E11	Consultant	Engineer	13	Yes	5
E12	Private property developer	Director	8	No	
E13	Government department	Deputy Chief Division	12	Yes	8
E14	Consultant	Quantity Surveyor	8	Yes	4
E15	Government department	Maintenance manager	9	Yes	4
E16	Private property developer	Project manager	6	No	
E17	Consultant	Architect	8	Yes	6
E18	Private property developer	Managing Director	13	No	
E19	Contractor	Engineer	10	No	
E20	Consultant	Property maintenance manager	7	No	

Round 1 was the exploration and identification process, where the experts were asked to identify the general factors that can help the integration between spatial data and BIM. The experts were free to identify any variables based on their knowledge and experience.

The interview data were analysed using content analysis. Since existing literature on the subject matter is limited, a predetermined coding scheme was not used. The interview data were transcribed verbatim and read repeatedly for familiarisation. Then each transcript was scrutinised to identify variables that portray factors that were important for inclusion of spatial data in BIM and these variables were highlighted. The intention was to pick and gather the actual variables from the transcripts. The 'find' feature in the word document was used to identify similar variables in the transcripts of subsequent experts. In addition, new variables were added if they did not fit with the existing variables. The process was repeated until no new variable could be found. Figure 2 depicts the content analysis process. The outcome of the content analysis was a list of variables proposed by the experts and their frequencies (Table 2).

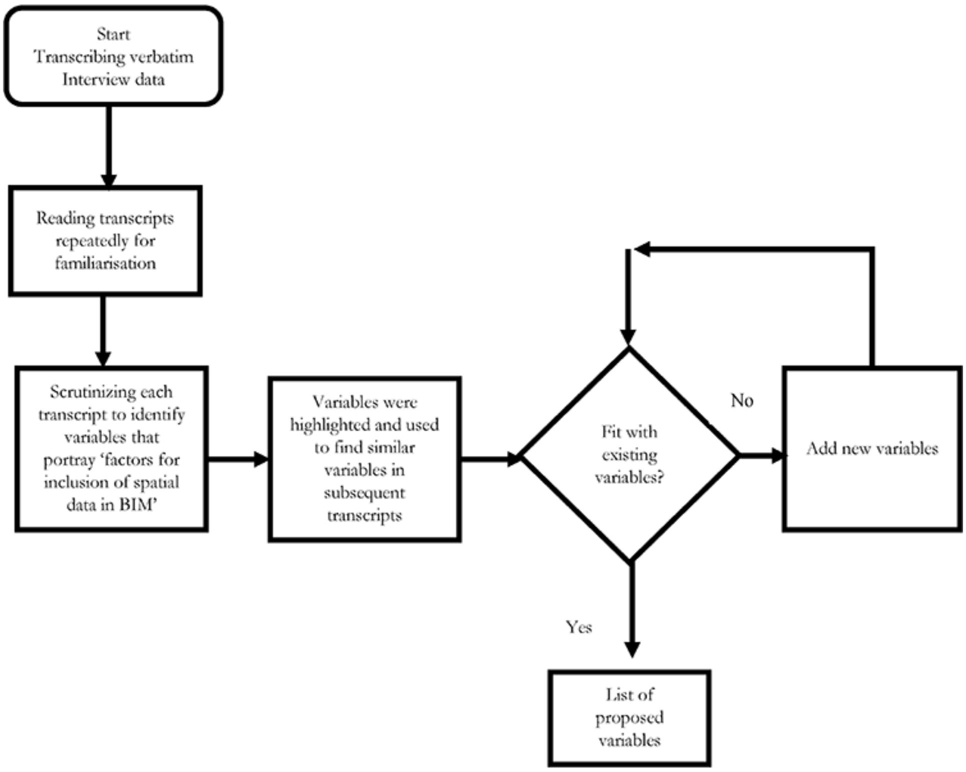

Figure 2 The content analysis process

As previously mentioned, the study focuses on obtaining consensus from the experts rather than individual opinions. Therefore, as suggested by Chan et al. (2001) and supported by Okoli et al. (2004) and Xia and Chan (2012), only the variables that were proposed by a minimum of 50% of the experts were retained and considered for the subsequent round. Eighteen variables that obtained more than 50% suggestions were identified. Five other variables - Tax reduction, BIM champion by Construction Industry Development Board (CIDB), public projects lead, role of professional body, and research and development were omitted because they obtained less than 50% suggestions. Table 2 presents the results of Round 1.

Table 2 Result of Round 1 – Delphi method

Variables for incorporating spatial data in BIM	Proposed Frequency (%)
1. Affordable technology	100%
2. Technology Integration/compatibility	100%
3. Practical application	100%
4. Added quality to products or services	100%
5. Semantic Interoperability	95%
6. Technology availability - open-source solution	95%
7. Client demand or pressure, awareness	90%
8. Knowledge about systems and their functionalities	90%
9. Skilled staff	90%
10. Common data format	85%
11. Technology capability	85%
12. Data management, storage, processing time	80%
13. Automated integration	80%
14. Time saving	80%
15. Liability for inaccuracies of the spatial data, data ownership	75%
16. Legal support (new building codes/regulations)	75%
17. Management commitment, support	65%
18. Standard procedure	65%
19. Tax reduction	20%
20. BIM champion by Construction Industry Development Board CIDB)	10%
21. Public projects lead	10%
22. Role of professional body	5%
23. Research and development (R&D)	5%

Round 2 is the narrowing down or categorising process where the experts were asked to categorise the eighteen variables from Round 1 into smaller groups. The first emails resulted in 90% of the experts identifying seven factors, i.e., Added Value, Client Demand, Data Management, Management Commitment, Regulations, Skilled Staff and Technology. Another two experts identified one new factor each- 'Automated Integration' and 'Standard Procedure'. To produce the final consolidated factors, 95% consensus among the experts is desired. Subsequently, in the second emails, the experts were asked to validate and reassess the suitability of the nine factors. The returned assessment indicated that 95% the experts proposed seven consolidated factors. Table 3 depicts the final agreed upon consolidated factors and their respective variables.

Table 3 Results of round 2 - the final agreed upon consolidated factors

Consolidated factors	Variables
1. Added Value	Added quality to products or services, Overall time saving, Practical application
2. Client Demand	Client demand or pressure, Client awareness
3. Data Management	Data storage, Processing time, Common data format, Automated integration
4. Management Commitment	Management support, Standard procedure
5. Skilled Staff	Skilled staff, knowledge about systems and their functionalities
6. Regulations	Liability for inaccuracies of the spatial data, Legal support (new building codes/regulations), Data ownership
7. Technology	Affordable technology, Technology compatibility, Technology availability, Open-source solution, Semantic Interoperability, Technology capability

Round 3 of the Delphi method is the ranking process. The results from Round 2 were used in this round, where the experts were asked to rank the factors according to their importance. The purpose of Round 3 is to develop an agreement among the experts regarding the importance of each spatial data-BIM factor. The results showed that the experts ranked Technology as the most important factor for incorporating spatial data in BIM at the preconstruction planning stage with the mean score of 6.25, followed by Client Demand (mean = 5.15) and Added Value (mean = 4.65) while Data Management (mean = 1.04) is ranked as the least important factor. Figure 3 depicts the results of Round 3 – Delphi Method.

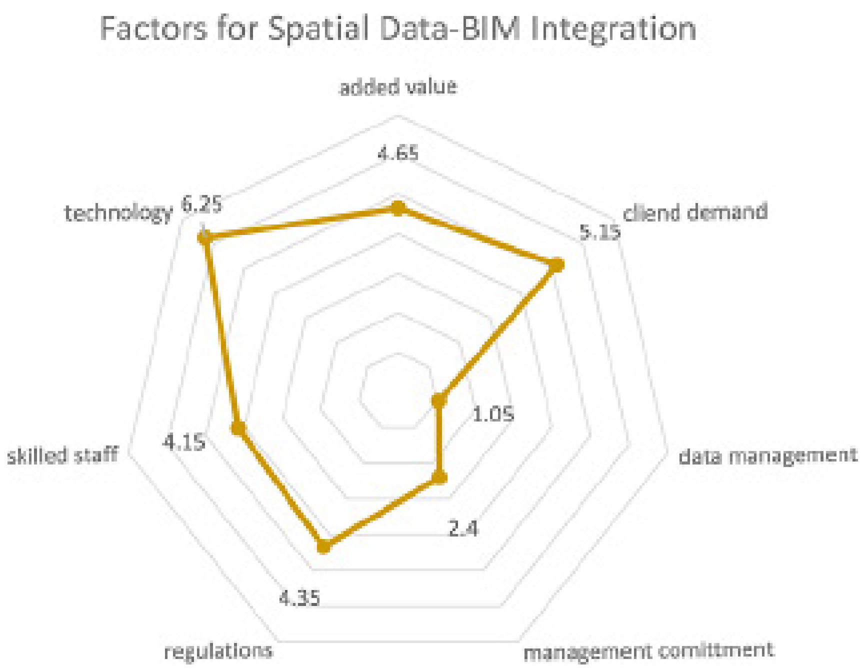

Figure 3 Result of Round 3 – Delphi Method

As suggested by Xia and Chan (2012), the level of agreement among the experts needs to be calculated using the Kendall's Coefficient of Concordance (*W*). Kendall's Coefficient of Concordance (W) is indicated by 0 to 1. If $W = 0$, this indicates that the experts are in complete disagreement with each other, whereas if $W = 1$, this indicates that the experts are in perfect agreement with each other with regards to the ranking of the factors for inclusion of spatial data into BIM. The formula for Kendall's *W* Coefficient is as follows:

$$W = \frac{12S}{m^2(n^3 - n)}$$

where S is the sum of squared deviations, m is the number of experts ($m = 20$), and n is the total number of factors being ranked ($n = 7$). In the present study, $W = 0.6505$ significant at < 0.005 indicating that the experts were significantly in agreement with each other.

Discussion

The findings revealed seven important factors that should be considered to ensure successful inclusion of spatial data into BIM at the preconstruction planning stage. The top three are Technology, Client Demand and Added Value factors. The Technology factor was identified as the most important factor that should be considered by the respective players, and this technology should be affordable, compatible and effective, allowing for information and the meanings of spatial data to be incorporated into the BIM environment. One expert, who is a surveyor, revealed that his firm collected spatial data manually using five field workers which was very time consuming. If his firm was to incorporate spatial data into BIM, he would need to upgrade the current software and hardware into a compatible technology and address the question about whether such a technology exists and if so, what would be its cost. Another expert who is a BIM user, brought up the issue of semantic interoperability. In his opinion, to ensure fruitful integration, it is very important to ensure that the spatial data can be transferred into BIM without any data loss and with retention of the meaning of the spatial data.

Next, is the Client Demand factor where pressure from clients can ensure spatial data can be incorporated into BIM at the preconstruction planning stage. Clients that are well-informed about the importance of fully utilising BIM will put pressure on the other players at the preconstruction planning stage to ensure that spatial data is incorporated into BIM. Another expert who is a BIM user disclosed that the Client Demand factor is vital to ensuring BIM application. If the client is aware about the benefits of utilising BIM at the earliest stage of the building lifecycle, and insists for BIM application, the consultants and contractor have to abide by the client's wish in order to get the job.

The third most important factor for inclusion of spatial data into BIM at the preconstruction planning is the Added Value, which such inclusion could provide to the overall performance in terms of the quality of products or services, time-saving, cost reduction and increased profits. In the words of one expert who is a non-BIM user "At the end of the day what is important is what do we (industry players) get (from the integration). Better service? Faster job completion? Can we make our clients happy and ask for higher surveying fees?". According to the expert, the answer to these questions is important to encourage the inclusion of spatial data into BIM. The importance of Added Value has been ignored by most previous studies. Precise spatial data that can be collected and prepared easily, faster, safely and less expensively is crucial because it will act as a basis for a design decision in the subsequent building phase.

Subsequently, Regulations and Skilled Staff were ranked fourth and fifth, respectively, by the experts. The Regulations factor includes the legal protection, the liability for inaccurate data by the consultants who provided the spatial data, and the flexibility of the existing building codes or planning regulations that allow smooth application of spatial data-BIM in the layout plan for planning permission purposes is ranked fourth by the experts after Added Value. The fifth important factor is Skilled Staff, which includes both the knowledge and skills of the consultants and their staff who are involved in collecting and providing spatial data. Their knowledge and skills should cover new authoring software that allows spatial data to be imported to BIM.

Two factors were ranked as least important for incorporating spatial data into BIM: Data Management and Management Commitment. Data Management includes data storage, data processing time, common data format and automated transformation. One possible reason why the experts ranked Data Management as the least important is that they perceived data management as relatively easy to handle through knowledge and skill enhancement. The second least important factor was Management Commitment or support from the management to ensure successful integration of spatial data into BIM. Included in Management Commitment is the existence of standard procedure or best practice that can ease the integration of spatial data into BIM. Since the majority of experts are the top management in their respective firms, it is likely they would not want to assume responsibility for incorporating spatial data into BIM.

The findings are in line with Park and Kim (2016), who stressed the importance of new technology which can enable BIM to be extended from its current focus on buildings to their surrounding area, town and region by including spatial data. A new technology such as a middleware system that is easy to use, less time consuming, and at the same time able to address the building site design issues will make BIM usage at the preconstruction stage feasible (Park and Kim, 2016). The ability of this new technology to utilise common gadgets that can collect spatial data such as smartphones and GPS receiver devices in both online and offline modes will make the integration of spatial data into BIM easier and affordable.

The findings support Liu et al. (2017) about the complexity of including spatial data into BIM, i.e., technology alone is insufficient to incorporate spatial data into BIM. Increased awareness of clients about the importance of BIM at the preconstruction stage can raise support for involving a surveying consultant in the project team and BIM utilisation at the earliest stage of the building lifecycle. Client demand is critical to encourage openness and a collaborative attitude among construction players, which Liu et al. (2017) argued are needed to address the complexity issue of incorporating spatial data into BIM. One example of such an attitude is clear communication between the respective project team members on the types of spatial data and their level of detail that are necessary for the subsequent building phase.

Similarly, the findings support the work by Juhász et al. (2016) that identified the importance of regulations for the inclusion of spatial data into BIM. Application Programming Interfaces (APIs) to extract spatial data provides alternative information for users, however, their legal status needs to be verified prior to usage. Liability for inaccurate data and penalties for unnecessary variances should be in place to avoid errors and imprudent conduct, and the consequences are borne by the responsible party.

Based on the findings, a proposed framework for the inclusion of spatial data into BIM is developed and presented in Figure 4.

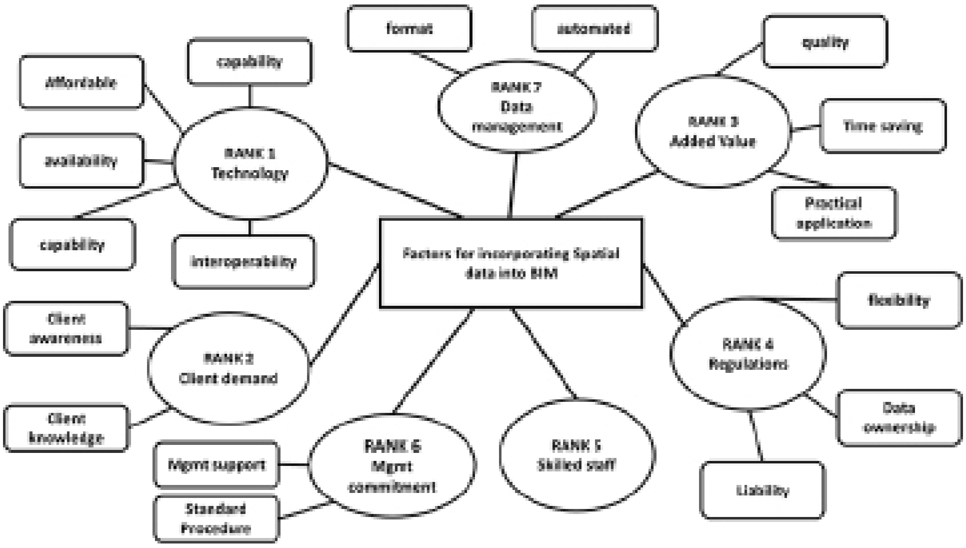

Figure 4 A proposed framework for the inclusion of spatial data into BIM

Conclusion

The present study aimed to identify the factors that are important for incorporating spatial data into BIM at the preconstruction planning stage. The study utilised the Delphi method to develop consensus among construction industry experts about the relative importance of factors for incorporating spatial data into BIM. Eighteen variables were identified and subsequently were categorised into seven consolidated factors. Next, these seven factors were ranked according to their importance. Technology, Client Demand, and Added Value are the top three, followed by Regulations, Skilled Staff, Management Commitment and Data Management.

The findings provide both theoretical and practical implications. Theoretically, the findings of this study provide a greater understanding about the potential of BIM application specifically for sustainable layout and urban planning, advancing the work of Clark and Gray (2014) by incorporating spatial data into BIM. The proposed framework can act as a starting point for future exploration of determinants of BIM implementation. Practically, the findings allow construction players to understand the requirements for utilising spatial data into BIM at the preconstruction planning stage, thus ensuring the sharing of spatial data with BIM in a meaningful way. Also, the findings help the respective professional bodies to identify the prerequisites for BIM application at the preconstruction planning stage and to improve the existing training for the professional development of their members.

The study has several limitations. First, due to limited information on the subject matter, the present study used the Delphi method to obtain agreement among industry experts on factors that need to be considered when incorporating spatial data into BIM. Future studies should utilise quantitative research methodology such as structured surveys to enable refining and validating of the proposed framework to add value to our knowledge on important factors for incorporating spatial data into BIM. Secondly, the study was carried out in Malaysia, a developing country which is experiencing rapid growth in the construction sector where BIM application is still at the beginning despite initiatives to increase its application. The findings can be generalised to other developing countries similar in context to Malaysia such as India, Peru, Brazil, Croatia and the Czech Republic (see Ahuja et al., 2017; Murguia et al., 2017; dos Santos et al., 2015 and Galić et al., 2017). These countries have acknowledged BIM as one of the measures to improve construction industry productivity and several measures have been carried out by the governments mentioned to encourage BIM application, but they faced greater challenges due to lack of funds, technology and skilled manpower. These developing countries do not enjoy technologies for the smooth integration of spatial data into BIM, such as robotic stations, 3D laser scanning and Scan-to-BIM software that are available in countries with advanced BIM usage. The present study has identified the factors that experts perceive as important for incorporating spatial data into BIM and ranked these factors in importance. Based on this ranking, future researchers can use the ranking to prioritise factors that give the highest impact. Last but not least, the present study follows the Delphi method protocol, which transformed individual opinion into group consensus. As such, to achieve consensus among the industry experts, only factors that are agreed upon by the majority were considered. Future studies should utilise other methods of data collection, such as general expert interviews, to consider all possible factors.

References

Adimin, M. K. & Rashid, M. H. A. 2016. Roles and Readiness of Land Surveyors towards the Implementation of BIM in Malaysia. GeoSmart Asia 2016. Kuala Lumpur: JUPEM and GeoSmart.

Alreshidi, E., Mourshed, M. & Rezgui, Y. 2017. Factors for effective BIM governance. *Journal of Building Engineering*, 10, 89-101. https://doi.org/10.1016/j.jobe.2017.02.006

Alshammari, T., Alshammari, N., Sedky, M. & Howard, C. 2018. SIMADL: Simulated Activities of Daily Living Dataset. *Data*, 3, 11. https://doi.org/10.3390/data3020011

Amirebrahimi, S., Rajabifard, A., Mendis, P. & NGO, T. 2016. A BIM-GIS integration method in support of the assessment and 3D visualisation of flood damage to a building. *Journal of Spatial Science*, 61, 317-350. https://doi.org/10.1080/14498596.2016.1189365

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C. & O'reilly, K. 2011. Technology adoption in the BIM implementation for lean architectural practice. *Automation in Construction*, 20, 189-195. https://doi.org/10.1016/j.autcon.2010.09.016

Ashhar, S. M. M. 2017. *Pelaksanaan BIM di Jabatan kerja Raya (JKR)* [Online]. JKR. Available: http://www.architecturemalaysia.com/Files/Pool/90_170525_1641444144_bim_in_jkr_cidb_penang.pdf [Accessed 13 Sept 2017].

Azhar, S., Khalfan, M. & Maqsood, T. 2015. Building information modelling (BIM): now and beyond. *Construction Economics and Building*, 12, 15-28. https://doi.org/10.5130/ajceb.v12i4.3032

Backes, D., Thomson, C., Malki-Epshtein, L. & Boehm, J. Chadwick *GreenBIM: Advancing operational understanding of historical buildings with BIM to support sustainable use*. 2014. UCL (University College London).

Baik, A. 2017. From point cloud to Jeddah Heritage BIM Nasif Historical House – case study. *Digital Applications in Archaeology and Cultural Heritage*, 4, 1-18. https://doi.org/10.1016/j.daach.2017.02.001

Bui, N., Merschbrock, C. & Munkvold, B. E. 2016. A Review of Building Information Modelling for construction in developing countries. *Procedia Engineering*, 164, 487-494. https://doi.org/10.1016/j.proeng.2016.11.649

Chan, A. P., Yung, E. H., Lam, P. T., Tam, C. & Cheung, S. 2001. Application of Delphi method in selection of procurement systems for construction projects. *Construction Management and Economics*, 19, 699-718. https://doi.org/10.1080/01446190110066128

Chong, H.-Y., Lee, C.-Y. & Wang, X. 2017. A mixed review of the adoption of Building Information Modelling (BIM) for sustainability. *Journal of Cleaner Production*, 142, 4114-4126. https://doi.org/10.1016/j.jclepro.2016.09.222

Chris Houghton, David Berry, Michael Byrne & Nicholas Davies 2013. *Surveying for BIM*. In: Holzer, D. (ed.) BIM in Practice. Australia: Australian Institute of Architects (AIA).

Clark, J. & Gray, C. 2014. A new way of thinking. *Land Journal*, 6.

Galić, M., Venkrbec, V., Chmelik, F., Feine, I., Pučko, Z. & Klanšek, U. 2017. Survey of accomplishments in BIM implementation in Croatia, the Czech Republic, Germany, and Slovenia. *Electronic Journal of the Faculty of Civil Engineering Osijek-e-GFOS*, 8(15), 23-35. https://doi.org/10.13167/2017.15.3

Haron, A. T. 2013. *Organisational readiness to implement building information modelling: A framework for design consultants in Malysia*. University of Salford.

Hasson, F., Keeney, S. & Mckenna, H. 2000. Research guidelines for the Delphi survey technique. *Journal of advanced nursing*, 32, 1008-1015. https://doi.org/10.1046/j.1365-2648.2000.t01-1-01567.x

Hjelseth, E. & Thiis, T. 2008. Use of BIM and GIS to enable climatic adaptations of buildings. https://doi.org/10.1201/9780203883327.ch46

Ishak, S. S. M., Esa, M., & Ismail, M. H 2017. Social capital, social network and BIM practices. *33rd Annual ARCOM Conference Cambridge, United Kingdom.: Association of Researchers in Construction Management*.

Juhász, L., Rousell, A. & Jokar Arsanjani, J. 2016. Technical guidelines to extract and analyze VGI from Different Platforms. *Data*, 1, 15. https://doi.org/10.3390/data1030015

Kamal, E. M., Yusof, N. A. & Iranmanesh, M. 2016. Innovation creation, innovation adoption, and firm characteristics in the construction industry. *Journal of Science and Technology Policy Management*, 7, 43-57. https://doi.org/10.1108/JSTPM-03-2015-0011

Karan, E., Irizary, J. & Haymaker, J. 2015. *BIM and GIS Integration and Interoperability Based on Semantic Web Technology*.

Kasprzak, C. & Dubler, C. 2015. Aligning BIM with FM: streamlining the process for future projects. *Construction Economics and Building*, 12, 10.

Keat, Q. 2013. What it will take to ensure 5D BIM sustainability in Malaysia. Retrieved December, 20.

Kumar, S. S. & Cheng, J. C. P. 2015. A BIM-based automated site layout planning framework for congested construction sites. *Automation in Construction*, 59, 24-37. https://doi.org/10.1016/j.autcon.2015.07.008

Lai, K. S., Yusof, N. A. & Kamal, E. M. 2016. Innovation orientation in architectural firms. *Construction Innovation*, 16, 425-445. https://doi.org/10.1108/CI-05-2015-0030

Landpoint. nd. *Pre-Construction Planning Process: How Land Surveying Services Help* [Online]. Available: http://www.landpoint.net/value-added-land-surveying-services-pre-project-planning/ [Accessed 5 Sept 2017].

Latiffi, A. A., Brahim, J. & Fathi, M. S. Transformation of Malaysian construction industry with building information modelling (BIM). *MATEC Web of Conferences, 2016*. EDP Sciences, 00022. https://doi.org/10.1051/matecconf/20166600022

Latiffi, A. A., Mohd, S., Kasim, N. & Fathi, M. S. 2013. Building information modeling (BIM) application in Malaysian construction industry. *International Journal of Construction Engineering and Management,* 2, 1-6.

Lee, S. & Yu, J. 2017. Discriminant model of BIM acceptance readiness in a construction organization. *KSCE Journal of Civil Engineering*, 21, 555-564. https://doi.org/10.1007/s12205-016-0555-9

Liao, L., Teo, E. A. L. & Low, S. P. 2017. A project management framework for enhanced productivity performance using building information modelling. *Construction Economics and Building*, 17, 26. https://doi.org/10.5130/AJCEB.v17i3.5389

Liu, X., Wang, X., Wright, G., Cheng, J. C., Li, X. & Liu, R. 2017. A state-of-the-art review on the integration of Building Information Modeling (BIM) and Geographic Information System (GIS). *International Journal of Geo-information*, 6, 21. https://doi.org/10.3390/ijgi6020053

Livesey, P. V. 2016. Insights of project managers into the problems in project management. *Construction Economics and Building*, 16, 14. https://doi.org/10.5130/AJCEB.v16i1.4600

Ma, Z. & Ren, Y. 2017. Integrated Application of BIM and GIS: An Overview. *Procedia Engineering*, 196, 1072-1079. https://doi.org/10.1016/j.proeng.2017.08.064

Mele, R. & Poli, G. 2017. The effectiveness of geographical data in multi-criteria evaluation of landscape services †. 1*Data*, 2, 9. https://doi.org/10.3390/data2010009

Murguia, D., Brioso, X., Ruiz-Conejo, L. & Fernandez, L. 2017. Process integration framework for the design phase of a residential building. *Procedia Engineering*, 196, 462-469. https://doi.org/10.1016/j.proeng.2017.07.225

Nilsiam, Y. & Pearce, J. M. 2017. Free and open source 3-D model customizer for websites to democratize design with openSCAD. *Designs*, 1, 5. https://doi.org/10.3390/designs1010005

Nor'aini Yusof, K. S. L., Ernawati Mustafa Kamal, 2017. Characteristics of innovation orientations in construction companies. *Journal of Engineering, Design and Technology*, 15, 436-455. https://doi.org/10.1108/JEDT-06-2016-0037

Okoli, C. & Pawlowski, S. D. 2004. The Delphi method as a research tool: an example, design considerations and applications. *Information & management*, 42, 15-29. https://doi.org/10.1016/j.im.2003.11.002

Oo, T. Z. 2014. *Critical Success Factors for Application of BIM for Singapore Architectural Firms*. Heriot-Watt University School of the Built Environment.

Peckiene, A. & Ustinovičius, L. *Possibilities for Building Spatial Planning using BIM Methodology.* 2017. 851-858. https://doi.org/10.1016/j.proeng.2017.02.085

Ralf Becker, V. F., Sabrina Hoenen, Sören Loges, Sven Stumm, Jörg Blankenbach, Sigrid Brell-Cokcan, Linda Hildebrandt & Dirk Vallée 2018. BIM – Towards the entire lifecycle. *International Journal of Sustainable Development and Planning,* 13, 84-95. https://doi.org/10.2495/sdp-v13-n1-84-95

Rogers, J., Chong, H.-Y. & Preece, C. 2015. Adoption of Building Information Modelling technology (BIM): Perspectives from Malaysian engineering consulting services firms. *Engineering, Construction and Architectural Management*, 22, 424-445. https://doi.org/10.1108/ECAM-05-2014-0067

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Santos, R., Costa, A. A. & Grilo, A. 2017. Bibliometric analysis and review of Building Information Modelling literature published between 2005 and 2015. *Automation in Construction*, 80, 118-136. https://doi.org/10.1016/j.autcon.2017.03.005

Singh, M. M., Sawhney, A. & Sharma, V. 2017. Utilising building component data from BIM for formwork planning. *Construction Economics and Building*, 17, 17. https://doi.org/10.5130/AJCEB.v17i4.5546

Stanley, R. & Thurnell, D. P. 2014. The benefits of, and barriers to, implementation of 5D BIM for quantity surveying in New Zealand. *Construction Economics and Building*, 14, 13. https://doi.org/10.5130/ajceb.v14i1.3786

Strzalka, A., Bogdahn, J., Coors, V. & Eicker, U. 2011. 3D City modeling for urban scale heating energy demand forecasting. *HVAC&R Research*, 17, 526-539.

Thomson, C. 2016. *From Point Cloud to Building Information Model: Capturing and Processing Survey Data Towards Automation for High Quality 3D Models to Aid a BIM Process.* UCL (University College London).

Vijay K. Bansal, M. P. 2009. Extended GIS for construction engineering by adding direct sunlight visualisations on buildings. *Construction Innovation*, 9, 406-419. https://doi.org/10.1108/14714170910995949

Xia, B. & Chan, A. P. 2012. Measuring complexity for building projects: a Delphi study. *Engineering, Construction and Architectural Management*, 19, 7-24. https://doi.org/10.1108/09699981211192544

Yaakob, M., Ali, W. N. A. W. & Radzuan, K. Identifying critical success factors (CSFs) of implementing building information modeling (BIM) in Malaysian construction industry. *AIP Conference Proceedings, 2016*. AIP Publishing, 020105. https://doi.org/10.1063/1.4960945

Yeong, E. & Ragananthini, V. 2017. *CIDB to launch myBIM Centre in May*. The Sun, p.13.

Yusof, N., Mohd Shafiei, M. W., Said, I. & Zainul Abidin, N. 2010. Factors influencing firms' readiness towards innovation in house building industry: a multi-dimensional construct. *International Journal of Organizational Innovation*, 2, 74-88.

Yusof, N. A., Abu-Jarad, Y. & Badree, M. H. 2012. The effectiveness of government incentives to facilitate an innovative housing delivery system: the perspective of housing developers. *Theoretical and Empirical Researches in Urban Management*, 7, 55-68.