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Building Information Modelling for Building Services Engineering: Benefits, Barriers and Conducive Measures

Abstract

Purpose - Mandating the use of building information modelling (BIM) in building projects has sprawled, but the uptake of BIM in building services engineering (BSE) remains sluggish. The purpose of this paper is to explore how to achieve wider adoption of BIM in BSE.

Design / methodology / approach - Through an extensive literature review, the benefits of, barriers to and measures conducive to, using BIM for BSE were identified and classified. Built upon the review and a focus group meeting, a questionnaire was devised for an industry-wide survey in Hong Kong and the survey data were processed by statistical analyses.

Findings - On the ranking of the benefits, strong agreements existed between the BSE and non-BSE respondent groups; yet no signification agreement was found between the two groups on the rankings of the barriers or the conducive measures. The top conducive measure, according to the BSE group, is "Allow enough time in project programme for BIM model development".

Research implications - The data collection and analysis methods of this study may be used for similar BIM studies in other places.

Practical implications - The priority order of the conducive measures, which can aid policy or decision makers in formulating how to get BIM effectively implemented in BSE, are useful information in the pursuit of a more productive and sustainable built environment.

Originality/value – This BIM study is specifically on BSE rather than the other disciplines (e.g. architecture, structural engineering) that have been widely studied.

Keywords: Barrier, benefit, building information modelling, building services engineering, conducive measure, construction

1. Introduction

Building information modelling, or BIM, involves development and use of computer-generated models to manage and integrate the essential building design with project data in different phases of a building's life cycle. Emerged as a concept with the first notion of virtual buildings introduced in the 1970s (Eastman et al., 2011; Xiao and Noble, 2014), BIM was not widely implemented until the beginning of the recent decade. Notable examples of the growth of BIM include: in the US, BIM submissions for government projects have been made mandatory since 2006; in Singapore, BIM submissions for new building projects larger than 5000 square meters have been made mandatory since 2015; and in the UK, the government mandated the use of BIM to maturity Level 2 on all centrally procured government projects by 2016 (UK Government, 2012; Poole, 2015; Fung, 2017; Designing Buildings Wiki, 2019). In parallel to the growth of BIM, more and more studies have been conducted by academics, professional groups and software vendors (Autodesk, 2010; Volk et al., 2014; Parn et al., 2017).

Hong Kong, a metropolis located at the south-eastern tip of China, has an exceptionally high building density - more than 40,000 buildings over a land area of 1,106 square kilometres (HAD, 2019; HKSAR Government, 2019). Realizing the potentially positive impact of BIM on the construction industry, the Construction Industry Council (CIC) of Hong Kong issued a roadmap for BIM strategic implementation in the construction industry (Construction Industry Council, 2014). Nevertheless, the roadmap covers mainly the architectural and structural aspects; the coverage on building services engineering (BSE) is limited. The use of BIM in the building industry, in fact, remains voluntary and hence uncommon (Fung, 2017; Poole, 2015).

In practice, BSE is a multi-disciplinary profession that covers several trades of facilities: water supply and drainage; gas, phone and electricity; and air-conditioning and fire services, etc. (Yik et al., 2010; 2013). The term “BSE” is widely used in the United Kingdom, Ireland, Canada and Australia; in the US, it is often known as MEP (i.e. mechanical, electrical, and plumbing), architectural engineering or building engineering. Given that building services (BS) systems (e.g. chiller plant and chilled water pumping system for air-conditioning) and their components (e.g. chilled water pump, water pipe, valve, air handling unit, ductwork, damper, etc.) are sophisticated, the use of BIM in the BSE field is rare.

While the volume of BIM studies has continued to expand, there is a limited occurrence of research into the potentials of BIM in the BSE profession. Against this background, the Chartered Institution of Building Services Engineers (Hong Kong Branch), the Hong Kong Institution of Engineers (Building Services Division) and the Hong Kong Polytechnic University collaborated to carry out a research study, which aims to investigate how BIM could be effectively adopted in the BSE field, thereby bridging the gap of BIM usage in the building industry at large.

2. Literature Review

2.1 BIM – concept and theoretical background

Originated from simple computing applications in the 1960s, the concept of BIM evolved with solid modelling programmes improvements in the 1970s (Smith, 2014). Although the BIM concept has existed for many years, there is no single definition of BIM; rather, there are various ways of interpreting BIM. On one aspect, BIM is regarded as the development and the use of computer software model to simulate the construction and operation of the facility (NIBS, 2007). The resulting BIM model is a digital representation of the physical and functional characteristics of a facility, which serves as a shared knowledge of resource to the needs of various users and supports collaboration between different stakeholders at different phases of the life cycle (GSA, 2007, NIBS, 2007; Wheatley and Brown, 2007). Gu and London (2010), sharing the same idea, considered that BIM is an IT approach that enables the management of digital building information in different project phases in the form of a data repository. From another point of view, BIM is related to the management of information throughout the entire life cycle of a design process, from early conceptual design through construction administration till life cycle asset management (Ahmad et al. 2012). In a similar vein, Autodesk (2010) viewed BIM as an integrated process that vastly improves project understanding and allows for predictable outcome. Bearing a more inclusive definition, BIM can be regarded as a verb or adjective phrase to describe tools, processes, and technologies that are facilitated by digital machine-readable documentation about a building, its performance, its planning, its construction, and later its operation (Eastman et al., 2011).

Despite the varied definitions, BIM is far more than a digital model in which just the 3D information of the model is stored. The information contained in the project modelling can be expanded to 4D with construction process and scheduling, 5D with cost estimation for the project, 6D modelling with sustainability of the project, 7D modelling with facilities management and application, and even nD modelling (Ahmad, 2018; Wang, 2011). In fact, most of the definitions encompass a broad expense of common key features and capabilities of BIM, such as virtual modelling, information management, coordination / collaboration, standards support and ease to use (Ahmad, 2012).

For research applications, in general, a framework is a structure configured to contribute towards or guide an approach, interpretation and understanding of a certain subject (Kuiper and Duffield, 2018). In the context of BIM, however, the usage of the term “framework” varies considerably. Succar (2009) and Kassem (2014) suggested that a BIM framework is a theoretical structure explaining or simplifying complex aspects of the BIM domain by identifying meaningful concepts and their relationships. Under this category, a number of BIM research studies were conducted, with the term “BIM-based”, “BIM-aided” or “BIM-supported” used as a key descriptor. Inferred on this basis, the role that BIM plays in the research is secondary, as opposed to being the primary subject of the respective framework (Kuiper and Duffield, 2018).

From another perspective, a BIM framework is: "An integrated framework (incorporating) different approaches to information within a consistent whole. It might incorporate not only the information model but also the reference process model and dictionaries. It is possible that it may go further and also enable the inclusion of ontology / taxonomy developments from the world of classification" (Liebich, 2002). In other words, it attributes towards conceptualizing or explaining the phenomenon of BIM generally, including ensuring a BIM framework is "comprehensive enough to address all relevant BIM issues" and "concise enough to present key issues in a systematic manner" (Jung and Joo, 2011; Kuiper and Duffield, 2018).

In principle, the functions of BIM can be grouped into five categories (Baldwin, 2012): design (existing conditions modeling, spatial programming, design coordination); analysis (structural / energy / lighting analysis, model auditing, code checking); construction (site utilization, construction sequencing, cost estimation); operation (asset and space management, maintenance scheduling) and data management (managing metadata, linking database, interoperability and file exchange). While it is often impractical for any single BIM user to have expertise in all there areas, it is important to select which BIM functions are most applicable to one's own business (Baldwin, 2012).

Central to BIM is the creation and management of building "information", which depends on the Level of Development (LoD) adopted for the concerned BIM model. The LoD protocol is to enable construction professionals in the architecture, engineering, construction, and operations (AECO) industry to specify and articulate with a certain level of content clarity as well as reliability of the BIM models at various stages (Latiffi et al. 2015). LoD is associated with Level of Detail (Levy, 2012). The latter refers to the amount of graphical content provided in the building model elements whereas LoD is used to indicate the reliability of the element's geometry and related information (Latiffi et al. 2015; Law and Lai, 2018; Leite et al. 2011; Love et al. 2013). Basically, there are five main classes of LoD: 100, 200, 300, 400 and 500, among them different choices may be selected for different stages (from conceptual design to facility management) of a project (Latiffi et al. 2015).

2.2 BIM and BSE

BIM enables the management of graphical components and attributes of building information, allowing computer-aided generation of drawings and reports, design evaluation, project scheduling clash detection and resource organization from project design to building operation (Chan, 2014; Smith and Tardiff, 2009). These functions are useful to a great many building professionals, including the building services engineers (“BS engineers”).

The roles of BS engineers range from design, construction, operation to maintenance of facilities that are essential to the safety, comfort and environmental sustainability of buildings. Because the involvement of BSE in a project’s construction sequence hinges on other critical disciplines such as architecture and structural engineering, BSE is one of the riskiest sectors in the construction industry (Hanna et al., 2013). Yet, the rising interest of BIM in the BSE sector in recent years can be seen by referring to the potential merits it can bring to the consultants and contractors of building projects.

In some places, BSE is broadly divided into two main trades of installations: electrical and mechanical. In investigating the state of BIM practice in the US and the Canadian mechanical and electrical industries (Boktor et al., 2014; Hanna et al., 2013; 2014), a significant increase was found with the use of BIM in electrical contracting. Simonian et al. (2009) found that electrical contractors are able to expand their services with BIM implementation. Some studies found that 10-30% conflicts can be resolved by using BIM prior to the construction stage (Eastman et al., 2011), and the use of BIM in mechanical and electrical works can lead to an approximate 2% cost saving and 3% time saving (Korman et al., 2008). A few other studies, in addition, provided insights into the use and value of BIM in the mechanical and electrical construction industries (Azhar and Cochran, 2009; Azhar et al., 2008; Cerovsek, 2011; Holness, 2006; Howard and Bjork, 2008; Sacks et al., 2010). In Hong Kong, however, research on BIM for BSE is limited, and the pace of getting BIM implemented in BSE remains sluggish (Law and Lai, 2018).

2.3 Benefits of adoption of BIM

Worldwide many studies have proved that the adoption of BIM can bring multiple benefits to the AECO industry. Such benefits include: facilitate interdisciplinary communication and coordination, improve productivity and business outcomes, enhance customer service, and enable stakeholder and public engagement (Azhar, 2011; Boktor et al., 2014; Chan, 2014; Demian and Walters, 2014; Farnsworth et al., 2014; Hosseini et al., 2016; Rogers et al., 2015).

In both the design and construction stages, the use of BIM can achieve cost reduction or monetary gain (Azhar, 2011; Hanna et al., 2013; 2014; Hosseini et al., 2016; Rogers et al., 2015), reduction in project duration, improvements in information exchange and management, improved design quality and outcomes, improved interoperability and better visualization of information, better decision making, efficient assembly of data and information, and creation of a forward thinking platform etc. (Chen and Luo, 2014; Demian and Walters, 2014; Doumbouya et al., 2016; Eastman et al., 2011; Gerges et al., 2016; Love et al., 2014; Matarneh and Hamed, 2017; Rogers et al., 2015; Soon et al., 2015). Additionally, different project stakeholders are also beneficial from BIM adoption in these stages. For instance, architects can benefit from the capability of BIM in creating 3D renderings, graphically accurate models and digitized construction documents (Eastman et al., 2011); whereas quantity surveyors can also take advantage of BIM in carrying out more accurate cost planning, estimation and quantity takeoff in design stages (Aibinu and Venkatesh, 2013; Farnsworth, 2014; Holness, 2006; Popov et al., 2010; Stanley and Thurnell, 2014). In the construction stage, BIM is also beneficial to contractors for high profitability, better customer service, improved teamwork, safety planning and management, construction planning and monitoring, improved construction scheduling and progress tracking etc. (Hong et al., 2017; Succar, 2009; Volk et al., 2014; Zhang et al., 2013).

During the operation and maintenance stage of a building, BIM can enhance occupancy, whole lifecycle asset management, and sustainability and environmental performance (Azhar, 2011; Demian and Walters, 2014; Doumbouya et al., 2016; Eastman et al., 2011; Love et al., 2014; Parn et al., 2017). To building owners, implementation of BIM can enable them to achieve the desired outcomes, deliver explicit business benefits, and implement retrofit measures for the purposes of fuel and material savings, space optimization and configuration management, etc. (Love et al., 2013; 2014; Volk et al., 2014). To facility managers who look after buildings over their long operational period, the benefits of BIM include: data accuracy, visualization of assets, efficient data retrieval and storage, energy and space management, resource allocation and quality control (Becerik-Gerber et al., 2011; Love et al., 2014; Parn et al., 2017; Volk et al., 2014).

On the basis of the above review and an earlier review conducted by Chiu and Lai (2016), the benefits of BIM that are applicable to BSE were identified. In addition to the descriptions of such benefits and their reference sources, the building lifecycle stages to which the benefits are applicable are indicated in Table A1 in the Appendix Section.

2.4 Barriers to implementation of BIM

Against the above benefits are a plethora of barriers hindering the adoption of BIM. According to Azhar et al. (2008), for example, the issues leading to the slow uptake of

BIM fall into two types: "technical" and "managerial". Eastman et al. (2011), similarly, categorized the barriers to BIM adoption into: non-technical strategic barriers including legal and organizational issues, and technical barriers related to readiness and implementation.

In the technical aspect, three major issues retarding BIM implementation are: data interoperability across different software, computability of design data, and information exchange and maintenance among the BIM components (Autodesk, 2004; Azhar, 2011; Bernstein and Pittman, 2005; Girlo and Jardim, 2010; Matarneh and Hamed, 2017; Rogers et al., 2015; Sacks et al., 2010; Volk et al., 2014; Zhao et al., 2018). Some other technical barriers, including poor library, low running speed of the system, lack of table customization, lack of standards to guide for implementation, inaccurate data and information, were also identified (Azhar et al. 2008; Kiani et al., 2015; Luo, 2016; Rogers et al., 2015; Tse et al., 2005; Volk et al., 2014).

As regards the non-technical barriers, Sun et al. (2017) classified them into four categories, namely "cost", "management", "personnel" and "legal". The cost category contains factors such as high software service charge and training cost (Chan, 2014). The management category covers organization-related limiting factors such as lack of customized collaboration systems and data liability problem (Boktor et al., 2014; Hosseini et al., 2016; Porwal and Hewage, 2013; Matarneh and Hamed, 2017). The personnel category refers to the professional-related obstacles such as lack of knowledge, lack of skilled personnel and lack of education and training (Bin Zakaria et al., 2013; Bernstein and Pittman, 2004; Suprun and Stewart, 2015; Volk et al., 2015). Limiting factors in the legal aspect, which are caused by the immaturity of contractual / regulatory environment, include lack of standards to guide for implementation, legal and contractual constraints etc. (Azhar et al., 2008; RICS, 2011; Volk et al., 2014). Additionally, there are some other obstacles to BIM implementation, such as lack of government lead/direction, lack of client demand, and cultural issues (Abanda et al., 2014; Ayarici et al., 2009; Azhar et al., 2008; Hong et al., 2017; Rogers et al., 2015; Suprun and Stewart, 2015; Volk et al., 2015).

From a holistic perspective, Chiu and Lai (2016) classified the barriers that hinder the use of BIM into five categories: knowledge, finance, motivation, information and time (see detailed description in Table A2 in Appendix). The knowledge category refers to the limiting factors related to lack of familiarity and understanding of the relevant software and contractual requirements for BIM adoption, such as lack of training, education and new forms of contract. The financial category is about money-related limiting factors; for example, the BSE sector consists of not only large companies but also many small- and medium-sized companies that could hardly afford the high cost of BIM software. The motivation category is about lack of support from the relevant project parties, while for the information category, it refers to data-exchange and technology limiting factors. Timing issues, essentially, affect the opportunity of learning and practising the use of BIM.

2.5 Measures conducive to adoption of BIM

In order to seek answers to the question of what needs to be done to promote the uptake of BIM, professional groups such as RICS and the BIM4FM have conducted surveys to solicit opinions from industry professionals. From the responses of the surveys, measures that can help promote the adoption of BIM were drawn. Additionally, a number of countries have set up strategies to implement BIM technology (Ademci and Gundes, 2018). Critical strategies for successfully implementing BIM include: strong government support and leadership, further improvement of BIM standards, education and training on BIM certification and BIM technology (Ademci and Gundes, 2018; Smith, 2014).

In view of the global trend of using BIM, in Hong Kong, a seminar was organized to engage professionals and experts to share their relevant project experiences with the participants of the seminar. Grounded upon such expert opinions and experiences, the Construction Industry Council (2014) published a roadmap for the strategic implementation of BIM in the construction industry of Hong Kong. Forming an essential part of this roadmap are the measures recommended for promoting the use of BIM.

On the basis of the above-mentioned sources, a series of measures that are conducive to the adoption of BIM were collated, as summarized in Table A3 in Appendix.

2.6 Summary of literature review

The above review reveals that in some overseas places, there have been signs of increased use of BIM for building projects, including the electrical and mechanical engineering disciplines (i.e. BSE in the context of Hong Kong). The use of BIM can bring about a host of benefits to various stakeholders of building projects. Some of the benefits are applicable to the design and/or construction stage of building projects and some are even perpetual, realizable throughout the long operation and maintenance stage of existing buildings.

Beside the benefits, however, stands an array of barriers to the implementation of BIM. Such barriers include not only the technical difficulties but also the non-technical issues that restrain the spread of BIM over the AECO industry. From a more scrupulous perspective, there are five categories of the barriers: knowledge, financial, motivation, information and time. Any one of these barriers may discourage or prevent the project stakeholders from using BIM.

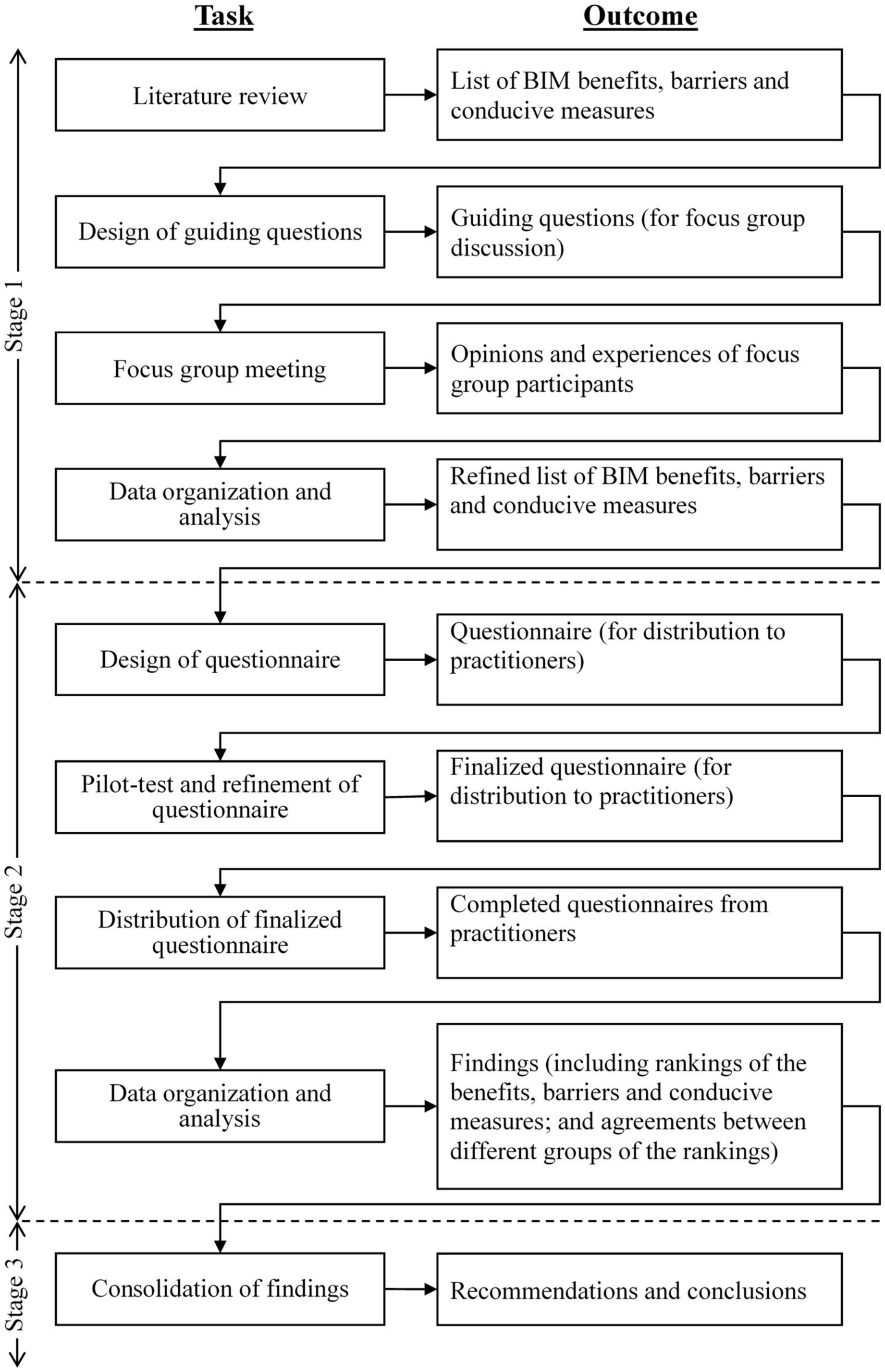
In recent years, more and more parties have attempted to identify what measures are helpful to lifting the adoption rate of BIM. Whereas a string of such measures have been proposed, to what extents they can conduce to the adoption of BIM in BSE are not known. If the measures are to be implemented, what would be their priority order? Questions of this kind are yet to be answered, given the limited occurrence of research on BIM potentials in the BSE sector.

To fill the above research gap, a study was initiated to investigate, from the eyes of the stakeholders of the building industry, the benefits of, barriers to, and measures that can help the implementation of BIM in the BSE profession. The means employed to collect data for the study, the data analysis methods and the analyzed findings are reported in the following.

3. Method and Data

The study was divided into three stages, as shown in Figure 1. In Stage 1, a research framework was formulated and an extensive literature review was conducted. Afterwards, a focus group meeting. In Stage 2, a questionnaire survey was conducted to gather views and opinions from practitioners about the benefits, barriers and conducive measures in the context of BIM for BSE in Hong Kong. After analyzing the data collected from the survey, the findings, upon consolidation in Stage 3, formed the basis for drawing the recommendations and conclusions given at the end of this paper.

Figure 1: Overall research process of the study



3.1 Data collection means

The focus group meeting, held after the literature review process, solicited in-depth opinions of the meeting participants, especially on the relevance and applicability of the review findings to the context of the study. Lasted for 3 hours, the meeting was attended by 15 experts, who were representatives of key stakeholder organizations including government departments, building developers, main contractors, and professional bodies of structural engineers, BSE consultants, BSE contractors, surveyors, facility managers and O&M professionals.

As reported in Ng and Lai (2016), the questions used at the meeting enquired into: usefulness of the key features of BIM for BSE; experiences of the representatives in using BIM; state of BIM applications; benefits of, and barriers to, BIM adoption; and possible ways for promoting the adoption. Each question was designed with multiple-choice answers or to be answered on a 7-point scale (none: 1; very little: 2; little: 3; moderate: 4; great: 5; very great: 6; entire: 7), such that the participants could select the answers that interpreted most closely their perceptions or experiences. Open-ended questions were also included in the questionnaire such that the participants could fully elaborate on their responses. The contents of the discussions were audio-recorded and transcribed.

After the focus group meeting, an online questionnaire was devised in order to gather the views and opinions of a large sample of respondents in the building industry. In preparing this questionnaire, the observations from the meeting were incorporated and some of the conducive measures identified from the foregoing literature review were adapted to suit the context of BSE. To ensure its validity, the questionnaire was reviewed by professionals working in the BSE sector before it was finalized.

The questionnaire comprises four sections. In the first section, the questions ask the respondents about their background, including work experience, professional membership and job discipline. Listed in the second and third sections are the benefits of, and barriers to, the use of BIM. The respondents were asked to rate, by referring to the same 7-point scale stated above, their level of agreement on how the benefits would help, or the barriers would hinder, the implementation of BIM for BSE. The questions in the last section requested the respondents to rate, using the same 7-point scale, how effective the conducive measures could help promote the adoption BIM for BSE.

With the support of 24 construction-related organizations (e.g. Real Estate Developers Association of Hong Kong, Hong Kong Institute of Architects, Hong Kong Institution of Engineers (Structural Division) Hong Kong Institution of Engineers (Building Services Division), Chartered Institution of Building Services Engineers (Hong Kong Branch), Hong Kong Institute of Surveyors, Hong Kong Construction Association, Hong Kong Institute of Facility Management, Building Services Operation and Maintenance Executives Society, Hong Kong Institute of Building Information

Modelling), their members were distributed with the online questionnaire. For the purpose of boosting the responses, two rounds of reminders were emailed to the recipients of the survey. Additionally the study team, through telephone calls, requested the organizations to broadcast a message to encourage their members to participate in the survey.

3.2 Data analysis methods

To start with, descriptive statistics on the key demographic information of the respondents, including their work experience, job nature and job level, were worked out. Using the 7-point ratings given by the respondents, the mean values for each of the rated items were calculated. Such a mean analysis (Lee et al., 2015; Li et al., 2017), applied to different groups of the responses, was used to establish the ranking of the benefits, barriers and conducive measures perceived by the respective groups.

For testing the agreements between different groups of rankings of the benefits, barriers and conducive measures, the Spearman's rank correlation method was used. This method, as a non-parametric measure of statistical dependence between the rankings of two variables, assesses how well the relationship between two variables can be described using a monotonic function.

The Mann Whitney *U* Test, also a non-parametric test, is a test of the null hypothesis that it is equally likely that a randomly selected value from one sample will be less than or greater than a randomly selected value from a second sample. The statistic of this test is the *U* value. The test can be used to compare whether two independent groups of respondents have the same rank distributions (George and Mallery, 2000). Here, the Mann Whitney *U* Test was conducted to determine whether the mean significance of each benefit, barrier and conducive measure item is equal across the BSE respondents and those of the non-BSE group.

4. Findings and Discussion

4.1 Participants of the survey

The total number of responses to the online survey was 419, among them 248 were received from BS engineers, 100 from non-BS practitioners, and the rest from those with mixed disciplines involving BSE. In the following analyses where a clear distinction between the opinions of BS engineers and non-BS practitioners was needed, the responses given by the first two groups (i.e. BSE and non-BSE), hereinafter referred to as "participants", were considered.

Of the 348 participants, over half (53.6%) were experienced practitioners who, on average, had more than 10 years of work experience (Figure 2a). The proportions of those working as designers and those working on construction of new buildings were the major groups of respondents (Figure 2b). A comparatively less proportion (6.0%) of the participants purely worked on existing buildings, responsible for facility management (FM) or operation and maintenance (O&M) of the buildings. As regards job level, most of the participants (77.0%) were at the middle level (e.g. manager, engineer) whereas the proportion of those at the senior level (e.g. director, department head) was close to the counterpart of the frontline level (e.g. foreman, technician) (Figure 2c).

Figure 2a: Work Experience

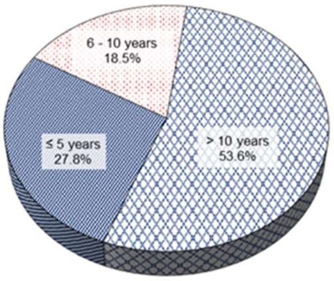


Figure 2b: Job Nature

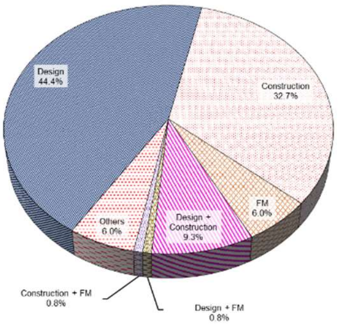
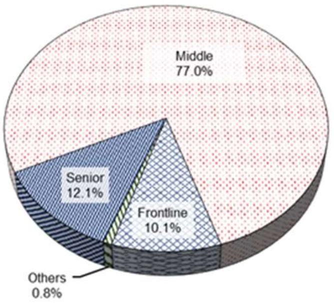


Figure 2c: Job Level



4.2 Rank orders of the benefits, barriers and conducive measures

Based on the responses of the participants, the mean value of each item in the three aspects (benefit, barrier and conducive measure) was calculated. This was done for all the responses (i.e. overall) and for each of the two subdivided groups (i.e. BSE and non-BSE). As space limitation prohibits a detailed presentation of all the calculated results here, the results shown and discussed in the following cover only the highly regarded items. Such items are among the top five in the overall ranking or the top three in either one of the two grouped rankings.

Figure 3a: Mean values and ranks of BIM benefits

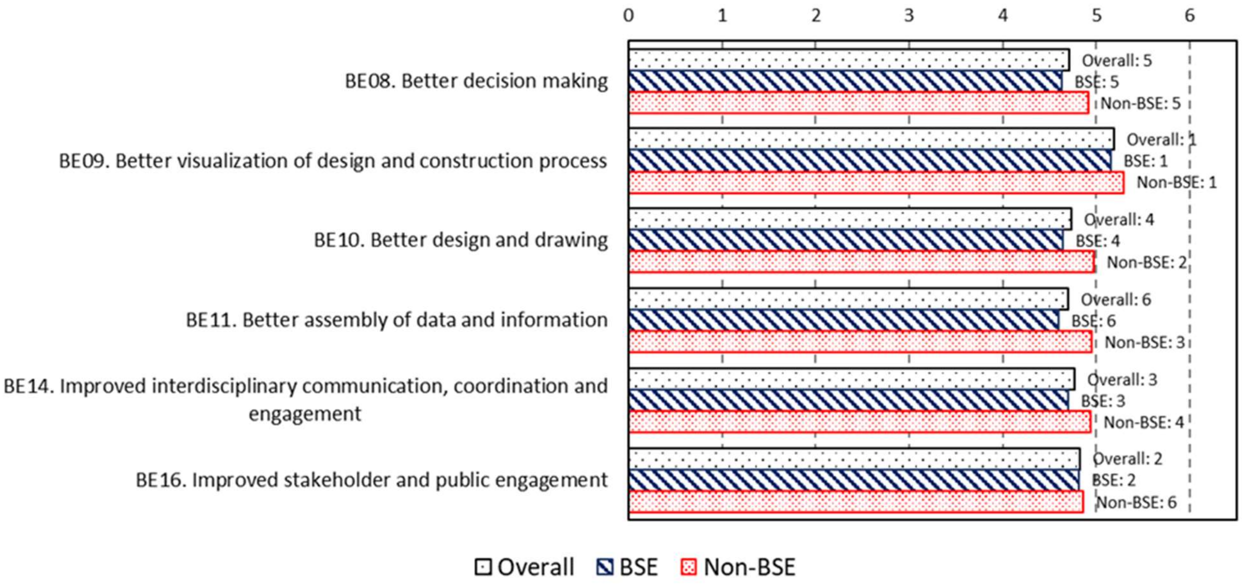


Figure 3b: Mean values and ranks of BIM barriers

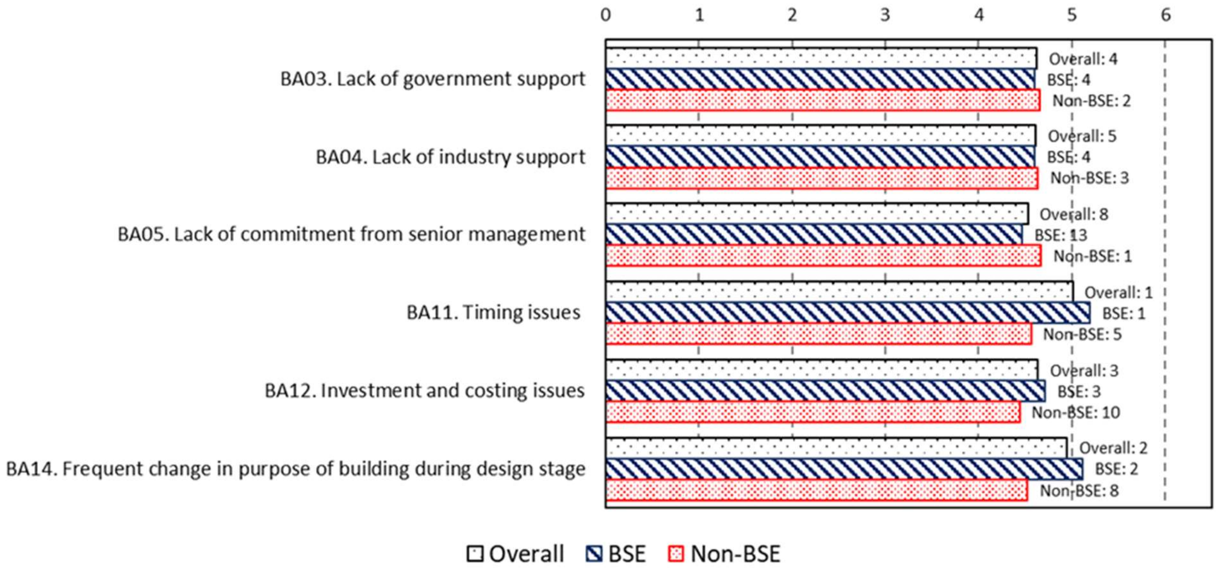
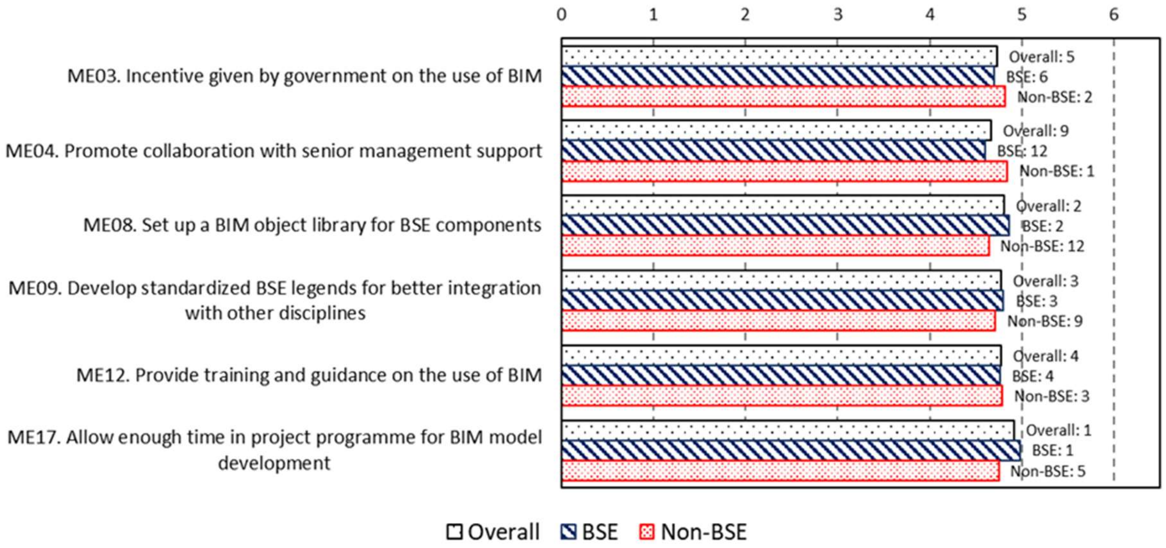


Figure 3c: Mean values and ranks of BIM conducive measures



Overall, as Figure 3a shows, “Better visualization of design and construction process (BE08)” was considered the most valuable benefit of using BIM for BSE. This benefit item also ranked the first, according to both the BSE and non-BSE participants. It is well known that the n-D depiction/visualization function of BIM software enables BS engineers to carry out coordination between the multiple trades of complex BS installations during the design and construction stages (Eastman et al., 2008; Lee et al., 2015). By creating visualization models, BS engineers can quickly analyse and compare design alternatives, saving time and cost for selecting the best design option.

“Improved stakeholder and public engagement (BE16)”, which came in the second place based on the responses overall and those of the BSE group, was rated by the non-BSE group as the sixth benefit to BSE. In practice, design proposals can be better understood through accurate visualizations (Construction Industry Council, 2014). Appropriate use of BIM, therefore, can help BS engineers to present their design intentions to project clients and members in the same project team, such as architects and structural engineers.

BIM is a collaborative approach that improves communication and coordination means between all of the design and construction disciplines (Eastman et al., 2008; McGraw Hill Construction, 2009; Succar, 2009). When BSE coordination work starts, project team members can readily refer to BIM models to retrieve any specific information needed instead of searching and requesting information from the right source. The interconnection between the team members, which is available through using BIM, can facilitate information sharing and exchange. This also enables the optimal use of team members’ competence in the project (Zhao et al., 2018). With these advantages, "Improved interdisciplinary communication, coordination and engagement (BE14)" was rated as the third benefit by the BSE group and the fourth by the non-BSE group.

Further inspections on the ranks of the remaining items found that for "Better design and drawing (BE10)" and "Better assembly of data and information (BE11)", their ranks differ between the two respondent groups, but the differences are not substantial. "Better decision making (BE08)" was ranked in the fifth place. This applies to the overall responses, the BSE group, and the non-BSE group.

Referring to the results in Figure 3b, "Timing issues (BA11)" was regarded by the BSE group as the strongest barrier to using BIM. But this item was ranked only the fifth, according to the responses of the non-BSE group. In real-world projects, design and construction programmes are typically tight. The parties involved seldom have enough time to consider and evaluate the applicability of BIM in the projects, which impedes the use of BIM in practice (McGraw Hill Construction, 2009).

"Frequent change in purpose of building during design stage (BA14)" and "Investment and costing issues (BA12)", while rated by the BSE group as the second and third strongest barriers respectively, received rather low ratings from the non-BSE practitioners. Investment on the use of BIM is dependent on the organization size and level of resources committed. Nowadays, small and medium-sized contractor organizations are not willing to use BIM tools because of the high implementation expenses, such as licence purchasing fees, costs of hardware and software upgrading, ingoing maintenance fees and staff training expenses (Hong et al. 2017; Jensen and Johannesson, 2013). Interestingly, "Lack of commitment from senior management (BA05)" was not rated high by the BSE group. This suggests that senior management of the BSE participants might have expressed their commitment in principle but not in action yet. Note that the implementation of BIM incurs not only high initial cost but also substantial resources for hardware, software and training (Hanna et al., 2013; 2014).

The remaining two barriers, namely "Lack of government support (BA03)" and "Lack of industry support (BA04)", recorded a tied rank of 4 when considering the responses of the BSE group. The ratings given by the non-BSE group on these two barriers are slightly higher. Contributory to these observations may include several factors. For instance, so far no subsidies or incentives have been launched by the Hong Kong government to support the implementation of BIM. Standardization of BIM objects for BS equipment (e.g. chiller, pump, fan) and their associated information and data is yet to be established by the relevant industry stakeholders, including contractors, suppliers and manufacturers.

Pragmatic measures are indispensable for making the use of BIM happen. The results in Figure 3c show that “Allow enough time in project programme for BIM model development (ME17)” was regarded by the BS practitioners as the most useful conducive measures for BIM adoption. This finding echoes the earlier observation that “time issues” is the top BIM barrier. Sufficient time, therefore, must be allowed in project programmes for the preparation of BIM models.

“Set up a BIM object library for BSE components (ME08)” and “Develop standardized BSE legends for better integration with other disciplines (ME09)”, though regarded by the BSE group as the second and third measures conducive to the use of BIM, obtained relatively low ratings in the non-BSE group. This is probably because of their little concern on the use of BIM objects and legends for BSE components. On the other side, in the absence of a consensus on the scope and content of product data files in BIM, the Chartered Institution of Building Services Engineers has endeavored to establish standard product data templates (PDTs) for BS components (CIBSE, 2017). But a full set of such PDTs, as of this writing, is not yet released.

Following the above three key measures include “Provide training and guidance on the use of BIM (ME12)” and “Incentive given by government on the use of BIM (ME03)”. Whereas “Promote collaboration with senior management support (ME04)”, according to the non-BSE practitioners, is the most conducive measure, it was not highly regarded by the BSE group. This result is consistent with the finding from Ding et al. (2015) that management support is not crucial to BIM adoption. One possible explanation is that the non-BSE practitioners, as compared to BS engineers who have limited experience in using BIM, are more aware of the benefit of BIM in improving their competitiveness. This implies that a top-down approach, with tangible support given by senior management of the BS practitioners, is essential for getting BIM implemented in BSE.

4.3 Spearman rank correlation results

To process the large volume of data about the agreement ratings for the items in the three aspects (benefits, barriers and conducive measures) of BIM for BSE, the SPSS software was used to calculate the Spearman’s rank correlation coefficients for the rankings of the items between the BSE and non-BSE participants. The rank correlation coefficient (2-tailed significance) for the items in the benefits aspect was found to be 0.933 (0.000). This shows that there were strong agreements between the ranking results of the two groups of participants.

The rank correlation coefficients for the other two aspects (i.e. barriers and conducive measures), on the other side, were found to be 0.294 (0.288) and 0.376 (0.137) respectively. These results imply that for both the barrier aspect and the aspect of conducive measures, the two groups had no significant agreement on the rankings of the rated items. In other words, the BS engineers and the non-BSE construction professionals held different views on the rankings of the extents to which the barriers hinder the adoption of BIM for BSE, and their views on the rankings of the conducive measures were also significantly different.

The analyses so far serve as a preliminary screening on the agreement between the views of the BS and non-BS practitioners on the three aspects about BIM for BSE. In order to identify any significant difference between the views of the two groups on each of the rated items (under the three aspects), a series of Mann Whitney *U* Tests were carried out.

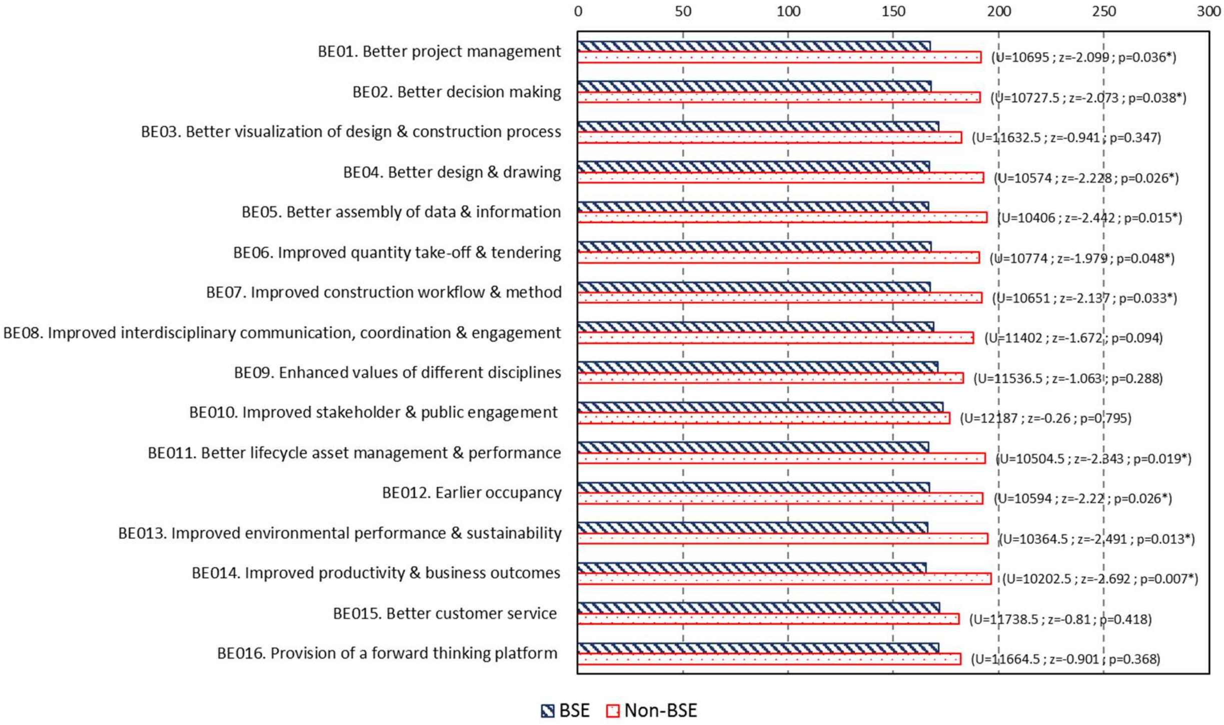
4.4 Mann Whitney U Tests results

Using the SPSS software, the mean rank values of the Mann-Whitney *U* Tests, the values of the test statistics *U*, *z* and probability (*p*; two-tailed) were obtained, as summarized in Figures 4 to 6.

4.4.1 *Benefits of using BIM for BSE*

Between the two groups (BSE and non-BSE), there were differences in the mean rank values of some benefit items (Figure 4). Further inspection on the test statistics revealed that most of the *p*-values are smaller than 0.05, indicating that there were significant differences between the views of the two groups on 10 of the 16 benefit items. The first two are: “Better project management (BE01)” and “Better decision making (BE02)”. Their mean rank values show that the non-BSE practitioners, when compared with the BSE group, perceived a higher level of the benefit of these two items. This observation is in line with those shown earlier: BIM can help construction professionals to better understand the project environment and facilitate progress monitoring for project management and decision making (Song et al., 2012; Taylor and Bernstein, 2009). The fact that the use of BIM in the BSE sector remains at a preliminary stage and the lack of real, comprehensive examples showing how to use BIM to actually manage and solve BS coordination problems should have contributed to the comparatively low ratings given by the BSE group on the two benefits. This situation may change if, and when, BIM has become more widely adopted in the BSE sector.

Figure 4: Mann-Whiney U Test results of BIM benefits



*Significant at the 0.05 level (2-tailed)

"Better design and drawing (BE04)" and "Better assembly of data and information (BE05)" are two other benefits that were more highly regarded by the non-BSE group than by the BSE group. It is known that architects can benefit from BIM's capability of creating n-D renderings, graphically accurate models and digital construction documents (Azhar et al., 2008; Kaner et al., 2008). BIM models are linked to databases and any changes in the databases will be reflected throughout the models, thus eliminating oversights and the need of revising the models and drawings (Arayici et al., 2012). While the use of BIM is also beneficial to the design and installation of mechanical and electrical services as well as their coordination with other building systems (Eastman et al., 2011; Holness, 2006), the frequent change in the services design in the construction stage hampers the use of BIM for BS design and drawing production. Given the typically tight programme for developing building projects in Hong Kong, moreover, BS engineers have difficulty in ensuring the required levels of details and accuracy of BSE data in the BIM models.

The benefits of using BIM for BSE, in terms of "Improved quantity take-off and tendering (BE06)" and "Better lifecycle asset management and performance (BE11)", received higher ratings from the non-BSE group. In fact, Nassar (2011) had proved that BIM will increase the precision and accuracy of quantity estimate. Being able to provide a high level of cost details for managing the functions of a facility throughout its entire life cycle, BIM is the future of facility management, which optimizes the operation and maintenance costs (Baldwin, 2012; Eastman et al., 2008; Lee et al., 2013). But when compared with surveyors who are charged with the responsibility of cost control, BS engineers are less involved in cost issues.

The Mann-Whitney *U* test results also show that the ratings given by the BSE group on "Improved construction workflow and method (BE07)" and "Earlier occupancy (BE12)" were lower than those given by the non-BSE group. In principle, the n-D modelling capability of BIM provides a powerful tool that gives project teams a better understanding of project milestones and construction plans. The simulation tool of BIM software also helps the teams in identifying problems well in advance of construction activities. In this way, the efficiency of construction can be improved, making it feasible to achieve earlier project completion. In reality, however, most of the BSE contractors are subcontractors of construction projects (Yik and Lai, 2008), with the main contractor often in charge of the main construction process. As such, BSE contractors do not have a great control on the overall construction workflow.

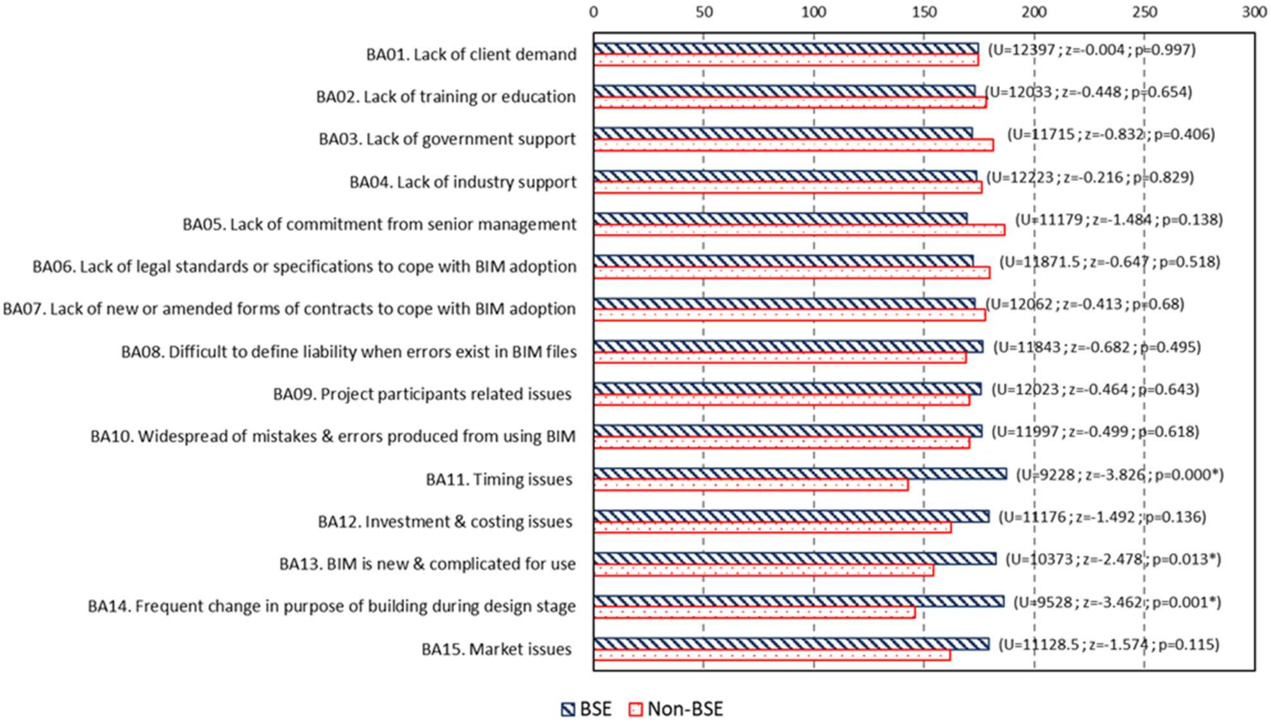
In parallel to the rising energy cost and environmental concerns, the demand for sustainable buildings with minimal environmental impact has increased (Azhar et al., 2009; Schade et al., 2011). BIM models can aid decision makers to predict the lifecycle performance of buildings and operate the buildings in a green way (Lee et al., 2013; Schade et al., 2011), leading to improved construction productivities and business outcomes. However, it is important to note that the improvement of environmental performance, productivity and business outcomes are long-term BIM implementation benefits, which are unlikely to be realized at the early stages of BIM implementation (Hong et al. 2017). Furthermore, in Hong Kong, the knowledge level of O&M practitioners about sustainable buildings was less than satisfactory (Lai and Yik, 2006). Although the need for O&M education has been revealed (Lai, 2010), higher education programmes tailored for producing building O&M graduates remain unavailable. These are the likely reasons for the comparatively low ratings given by the BSE group on benefit items BE13 and BE14, i.e. "Improved environmental performance and sustainability" and "Improved productivity and business outcomes".

4.4.2 Barriers to using BIM for BSE

Referring to the summary of test statistics of the Mann-Whitney *U* Tests in Figure 5, most of the *p*-values exceed 0.05, indicating that there were no significant differences in the views of the two groups (BSE and non-BSE) on most of the barriers to using

BIM for BSE. Yet, there are three exceptions, and two of them are: “Timing issues (BA11)” and “Frequent change in purpose of building during design stage (BA14)”. At least two factors may have constituted the significant difference between the perceived levels of the two groups on these two barrier items. First, the Hong Kong construction industry has a fast-track culture (Ren and Kumaraswamy, 2013). In order to minimize project periods, the participants of most projects, especially the BS engineers who need to handle multiple trades of BS installations, have to compress their worktime. Second, when there are changes in design requirements, e.g. upon client’s instruction, BS design consultants would find it difficult to cope with, resulting in construction delays (Chiu and Lai, 2017).

Figure 5: Mann-Whiney U Test results of BIM barriers



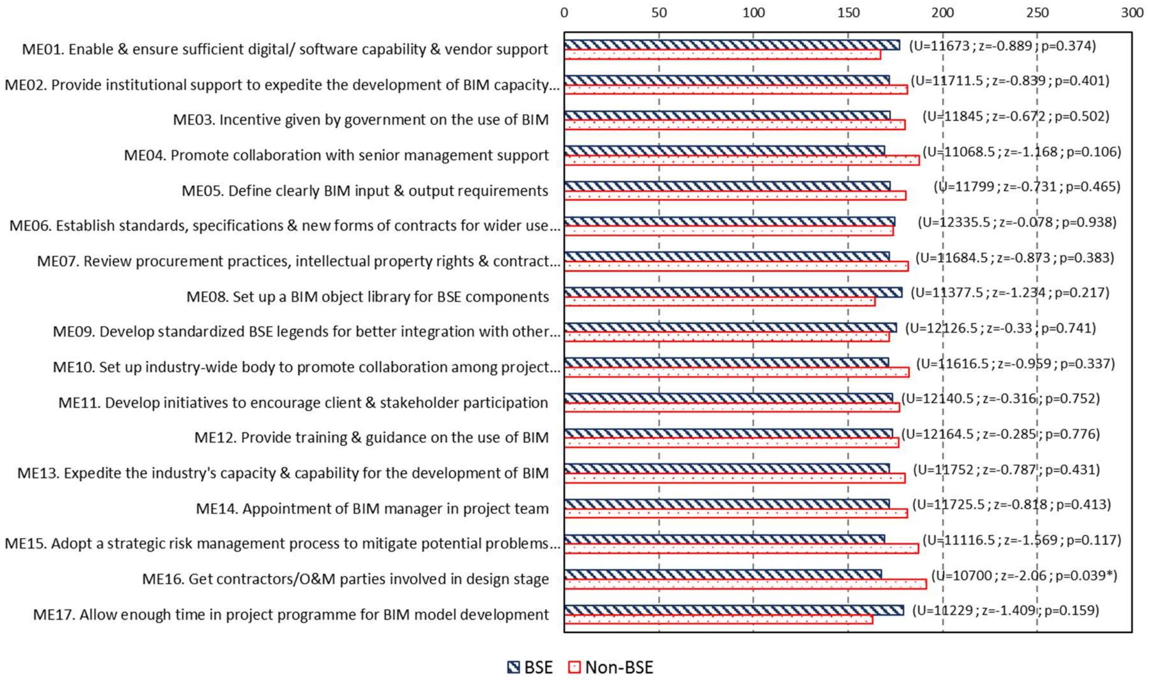
*Significant at the 0.05 level (2-tailed)

The BSE group indicated a higher level of perception of the barrier “BIM is new and complicated for use (BA13)” than the non-BSE group did. This is not unexpected because when taking up BIM, new technological requirements are needed to ensure effective interoperability and information exchange. The traditional roles and training received by the BS engineers may impede them learning new knowledge and skills for BIM. Some engineers may not even have the basic training to learn and apply BIM to fulfill their duties (Ding et al. 2015). To date, the coverage of BIM in the BSE programmes offered by the local universities is limited. Even though there are BIM short courses in the market, their contents are more about architecture or structural engineering rather than BSE. Thus, it is imperative to provide extensive training in order to avoid misuse or potential errors during the implementation of BIM (Ding et al. 2015).

4.4.3 Conducive measures for promoting adoption of BIM for BSE

There are no significant differences between the views of the BS practitioners and the non-BSE practitioners on all, except one, of the conducive measures (Figure 6). The only exception is “Get contractors/O&M parties involved in design stage”. The reasons for this finding come from two sides. To the non-BSE construction professionals, it is ideal from a project management perspective to allow contractors or O&M parties to get involved in the early stage of the project, as this can improve the design quality and foster an effective process for coordination between different project stakeholders. To the BS engineers, however, the effect of the measure (ME16) may not be high. This is because fragmentation has long been a problem of the BSE industry (Yik et al., 2006). The majority of the BS design or construction practitioners seldom switch to work in the O&M sector. Neither is it common for the O&M practitioners to take up BS design or construction jobs.

Figure 6: Mann-Whiney U Test results of BIM conducive measures



*Significant at the 0.05 level (2-tailed)

5. Roadmap for Enabling BIM Adoption in BSE

Among the various measures that could be taken to promote the use of BIM, there are three top measures that should be placed at the forefront of an enabling roadmap. The top measure (ME17) is that enough time must be allowed for BIM model development. This requires, during the project planning stage, the advice from BIM experts on the amount of time needed for the model development. Meanwhile, the support from the project client and the design team is indispensable for making this happen. The second measure (ME08) is to set up a BIM object library for BSE components. Given that BSE embraces multiple trades of work (e.g. air-conditioning, electrical, fire services, plumbing, drainage, etc.) and the numerous components of each trade, including the large (e.g. a packaged chiller) and smaller (e.g. a switch) ones, resolve and resources are needed to realize this measure. The third measure "Develop standardized BSE legends for better integration with other disciplines (ME09)" also entails substantial effort to achieve. Not only is this because BSE components are voluminous, but the practice that not all BSE legends have been standardized is also a hurdle to tackle.

6. Implications

Providing insights into the key features of BIM, the findings of this study contribute to improving the understanding of the benefits of, and barriers to, adoption of BIM for BSE. Measures that can help promote the use of BIM are also made clear. The way in which the benefits and barriers were categorized (with respect to the different lifecycle stages of a building project) in this study can serve as a reference model for classifying similar matters to be investigated in other studies.

The research approach of this study can be taken to investigate how to raise the uptake of BIM in other places with a built environment akin to that of Hong Kong. The study results, especially the priority order of the conducive measures, can help formulate how to get BIM effectively implemented in BSE.

7. Conclusions

The advantages of BIM have been well known, the realm of BIM studies has continued to expand, and the use of BIM for building projects has been increasingly mandated around the world. But in places such as Hong Kong where the buildings have been densely developed, the use of BIM remains a voluntary option and the effort made to encourage the implementation of BIM for BSE is far less than the counterpart for other disciplines (e.g. architecture and structural engineering) of the AECO industry.

The extensive literature review completed under the study identified the benefits of BIM to

BSE and classified their applicability by different building lifecycle stages (design, construction and maintenance). The barriers to using BIM for BSE were revealed, with the categories (knowledge, financial, motivation, information and time) to which they belong determined. Also made clear from the review are the measures that can facilitate the uptake of BIM in BSE.

The statistical analyses made on the responses to the industry-wide survey show that on the ranking of the benefits of BIM to BSE, strong agreements existed between the BSE and non-BSE respondent groups. On the rankings of both the barriers and the conducive measures, however, no signification agreement was found between the two groups. Such a difference in opinions is an essential point to note when promoting the use of BIM.

To both the BSE and non-BSE practitioners, “Better visualization of design and construction process” is the greatest benefit of BIM. According to the non-BSE group, “Timing issues” is not a top barrier to using BIM, but the finding that the BS practitioners considered it as the greatest hurdle warrants particular attention. Given that the BSE group also regarded “Allow enough time in project programme for BIM model development” as the paramount measure conducive to BIM adoption, priority should be given to incorporate it into the action plan for boosting the uptake of BIM.

Two other measures that conduce to the use of BIM, namely “Set up a BIM object library for BSE components” and “Develop standardized BSE legends for better integration with other disciplines”, were highly regarded by the BS practitioners. These two measures and the above top-priority measure, on the other hand, were considered by the non-BSE practitioners as of low importance. This underscores the significance of investigating and distinguishing the differences in the opinions between different stakeholders, in this case the BSE and non-BSE groups.

8. Limitations and future studies

Although the research team has made every effort possible in conducting the above study, it is not without limitations. First, the survey participants of the study were based in Hong Kong. Before the study findings could be generalized to represent the phenomenon in an international context, further studies need to be carried out to cover participants from other places. Second, the analyses were focused on examining any difference in the responses between the BSE and non-BSE participants. Studies in future should investigate the opinions and experiences of practitioners playing different roles in a building life cycle, such as client, consultant, constructor, operator, maintainer and facility manager.

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Appendix

Table A1: Summary of BIM benefits

Benefit [description]	**Source**	**Stage***		
		D	**C**	**M**
Better project management [BIM systems having model production enables the construction sequence to be simulated prior to construction, which also facilitates activity programming for project management]	Boktor et al. (2014), British Standards Institution (2010), Bryde et al. (2013), Bynum et al. (2013), Chan (2014), Construction Industry Council (2014), Doumbouya et al. (2016), Guo et al. (2014), Hanna et al. (2013), Hanna et al. (2014), Khanzode et al. (2008), McGraw Hill Construction (2009)	•	•	•
Better decision making [Visual representations of BIM can help to enhance project stakeholders to understand the design details, resolve problems and aid decision-making]	Allen Consulting Group (2010), Construction Industry Council (2014), Lee et al. (2015)	•	•	
Better visualization of design and construction process [BIM shows what different options look like, not only upon completion but before and during the works. Its visualization capacity can help project participants to better understand the design and construction process]	Ahmad et al. (2012), ASHRAE (2009), Azhar (2011), Boktor et al. (2014), Chan (2014), Guo et al. (2014), Hanna et al. (2014), Hong et al. (2017), Khanzode et al. (2008), Stanley and Thurnell (2014)	•	•	
Better design and drawing [Using BIM in the design phase can help to ensure consistency among a project's many plans and drawings and monitor changes easily throughout the design process]	Azhar et al. (2008); Azhar (2011), Boktor et al. (2014), Chan (2014), Construction Industry Council (2014), Doumbouya et al. (2016), Eastman et al. (2008), Hanna et al. (2013), Hanna et al. (2014)	•		
Better assembly of data and information [With consistent and standardized exchange of information, BIM can reduce the information lost during handover from designer to contractor]	Azhar (2011), British Standards Institution (2010), Construction Industry Council (2014), Chan (2014), Demian and Walters (2014), Doumbouya et al. (2016), Hong et al. (2017)	•	•	
Improved quantity take-off and tendering [When BIM is correctly aligned with the method of measurements, the programme can generate the necessary quantity of materials for measurement purpose]	Boktor et al. (2014), British Standards Institution (2010), Chan (2014), Stanley and Thurnell (2014), Eastman et al. (2011)	•	•	

Benefit [description]	**Source**	**Stage***		
		D	**C**	**M**
Improved construction workflow and method [BIM provides previews of the site planning and construction works, which facilitates the enhancement of construction sequence and method]	Boktor et al. (2014), Doumbouya et al. (2016), British Standards Institution (2010), Construction Industry Council (2014), Khanzode et al. (2008), McGraw Hill Construction (2009)		•	
Improved interdisciplinary communication, coordination and engagement [BIM enables significant improvements in inter-disciplinary coordination and communication through the use of consistent and standardized information]	Boktor et al. (2014), British Standards Institution (2010), Bryde et al (2013), Chan (2014), Construction Industry Council (2014), Hanna et al. (2013), Hanna et al. (2014), Khanzode et al. (2008), McGraw Hill Construction (2009)	•	•	•
Enhanced the value of different discipline [BIM help the professionals to execute labour intensive work (e.g. CAD drafting, quantity measurement), thereby freeing professionals to focus on value-added work and activities]	Allen Consulting Group (2010), Construction Industry Council (2014), Eastman et al. (2011)	•	•	•
Better lifecycle asset management and performance [An accurate BIM model captures the requirements, design, construction and operational information etc. facilities management of the building. Through more detailed asset and lifecycle planning, lifecycle costs are better understood and performance is more predictable]	Azhar (2011), Becerik-Gerber et al. (2012), BIM4FM (2013), Boktor et al. (2014), British Standards Institution (2010), Bynum (2013), Construction Industry Council (2014), Guo et al. (2014); Love et al. (2014), Parn et al. (2017), Volk et al. (2014)			•
Earlier occupancy [By utilizing BIM, the efficiency of construction can be improved and hence earlier use of the building can be achieved]	ASHRAE (2009), Boktor et al. (2014) Construction Industry Council (2014)		•	•
Improved environmental performance and promote sustainability [The full 3D energy consumption analysis can be performed by the BIM model and simulation programme with a short lead time]	ASHRAE (2009), Azhar (2011), BIM4FM (2013), Boktor et al. (2014), British Standards Institution (2010), Bynum et al. (2013), Construction Industry Council (2014), Doumbouya et al. (2016), Eastman et al. (2011); Love et al. (2014), Parn et al. (2017)		•	•
Improved productivity and business outcomes [As a clearer link between design decisions and cost implications are developed through BIM adoption, the client are able to attain better productivity and business outcomes for the company, such as fuel and material savings, comfort management and space optimization]	Boktor et al. (2014), Bryde et al (2013), Chan (2014), Construction Industry Council (2014), Demian and Walters (2014), Guo et al. (2014), Hosseini et al. (2016), Love et al. (2014), McGraw Hill Construction (2009)	•	•	•
Better customer service [By improving communication and understanding of the clients' needs for the project at the at the planning and design stage, BIM can help the construction professionals and contractors to provide better service to the client]	Azhar (2011), Chan (2014), Construction Industry Council (2014)	•	•	•
Improved stakeholder and public engagement [BIM improves a project team's ability to present the specifics of a design and their intentions to stakeholders and the public.	Chan (2014), Construction Industry Council (2014), Lin (2014), Farnsworth et al. (2014)	•	•	•

Benefit [description]	**Source**	**Stage***		
		D	**C**	**M**
Proposals can be better understood by the public through accurate visualizations]				
Provision of a forward thinking platform [BIM "pre-builds" a project, allowing problems to be addressed as and when found throughout the design process]	Construction Industry Council (2014), Khanzode et al. (2008)	•	•	

*Lifecycle stage: D – Design; C – Construction; M – Maintenance.

Table A2: Summary of BIM barriers

Barrier [description]	**Source**	**Barrier***				
		K	**F**	**O**	**I**	**T**
Lack of client demand [Adopting BIM incurs the client to pay more professional fees to the design professionals. Private clients will demand BIM in their project design and construction when they realized the benefits of BIM]	Azhar and Cochran (2009), Chan (2014), Gerges et al. (2016), Kiani et al. (2015), RICS (2011), Rogers et al. (2015), Tse et al. (2005), Volk et al. (2014)			•		
Lack of training or education [Although there is a wide range of BIM short courses offering in the market, the quality of these BIM courses varies considerably as no clear BIM guidelines are available for institutions to follow]	Chan (2014), Gerges et al. (2016), Gu et al. (2008), Kiani et al. (2015), Matarneh and Hamed (2017), RICS (2011), Yan and Demian (2008)	•				
Lack of government support [Government support is strongly related to the ambitious of BIM implementation in the construction industry]	Bin Zakaria et al (2013), Crowley (2013); Chan (2014), Hosseini et al. (2016), Matarneh and Hamed (2017), Mitchell and Lambert (2013), RICS (2011)			•		
Lack of industry support [There is insufficient number of case studies showing the potential financial benefit of BIM, the AEC industry is generally not interested in investing towards the change in technology]	Gu and London (2010), Hosseini et al. (2016), Rogers et al. (2015), Yan and Demian (2008)			•		
Lack of commitment from senior management [The senior management displays a hesitancy in implementing BIM on a project because of the lack of knowledge about BIM and its distinctive capabilities in the field of construction industry, where BIM benefits are still misunderstood or not known to those not use it in their works]	Becerik-Gerber et al. (2011); Gerges et al. (2016), Mitchell and Lambert (2013), Soon et al. (2015), Yan and Demian (2011)		•	•		
Lack of legal standards or specification to cope with BIM adoption [There is a lack of relevant contract terms and legal standards that reflect the changes in data ownership, confidential information, risk allocation, and procurement practices that will be affected by the adoption of BIM]	Aibinu and Venkatesh (2013), Azhar et al. (2008), BIM4FM (2013), Bin Zakaria et al (2013), Burcin and Kensek (2010), Chan (2014), Construction Industry Council (2014), Kiani et al. (2015),	•				

Barrier [description]	Source	Barrier*				
		K	F	O	I	T
	RICS (2011), Stanley and Thurnell (2014)					
Lack of new or amended form of contract to cope with BIM adoption [Prior to BIM adoption, there is a need to review existing contract provisions as to ensure the responsibilities and risks among contracting parties can be properly reflected]	Boktor et al. (2014), Burcin and Kensek (2010), Chan (2014), Construction Industry Council (2014), RICS (2011), Volk et al. (2014)	•				
Difficult to define liability when errors exist in BIM files [If a perceived design error is found in the owner of the building files, contributors of the BIM process will look to each other to try to determine who has responsibility for the matter raised. If disagreement ensues, the lead professional will not only be responsible as a matter of law to the claimant but may have difficulty proving fault with others]	Aibinu and Venkatesh (2013); Azhar et al. (2008); Becerik-Gerber et al. (2011); Gu et al. (2008); Gu and London (2010), Volk et al. (2014)				•	
Project participants related issues [Project participants may not appreciate the value of collaboration among different parties working on the same project throughout its duration]	Arayici et al. (2009), Azhar and Cochran (2009); BIM4FM (2013), Boktor et al. (2014), Burcin and Kensek (2010), Bynum et al. (2013), Chan (2014), Construction Industry Council (2014), Gu and London (2010), Hanna et al. (2014), Mitchell and Lambert (2013), NBIMS (2010), RICS (2011), Volk et al. (2014), Yan and Demian (2008), Zhao et al. (2018)	•		•	•	
Widespread of mistakes and errors produced [BIM's integrated concept blurs the accuracy and control of data entered into the model of which an error will be propagated among stakeholders if a mistake is produced]	Chan (2014), Choi (2009), Lee et al. (2009)	•				
Timing issues [Most of construction projects have a tight design schedule and intensive construction period in terms of return on investment philosophy. However, design consultants cannot avoid the uncertainty of design changes according to clients' requests. This not only increases the difficulties for design consultants to reduce time on project documentation, but may also contribute to delay in construction phase]	BIM4FM (2013), Kiani et al. (2015), Ren and Kumaraswamy (2013)					•
Investment and costing issues [Investment of BIM is strongly related to high level management commitments as adopting BIM incurs initial investment costs related to management and administrative processes, including staff time, hardware, software and training]	Azhar and Cochran (2009), Boktor et al. (2014), Bynum et al. (2013), Chan (2014), Construction Industry Council (2014), Hanna et al. (2013), Hanna et al. (2014), Kiani et al. (2015), Matarneh and		•			

Barrier [description]	**Source**	**Barrier***				
		K	**F**	**O**	**I**	**T**
	Hamed (2017), Porwal and Hewage (2013), Rogers et al. (2015)					
BIM is new and complicated for use [Adopting BIM is difficult for certain amount of design professionals as they are educated and trained in the conventional 2D CAD environment and do not know much about BIM]	Azhar and Cochran (2009), Bin Zakaria et al (2013), Bynum et al. (2013), Chan (2014), Kiani et al. (2015), Rogers et al. (2015), Stanley and Thurnell (2014), Suprun and Stewart (2015)	•				
Frequent change in purpose of building during design stage [The construction industry is known for its conflicts regarding change and mistakes where owners like to change their mindset for the use of the building before the construction work starts. This compresses the time available for design in the project process to mostly inadequate levels, which also leads to numerous changes during the construction phase of the project]	Bernstein and Pittman (2004), Ren and Kumaraswamy (2013)	•			•	•
Market issues [The n-D BIM requires the collaboration, database integration and commitment of construction professionals and companies to the use of BIM software, and that these areas are still in separated and fragmented state. It is because they are connected with certain obligations, risks and rewards in the building process, which they need to protect their interests. These issues also limit the effectiveness of the n-D BIM usage in the construction industry]	Gu and London (2010), Hosseini et al. (2016), Mandhar and Mandhar (2013), Olatunji et al. (2010), Stanley and Thurnell (2014)			•	•	

*Barrier type: K – Knowledge; F – Financial; O – Motivation; I – Information; T – Time.

Table A3: Summary of measures conducive to BIM adoption

Conducive measure [description]	**Source**
Provide key messages and case studies [Provide key messages and case studies to explain the benefits of BIM to stakeholders]	BIM4FM (2013), Construction Industry Council (2014)
Define clearly BIM input and output requirements [Define clearly BIM input and output requirements so that all construction stakeholders can maximize the value of BIM]	RICS (2011)
Promote collaboration among project participants [Set up industrywide body to promote collaboration among project participants]	Construction Industry Council (2014)
Appointment of BIM manager	Construction Industry Council (2014)

Conducive measure [description]	**Source**
[Appointment of BIM manager in the project team for communicating and developing an integration mindset and whole lifecycle systems mindset among project participants]	
Encourage client and stakeholder participation [Develop initiatives to encourage client and stakeholder participation, such as demonstrate the quantitative benefits of adopting BIM and illustrate how BIM can support a project in terms of standards, procurement, collaboration, work processes, benefits and issues, etc.]	Construction Industry Council (2014)
Establish delivery standards and common practices [Establish standards, specifications and new forms of contracts for wider use of BIM throughout the project lifecycle]	Construction Industry Council (2014) , RICS (2011)
Provide training and guidance on the use of BIM [Develop the industry's BIM capacity by driving curricular change in construction-related and computer science academic programmes, and provide BIM training to construction professionals on the use of BIM]	Construction Industry Council (2014) , RICS (2011)
Review procurement practices, and contract provisions [Review each discipline's current procurement system, intellectual property rights and contract agreements to enable the cooperative use of BIM among the different parties of a construction project]	Construction Industry Council (2014)
Establish data exchange standard and management framework [Establish data exchange standard and management framework for information sharing for all participants along the construction supply chain so that the information retrieval and exchange process can be improved, quality and scope of information delivered can be enhanced and data integrity can also be increased]	Construction Industry Council (2014), RICS (2011)
Provide institutional support [Provide institutional support to promote the technology and explain the benefits of BIM to clients and professionals]	Construction Industry Council (2014)
Expedite the industry's capacity and capability [Expedite the industry's capacity and capability for the development of BIM, such as extend BIM training to engineering and computer-science programmes and implement a fast-track BIM training programme for construction professionals]	Construction Industry Council (2014)
Provide compliant BIM tool [Provide compliant BIM tool to ensure that design standards and construction documents are able to suit current practice and fulfill the needs of facility management and frontline maintenance staff]	Construction Industry Council (2014)
Adopt a strategic risk management process [Commission a risk assessment for BIM implementation at a project and corporate level. The purpose of the risk assessment is to identify possible risk areas and determine how they can be mitigated individually and collectively to reduce and marginalise potential problems following the adoption of BIM-enabled technologies and collaboration]	Construction Industry Council (2014)