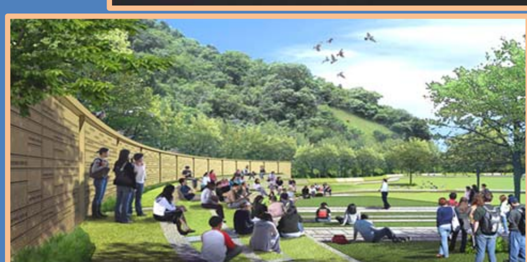
BIM Application in
Hong Kong Quantity Surveying Professionals



Research Project:

BIM Application in Hong Kong Quantity Surveying Professionals

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Contents

Executive Summary

The awareness of Building Information Modelling (BIM) implementation for quantity surveying (QS) has been rapidly increasing in Hong Kong. Although the benefits of BIM implementation have long been recognized (e.g., enhancing estimation efficiency and fostering information processing), the adoption of BIM, 5D-BIM in particular, is still limited due to the various challenges foreseen by quantity surveyors in Hong Kong (e.g., role ambiguity on information responsibility amongst the project team and lack of fit between BIM and measurement methods). In fact, the construction sector has long been recognized as low in innovation. To promote 5D-BIM in the construction sector, it is necessary to foster innovation adoption in the sector. Hence, this project aims at investigating how 5D-BIM (a well-recognized innovation in construction) can be fostered in the sector. To achieve this aim, this project is divided into three sections:

1. An overview of the impact of various management strategies on innovation (5D-BIM) adoption - Questionnaire survey study
2. Identifying key drivers, obstacles and consequences of 5D-BIM - Case & questionnaire survey studies
3. BIM implementation strategies for quantity surveying

The project results indicate that i) 5D-BIM adoption in construction is mainly hindered by lack of training (e.g., lack of competent professionals who are capable in both BIM and QS), poor learning transfer climate (e.g., professionals' reluctant to change), and poor innovation climate (e.g., lack of technical support); and ii) To foster 5D-BIM implementation, recognizing various positive consequences of BIM implementation is the key (especially for the client developers, who take a leading role in innovation implementation in projects). Based on the research results and the extensive literature review, proposed strategies for 5D-BIM implementation include: i) developing key performance indicators for BIM, ii) changing attitudes and behaviors of professionals, iii) developing international BIM standards, iv) establishing international construction measurement standards, and v) developing in-house expertise.

1. Background

5D-BIM means integrating data (such as quantity, location, measurement) from 3D-BIM with construction schedule (the 4th D: time) and project cost (the 5th D: cost). The awareness of using building information modeling (BIM) for quantity surveying (QS), i.e., 5D-BIM (QS and Estimation) has been increasing rapidly in Hong Kong. With reference to the QSD Chairman's message published in the Surveyors Times, BIM has emerged in the last few years as an ever-hotter topic around the world. The Hong Kong Institute of Surveyors (HKIS) has already set up a BIM sub-committee to foster knowledge exchange between its members. The Hong Kong Housing Authority (HA) has committed to implementing BIM on new housing projects from the design stage by 2014/15. Application of BIM is a definite trend that QS professionals should learn and use now in order to gain the greatest benefit. It should progress to focus on how to actually use and tap the greatest potential of BIM.

BIM has been recognized as the most significant innovation in construction in recent decade. Although awareness of BIM has increased rapidly amongst architectural, engineering and construction professionals in the past few years, the adoption of BIM, especially 5D-BIM, is still in its early stage in Hong Kong. In fact, the construction industry as long been previewed as low innovation and having poor performance (e.g., Dulaimi and Ling, 2002; Hampson and Manley, 2001; Miozzo and Dewick, 2004). Innovation in construction has been hindered by various factors, including the conservation of established practices, fear of failure, perceived high financial commitment needed in innovation, limited time and resources, and so on (Australian Expert Group in Industry Studies, 1999; Hampson, 2003). Even though the new knowledge of BIM is acquired, professionals are still hindered by their hesitation to change their original practices, lack of time and resources allocated to BIM training, fear of failure in adoption, and so on.

2. Objectives

Hence, the research study aims at facilitating the understanding of AEC company executives and BIM program managers (senior quantity surveyors) in Hong Kong on how to craft better BIM strategies for quantity surveying. To achieve this aim, the following objectives are to be achieved:

1. To identify key drivers, obstacles, and success factors influencing BIM implementation for quantity surveying;
2. To unveil both intended and unintended consequences of BIM strategies;
3. To develop a performance metric for evaluating BIM implementation strategies

To promote the 5D-BIM in the construction sector, it is necessary to foster innovation adoption in the sector. Hence, this study is divided into 3 sections:

- **An overview of the impact of various management strategies on innovation adoption** (Objectives 1-2 & Deliverable 1)

  A questionnaire survey based study: i) investigating the overall innovation level in the construction sector, ii) identifying management strategies for enhancing innovation in construction, iii) associating the relationships between various management strategies and innovation in construction, and iv) develop a framework for the following 5D-BIM specific studies.

- **Identifying key drivers, obstacles and consequences of 5D-BIM** (Objectives 1-2 & Deliverable 1)

  Both case and survey studies for 5D-BIM implementation in particular: i) a case study unveiling the drivers, obstacles and consequences of three 5D-BIM projects, ii) surveying study identifying the key drivers and obstacles of 5D-BIM in the sector, and iii) cross validation of the above qualitative and quantitative results.

- **Developing BIM implementation strategies and patterns for quantity surveying** (Objectives 1-3 & Deliverables 2-3)

  Based on the above research results, BIM implementation strategies, the importance of developing performance indicators for BIM, are developed and recommended.

3. An Overview of the Impact of Various Management Strategies on Innovation (5D-BIM) Adoption – The influence of leadership, innovation climate and learning transfer climate

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3.1 Fostering Innovation (5D-BIM) Adoption in Construction via Innovation Climate, Learning Transfer Climate and Leadership

BIM implementation has long been recognized as an innovation adoption in construction. However, innovation, in itself, evolves and re-innovates, so does BIM (from 3D, to 4D, 5D, and 6D). Cross-sectional survey studies are thus non-sustainable. A more sustainable way to investigate the adoption of BIM in construction is to escalate the study to the level of innovation adoption (i.e., an overview), followed by grounded studies for BIM adoption in construction (i.e., special cases). Hence, in this section, the impact of various management strategies on 5D-BIM adoption is firstly investigated by the hypothetical relationships between various management strategies and innovation in construction.

Although the definition of innovation deviates among researchers, innovation can generally be defined as – a *process* of "generation, development and implementation of ideas" (e.g., Dulaimi et al, 2005; p. 566; Atkin and Pothecary, 1994; p. 55) in different *forms* (e.g., product, process, marketing and management innovation (Pedersen, 1996; Higgins, 1994)), which are *new* (i.e., "novel to the institution" (Slaughter, 1998; p. 226)) and are expected to yield certain *values* (i.e., "reduction in cost and/or time associated with project delivery and improve the quality of outcomes" (Kissi et al., 2012; p. 12)). In fact, innovation has long been recognized as the key in resolving the confrontation of challenges and change (Green, 2011).

Different from the traditional procurement approach, new procurement systems like design and build, management contracting and concession contracting are increasingly popular for construction projects nowadays (e.g., RICS, 2010). The early contractor involvement, faster pace in construction projects, escalating expectations on project productivity, accuracy, quality and safety, growing complexity of project design, business philosophies and technologies all escalate the demands for innovations. It is under such change and challenges that BIM was innovated. BIM has become one of the most visible innovations that is rapidly transforming the global construction industry. In addition to overcoming the challenges arisen in complicated projects, BIM also plays an essential role in changing the traditional, fragmented work practice of AEC professionals in line with its evolution from 3D, to 4D (time) and now 5D (costing). The evolution of BIM is, therefore, an innovation *process* of generation, development and implementation of information processing tools /platform (*form*) for project management which are *novel* to the construction sector and has found to yield diversified positive *values*.

BIM adoption has found to enhance accuracy, productivity, reduce costing, and so on (Kubba, 2012). However, adoption of BIM is still low in the construction sector, in which there are only 31% of AEC professionals adopting BIM currently, while 48% of them are just aware of BIM. A survey report conducted by the RICS (2011) revealed that 57% of quantity surveyors are not using BIM, 29% of them rarely use BIM and only 10% of quantity surveyors are frequently adopting BIM in their daily works. In fact, innovation adoption is essential in enhancing the operational effectiveness (Neely and Hii, 1998), productivity (DIISR, 2011), financial performance (Jansen et al., 2006) and competitiveness (Daft, 2004; Egbu, 2001) of an organization. However, hindered by various factors—such as the conservation of established practices, fear of failure, perceived high financial commitment needed in innovation, and limited time and resources (Engineers Australia Innovation Taskforce, 2012) — the construction sector is often criticized as being low in innovation (e.g., Dulaimi and Ling, 2002).

3.2 Management Strategies for Innovation

Previous studies have investigated various factors predicting innovation in organizations, including organizational strategy (Naranjo-Gil, 2009), organizational structure (Kimberly, 1981), communication and engagement of stakeholders (Widen et al., 2013), positive expectations of innovation from the team (Carlfjord et al., 2010), and so on. However, becoming innovative demands more than these. ***Innovation climate*** has been identified as the root of innovation (e.g., Patterson et al., 2009). However, innovation climate is lacking in the construction organizations. Instead of innovating within the organisation boundary, construction firms tend to import innovation from outside sources. Construction firms place less importance on and invest less in innovation (e.g., their expenditure on innovation as a proportion of value added lags 40 times behind that of the manufacturing sector; Hampson, 2003). Even though an innovation is aware, it is not easy for it to diffuse through an organization boundary. For instance, diffusion of BIM in construction has found to be hindered by lack of openness to change and lack of financial support (Gu and London, 2010), which again revealed that innovation climate is low in the sector. According to a study conducted by Scott and Bruce (1994), innovation climate, in terms of support for innovation and supply of resources, are the antecedents of innovation.

Even if innovation climate is strong and that training is provided; transfer of learning can be inhibited by a ***learning transfer*** adverse ***climate*** (Mathieu et al., 1992). Due to conservatism in established practices and uncertainty in innovation outcome, the application of 5D-BIM by quantity surveyors is still low and limited. In cases where 5D-BIM training(s) occurs in a construction firm (i.e., 5D-BIM knowledge acquired), application of 5D-BIM can still be inhibited if quantity surveyors perceive 5D-BIM as a complicated skill and that they have doubt in their abilities to apply it in their jobs or if they are uncertain about whether their devoted effort to transferring learning in BIM would lead to enhancement in job performance or not (e.g., Ku and Taiebat, 2011). Learning transfer climate, in forms of transfer efforts to performance expectancies, performance to outcomes expectancies, perception on one's self-efficacy in learning transfers, values and norms towards change, and so on, was found to predict innovation (Bates and Khasawneh, 2005; Holton et al., 2000).

Innovation climate and learning transfer climate depend highly on **leadership**. In fact, leadership is one of the most critical factors determining the climate of an organization, and more directly, the degree to which employees strive for innovation (Amabile et al., 2004; Patterson et al, 2009). Although there are previous studies which identify leadership as a key enabler of construction innovation (e.g., Ozorhon et al., 2010), these studies tend to treat leadership as a general management tactic for fostering knowledge exchange and motivating team spirit. There is a lack of detailed investigation on the effectiveness of different types of leadership on construction innovation, such as transformational and transactional leaderships. Previous study, though not targeting the construction sector, indicated that different leadership styles, such as transformational versus transactional leaderships, have different impact on innovation (e.g., Scott and Bruce, 1994).

To promote 5D-BIM adoption in construction, innovation should be fostered. This section, thus, ***aims*** at providing an overview of innovation performance in construction, followed by unveiling the influence of various management strategies, including innovation climate, learning transfer climate and leadership, on innovation adoption.

3.3 The Questionnaire Survey Study

There are four main scales included in the survey, namely innovation, innovation climate, learning transfer climate and leadership. The *innovation scale* was developed by Kaiser and Holton (1998). This instrument aims to measure the ability of an organization to innovate, as perceived by employees (Kaiser and Holton, 1998). Sample items include "We have been able to develop successful new products/services from new things we have learned" and "We have improved the quality of our products/services by continuously looking for new and better ways to do things". On the other hand, a well-validated *innovation climate* scale, developed by Siegel and Kaemmerer (1978) and modified by Scott and Bruce (1994)), is employed to measure support for innovation and resource supply for innovation of an organization. Sample items include "Creativity is encouraged in my current organization" and "The reward system in my current organization encourages innovation". To determine *learning transfer climate* in construction, the learning transfer system inventory (LTSI) instrument for training-in-general developed by Holton and Bates (2002) is adopted. LTSI is a diagnostic tool developed for assessing learning transfer systems in organizations. Sample items include "I never doubt my ability to use newly learned skills" and "Training usually helps me increase my productivity". Lastly, to examine *leadership*, the leadership questionnaire (MLQ) scale, a well-validated scale developed by Bass and Avolio (1994) and further shortened and modified by Avolio and Bass (2004)), is adopted to examine the transformational and translational leadership levels of an organization. Sample items include "My direct leader expresses confidence that goals will be achieved" and "My direct leader articulates a compelling vision of the future". Respondents were asked to rate their levels of agreement with the statements given on a five-point Likert response format, a scale ranging from 1 (strongly disagree) to 5 (strongly agree).

The survey was disseminated to quantity surveyors via email, fax and in person. In order to control the quality of the data collection and maximize the sample size, purposive and convenience sampling, in which subjects are selected because of certain characteristic (Cooper and Schindler, 2006), is adopted by sending out questionnaires to quantity surveyors who have i) direct experience in quantity take-off in various construction projects in Hong Kong and Mainland China, ii) worked in major construction sectors, including developers, contractor firms and consultant firms, and iii) amassed at least one year working experience in his /her current organization (so as to ensure that the respondents rate the learning transfer climate and innovation levels of his /her organization based on their perceptions built up on the basis of their adequate experience) at the time the surveys were issued. Of the 500 distributed questionnaires, 147 were returned, representing a response rate of 29.4%. Of the respondents, 29% worked at developers, 37% worked at contractor firms and 31% worked at consultant firms.

3.4 Survey Results

3.4.1 Reliability of Factors

The reliability levels of the factors of innovation (INN), innovation climate (i.e., support for innovation (IC1) and resource supply (IC2)), learning transfer climate (i.e., performance self-efficacy (LTC1), openness to change (LTC2), and performance-outcome expectation (LT3)), and leadership (i.e., charisma (LD1), intellectual stimulation (LD2), individualized consideration (LD3) and contingent reward (LD4)) are determined by Cronbach's alpha values (a commonly used indicator of internal consistency; Pallant 2001) (refer to table 3.1). As the alpha values are all higher than 0.6, the variables are considered reliable for further analyses (Hair et al. 1998, Nunnally, 1978). The factor values are then obtained by totaling the ratings obtained from all items contributing to it. The score mean of the hypothetical variables are calculated in the next section.

Table 3.1 Cronbach Alpha Values of the Hypothetical Factors

Hypothetical Variables	Item no.	Cronbach alpha
Innovation (INN)	9	0.964
Innovation Climate		
Support for innovation (IC1)	16	0.816
Resource supply (IC2)	6	0.871
Learning Transfer Climate		
Performance Self-Efficacy (LTC1)	4	0.883
Openness to Change (LTC2)	5	0.865
Performance-Outcome Expectation (LTC3)	4	0.826
Leadership		
Charisma (LD1)	12	0.856
Intellectual stimulation (LD2)	4	0.729
Individualized consideration (LD3)	4	0.698
Contingent reward (LD4)	4	0.626

3.4.2 Innovation in Construction

Research studies tend to regard patent production and expenditure on research and development (R&D) as indicators of innovation (e.g., Birchall et al., 2011; Hu, 2003; Lazzarotti et al., 2011). However, this often results in ignorance of non-traditional, hidden innovation such as management and business models, novel combinations of existing technologies and processes, and solutions to small-scale problems and challenges that happen ‘under the radar’ in the construction sector (NESTA, 2008). For instance, the innovation of the BIM software can be considered as a traditional innovation which is measureable in term of expenditure spent on its R&D process; while the adoption of BIM and its consequences, such as the change of project management practices from fragmentation to integration, is a kind of hidden innovation which can hardly be measured. Since this study focuses on the adoption of BIM in construction (i.e., actors’ actions and reactions to innovation), a non-traditional method of measuring innovation is employed. Innovation competency governs the innovation behavior of an individual and is defined as “the disposition of a person to act and react in an innovative manner in order to deal with different critical incidents, problems or tasks that demand innovative thinking and reactions, and which can occur in a certain context” (Cerinšek and Dolinšek, 2009, p.166). Hence, this study employs a proxy approach to cover both traditional and hidden innovations by examining the root source of innovation, i.e., innovation competency, which can be referred as the ability of employees in a firm to create, adopt, or implement innovative ideas and knowledge in various forms to enhance organizational performance and competitiveness.

As shown in Figure 3.1, the mean score of innovation for respondents in general is found to be 3.29. Although it is above the neutral point of 3 in the 5-point Likert response format, there is still room for innovation to be enhanced in the construction sector. On the other hand, the mean scores of innovation for client developers, contractors and construction consultants are found to be 3.32, 3.21 and 3.37 respectively. It is interesting to note that construction consultants are found to be most innovative, followed by client developers and construction contractors.

Figure 3.1 Innovation of various respondent groups

3.4.3 Innovation Climate

Organizational climate is defined as the shared perceptions of both formal and informal policies, practices, and procedures amongst staff in an organization, which demonstrate the goals and strategy of the organization (Reichers and Schneider, 1990). Innovation climate refers to employees' perception about the degree to which an organization provides support to its staff, and encourages staff to take initiative and explore creative ideas that foster innovation in an organization (Martins and Terblanche, 2003; Mumford and Gustafson, 1988; Ubius and Alas, 2010). According to psychological climate theory (James and Sells, 1981), instead of responding to an objective environment, individuals tend to respond primarily to their cognitive perceptions of the environment. Hence, an employee's creative behaviours are highly susceptible to their perception of the environment. An innovation organizational climate can, thus, facilitate employees' adaption towards changes and their adoption of creative behaviours (Ekvall, 1999); it has also found to predict championing behaviours of construction project managers (Kissi, et al., 2012).

According to Scott and Bruce (1994), a climate for innovation can be conceptualized as support for innovation and supply of resources. Innovation climate is thus measured by these two variables in this study. Support for innovation refers to an organization which not only supports employees in pursuing new ideas, but also tolerates diversity among them (Siegel and Kaemmerer, 1978). Change is essential to the development and implementation of any innovative ideas (Poole and Van de Ven, 2004). Through managing changes in policy, procedures (i.e., first-order changes) or changes of fundamental organizational assumptions, like vision and core values (i.e., second-order changes) properly, an organization evolves (Rothwell et al., 2010; Wang and Sun, 2012). On the other hand, although diversity between employees may induce workgroup conflicts and decrease work efficiency, it is important to organizational innovation (Florida and Gates, 2003; Milliken and Martins, 1996; Scott and Bruce, 1994). It is because only employees with tolerance of diversity can be open-minded to new or improved ideas at work (Anderson and West, 1998). In addition, to nurture a group of creative employees, organizations should supply adequate resources, such as time, human resources, material, management support, and so on, so as to allow them to pursue innovation at work (Kesting and Ulhoi, 2010). Creativity of individual employees is the cornerstone of organizational innovation (Oldham and Cummings, 1996), while a supportive innovation climate is essential in fostering individual creativity (Gumusluoglu and Ilsev, 2009).

The mean scores of support for innovation and resource support for respondents in general are found to be 3.06 and 3.20 respectively (refer to Figure 3.2). Although it is above the neutral point of 3 in the 5-point Likert response format, there is still room for them to be enhanced in the construction sector. On the other hand, amongst the three construction parties, the mean scores of support for innovation for client developers, contractors and construction consultants are found to be 3.15, 3.02 and 3.02 respectively; while that for resource support are 3.24, 3.18 and 3.08 respectively (refer to Figure 3.3). It is interesting to note that client developers are found to have the strongest innovation climates in both dimensions.

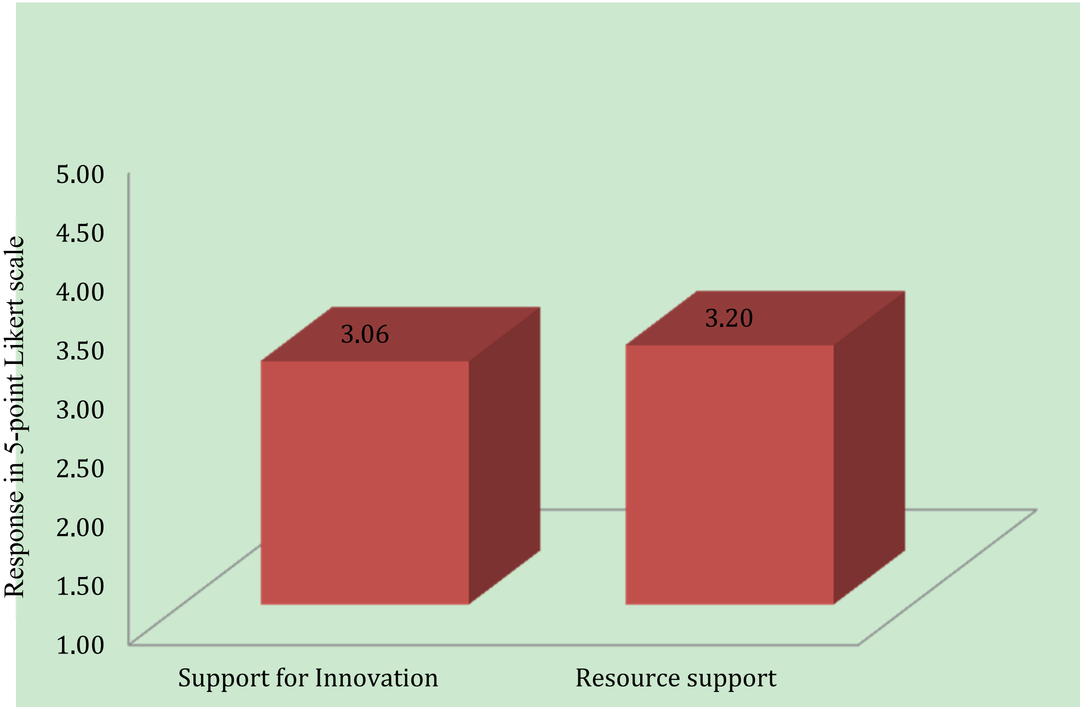

Figure 3.2 Innovation climate of all respondents

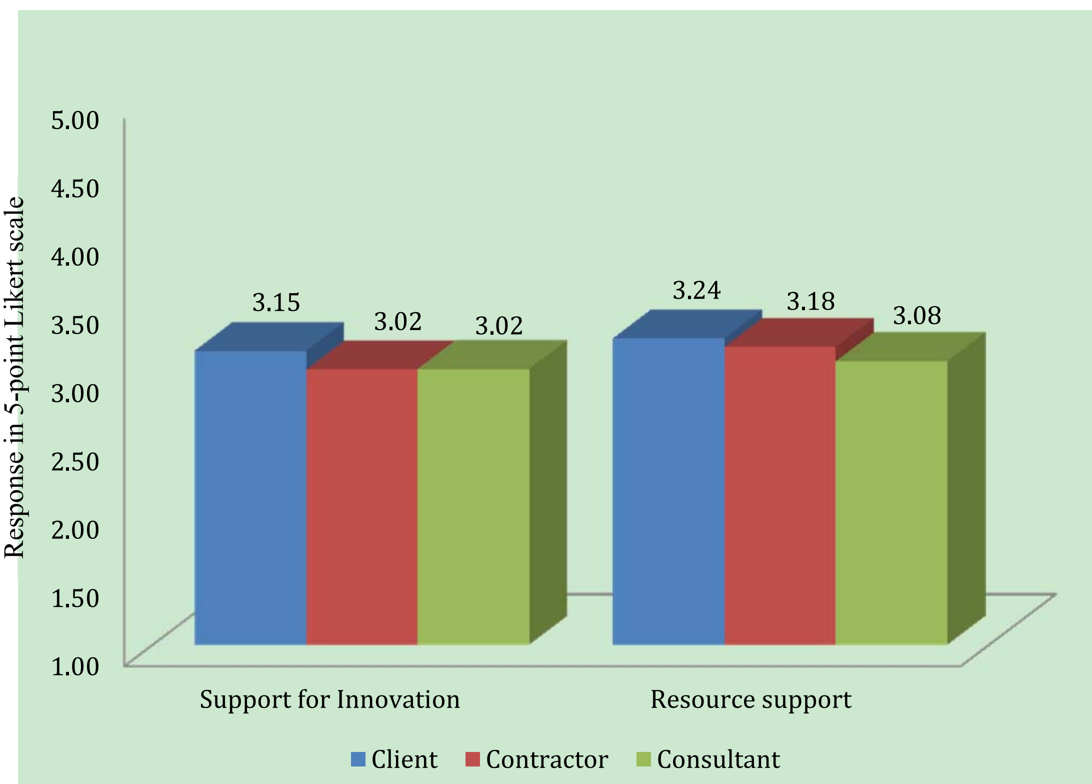

Figure 3.3 Innovation climate of various respondent groups

3.4.4 Learning Transfer Climate

In addition to innovation climate, learning transfer climate is also essential in fostering innovation adoption in an organization. Organizational learning has long been recognized as a key to foster innovation and organizational success (e.g., Armstrong and Foley, 2003; Porth et al., 1999). It refers to a process or set of learning activities (Tsang 1997). However, learning is much more than knowledge acquisition and compilation, particularly for learning in the innovation process. Siguaw et al. (2006), in the development of an innovation framework based on literature review, defined learning philosophy as a pervasive set of organizational understandings towards learning, thinking, acquiring, transferring, and using knowledge in the firm, and found that it was one of the antecedents of innovation outcomes. Learning transfer (or sometimes referred as knowledge /training transfer in the literature) is one of the most inevitable factors for fostering innovation (Bates and Khasawneh, 2005). Learning transfer refers to "the effective and continuing application, by trainees to their jobs, of the knowledge and skills gained in training both on and off the job" (Broad and Newstrom, 1992; p.6). To facilitate learning transfer, a learning transfer climate is the key (Mathieu et al., 1992).

According to the learning transfer system inventory model developed by Holton et al. (2000), learning transfer climate is a multi-level construct covering personal, training and organizational levels. There are five main factors developed under the learning transfer system for trainings in general: openness to change, performance feedback, performance self-efficacy, transfer effort-performance expectations, and performance-outcome expectations (Holton et al., 2000). The first two factors in the system were identified as *tasks support* elements (Bates and Khasawneh, 2005). Openness to change refers to trainees' perceptions towards their work group's attitude towards change, which can be manifested in groups' willingness to invest resource in change and the degree of support they received in the learning transfer process. Performance feedback refers to the degree to which trainees receive constructive feedback, coaching and assistance in the learning transfer process. The other three factors were related to *individual cognitive* states (Bates and Khasawneh, 2005). Performance self-efficacy refers to the degree to which the trainees are confident in apply the learnt skills on their jobs. Transfer effort-performance expectations refer to trainees' perception on whether learning transfer can enhance performance. Performance-outcomes expectations refer to trainees' perception on whether the enhanced performance can result in outcomes that they valued. Previous studies tend to focus on investigating the factors influencing learning transfer (e.g., Lim and Johnson, 2002; Ruona et al., 2002).

As shown in table 3.4, the mean scores of performance feedback, openness to change, performance self-efficacy, transfer effort-performance expectation and performance-outcome expectation for respondents in general are 3.07, 3.16, 3.66, 3.54 and 3.41 respectively. It is interesting to note that the mean scores of task support related learning transfer climate factors, that are the first two, were lower than all the other three individual cognition related factors. On the other hand, amongst the three construction parties, construction contractors were found to have the highest scores in performance feedback, openness to change, transfer effort-performance expectation and performance-outcome expectation, while construction consultants have the highest performance self-efficacy only (refer to Figure 3.5).

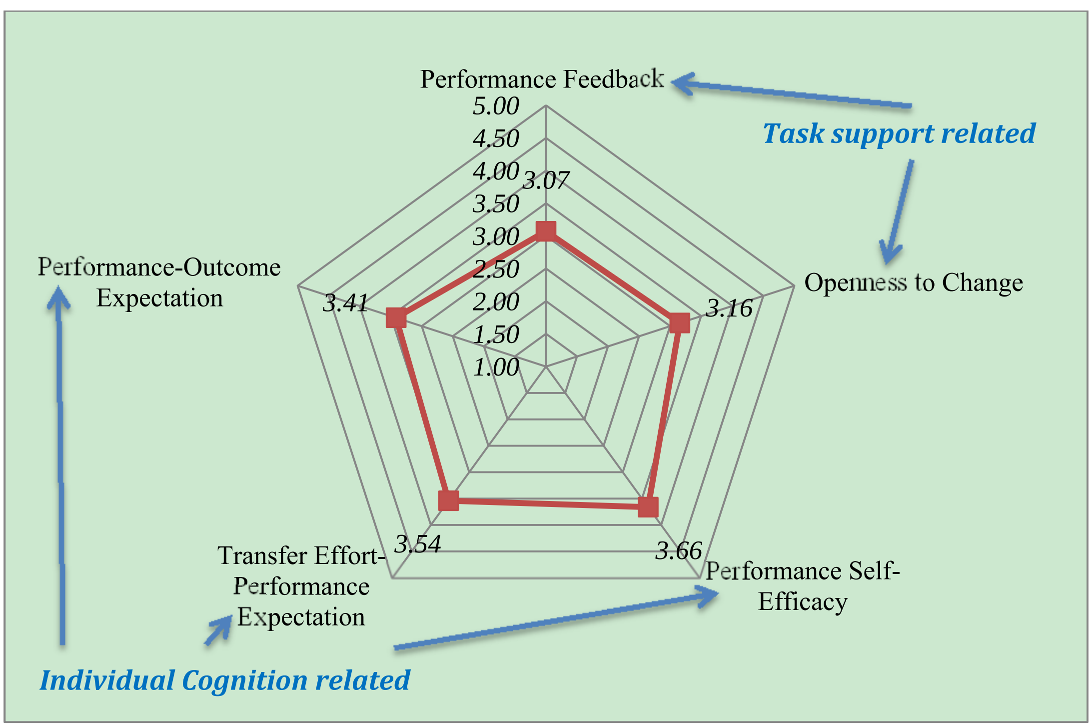

Figure 3.4 Learning transfer climate of all respondents

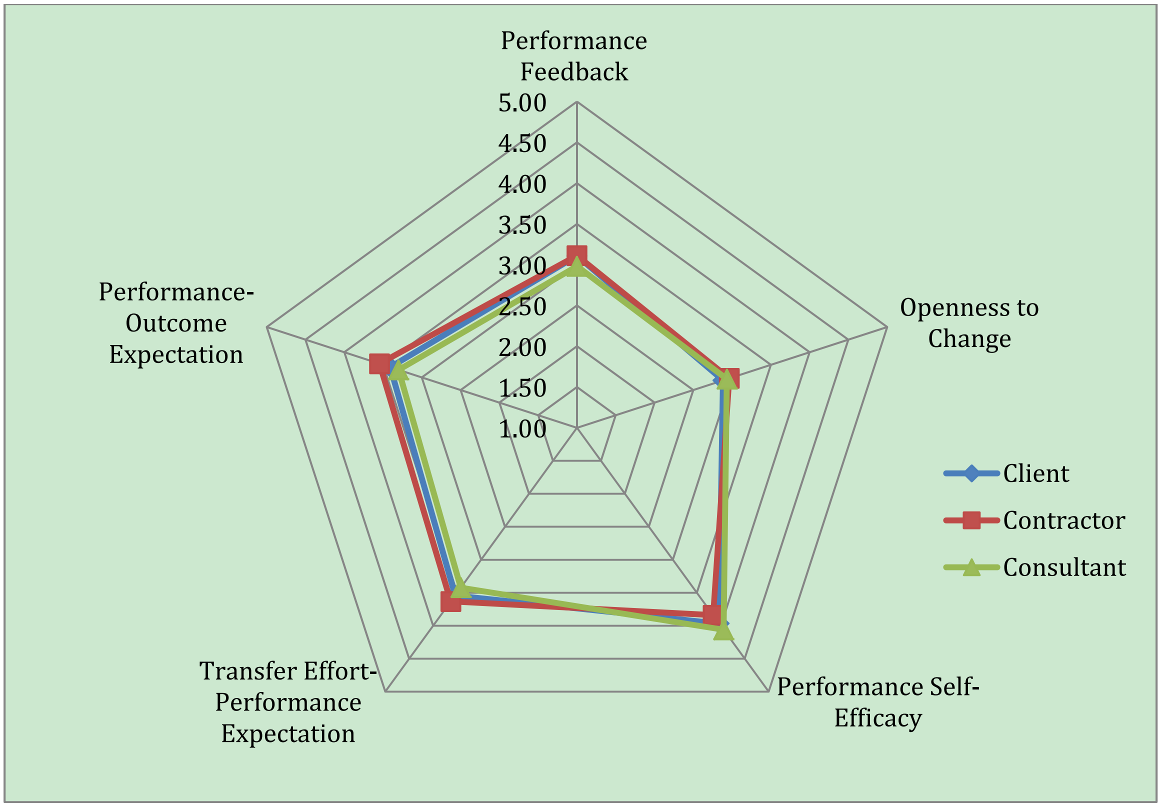

Figure 3.5 Learning transfer climate of various respondent groups

3.4.5 Leadership

Previous research studies have indicated the essential roles of leadership in fostering innovation and innovation adoption (e.g., Amabile et al., 2004; Damanpour and Schneider, 2006; Patterson et al, 2009). According to Bass and Bass (2008), leadership refers to "an interaction between two or more members of a group that often involves a structuring or restructuring of the situation and of the perceptions and expectation of the members...directing the attention of other members to goals and the paths to achieve them" (p.25). The concepts of transformational and transactional leadership have long been adopted (Avolio and Bass, 2004; Bass, 1985). Transformational leadership refers to leaders focused on fostering the higher order intrinsic needs of their followers, in preference to the short-term ones. This often results in followers identifying with the needs of the leader (Kuhnert and Lewis, 1987). Transactional leadership refers to leaders focused on satisfying the extrinsic needs of their subordinates, following which the subordinates perform what the leader asks in return.

The three key dimensions of transformational leadership include charisma (or idealized influence), intellectual stimulation and individualized consideration. Charisma refers to the degree to which a leader gathers followers by his charming personality and admirable behaviours. Charismatic leaders demonstrate a strong sense of purpose, emphasize the importance of having a collective sense of mission, and display a sense of power and confidence. They act in ways that builds respect from followers. Intellectual stimulation refers to a leader supporting followers to query their existing values, beliefs and practices. A leader with intellectual stimulation not only looks and criticizes tradition assumptions from different perspectives, but also encourages followers to apply this spirit at work. Individual consideration refers to the degree to which a leader treats each follower individually. A leader with individual consideration spends time to develop followers' strengths individually and takes their particular needs, abilities and aspirations into consideration. The key dimension of transactional leadership is contingent reward. It refers to the degree to which a leader establishes a system for followers to obtain contingent rewards for meeting an agreed expectation. Leaders carrying this trait express clearly what a follower will receive when an agreed goal is achieved.

As shown in table 3.6, the mean scores of charisma, intellectual stimulation, individualized consideration and contingent reward for respondents in general are 3.58, 3.53, 3.39 and 3.46 respectively. The transformational leadership of charisma and intellectual stimulation are found to be the highest. On the other hand, amongst the three construction parties, client developers' leadership are found to have the highest in all four dimensions (refer to Figure 3.7).

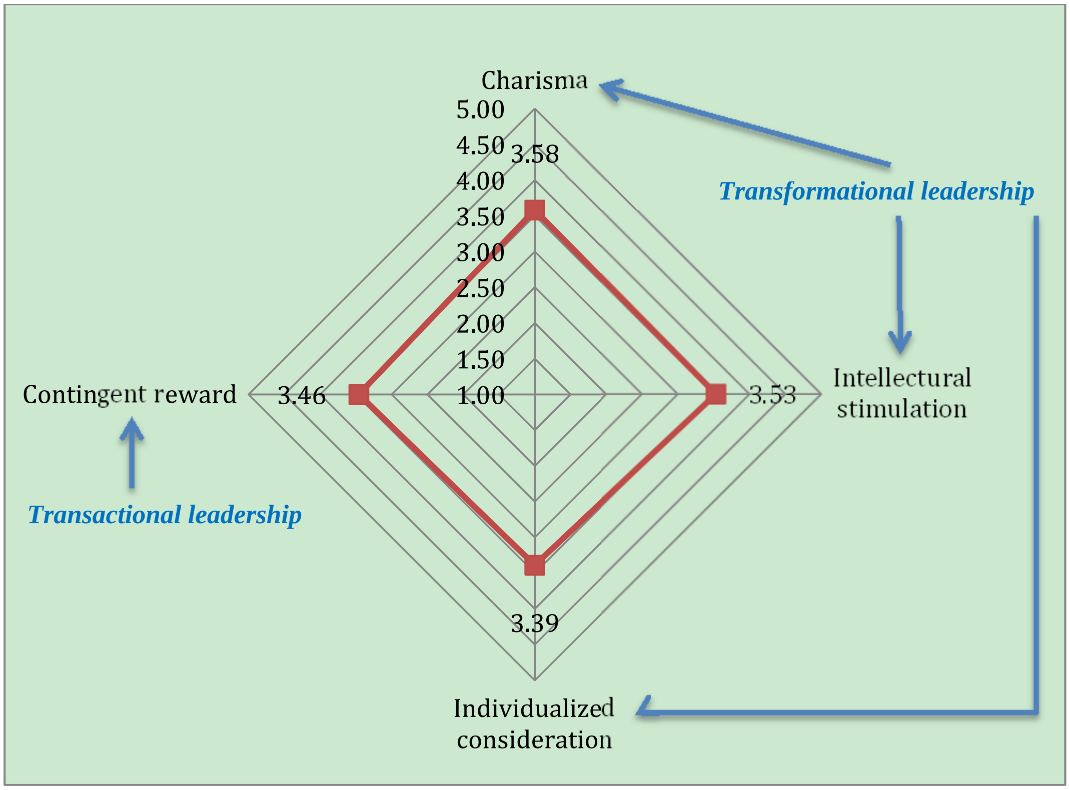

Figure 3.6 Leadership of all respondents

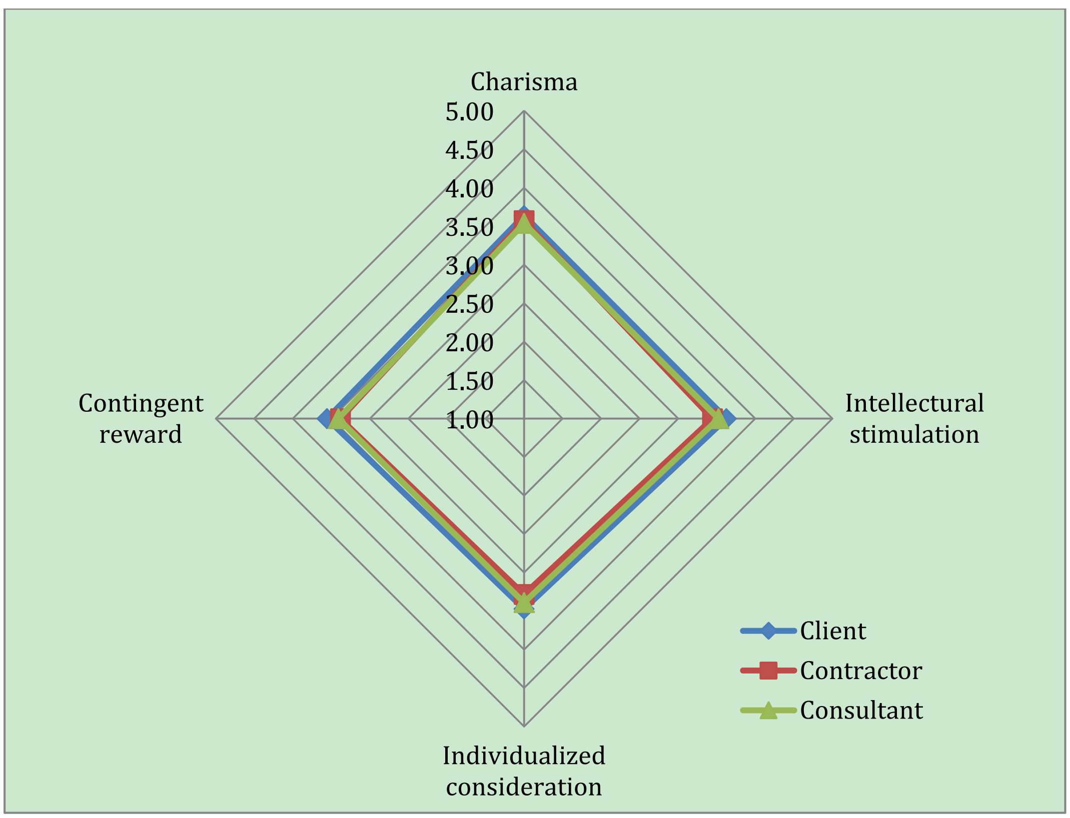

Figure 3.7 Leadership of various respondent groups

3.4.6 Relationships between Innovation and the various Management Strategies

The relationship of leadership, innovation climate, learning transfer climate and innovation is firstly tested using correlation analysis shown in Table 3.2 and Figure 3.8, followed by regression modelling shown in Tables 3.2-3.5 and Figure 3.9. The correlation results indicate that innovation is correlated positively with all leadership, innovation climate and learning transfer climate factors, including charisma (LD1), intellectual stimulation (LD2), individualized consideration (LD3), contingent reward (LD4), support for innovation (IC1), resource supply (IC2), performance self-efficacy (LTC1), openness to change (LTC2), performance-outcome expectation (LCT3) at $p<0.01$ significance. The highest variance inflation factor (VIF) value obtained in the current study is 2.778 (below the cut-off of 10), indicating there is no multicollinearity among the variables (Pallant 2001).

Table 3.2 Correlation between Innovation Climate, Leadership, Learning Transfer Climate & Innovation

Factors	LD1	LD2	LD3	LD4	IC1	IC2	LTC1	LTC2	LTC3	INN
Leadership										
Charisma (LD1)	1									
Intellectual stimulation (LD2)	**	1								
Individualized consideration (LD3)	**	**	1							
Contingent reward (LD4)	**	**	**	1						
Innovation Climate										
Support for Innovation (IC1)	**	**	**	**	1					
Resource supply (IC2)	**	**	**	**	**	1				
Learning Transfer Climate										
Performance Self-Efficacy (LTC1)	*	*	-	-	*	-	1			
Openness to Change (LTC2)	**	**	*	**	**	**	**	1		
Performance-Outcome Expectation (LTC3)	**	**	**	**	**	**	**	**	1	
Innovation (INN)	**	**	**	**	**	**	**	**	**	**1**

Note: ** denotes positive correlation coefficient significant at 0.001 level

* denotes positive correlation coefficient significant at 0.05 level

- denotes non-significant correlation coefficient

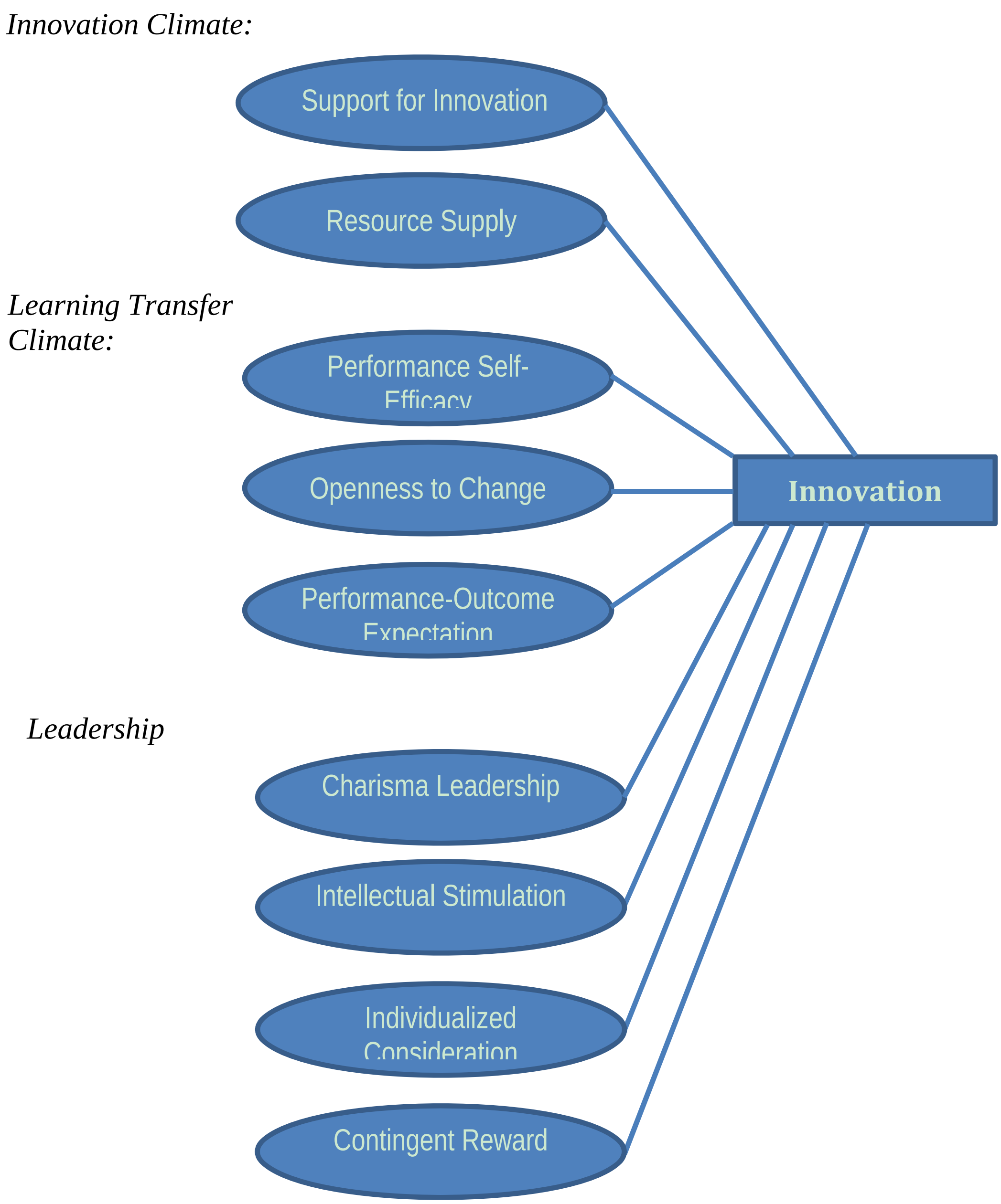

Figure 3.8 Correlations between Innovation and Innovation Climate, Learning Transfer Climate and Leadership

Note: ——— denotes positive and significant correlations (refer to Table 3.2)

Multiple regression analysis with forward selection method is further applied to investigate the innovation-innovation climate, innovation-learning transfer climate, and innovation-leadership associations of the total sample respectively. Modelling for the association between innovation and innovation climate is firstly conducted (refer to Table 3.3). Since the result of Pearson correlation indicates that the strength of correlation between support for innovation (IC1) and innovation is the highest (refer to Table 3.2), IC1 is selected as the first independent variable, with subsequent independent variable added to the regression analysis. A predictor would remain in the final model if the significant value of the variable is lower than 0.05, and if adding it can lower the standard error or raise the R square values of the model estimate (Tabachnick and Fidell, 2007). The model development ends at Step 2 after IC2 is included to the model and its significant value is also lower than 0.05. The final model (which explains 52.8% of the variance) reveals that innovation is positively predicted by both support for innovation and resource supply.

The same analysis is employed to investigate the three groups of client developers, construction consultants and contractors. IC1 is again selected as the first independent variable in the regression Model A2 for client developers (refer to Table 3.3). Then, IC2 is added to the model in step 2 since it has the second-highest correlation coefficient with innovation. However, the model development ends at Step 1; since the significant value of IC2 would be higher than 0.05 if it were entered into the model. The final model (Model A2) reveals that innovation in client developer firms is positively predicted by IC1 only, explaining 64.2% of the variance.

Similarly, Model A3 is developed for contractors and Model A4 is developed for the construction consultants. In Model A3, IC1 is selected as an independent variable in the regression and the final model reveals that innovation in contractor firms is positively predicted by IC1, explaining 44.3% of the variance. In Model A4, only IC2 is included in the mode since the significant value of IC1 would be higher than 0.05 if it were entered into the model, and the final model reveals that innovation in consultant firms is positively predicted by IC2, explaining 44.5% of the variance.

Table 3.3 Regression Models of Innovation Climate & Innovation

Steps	Dependent Variable	Independent Variables	Path Estimates	Sig.	R	R^2	(ANOVA) F	Sig.
Model A1 : Total Sample								
Step 1	Innovation	(constant)	-	0.108	0.695	0.483	78.567	0.000
		Support for Innovation (IC1)	+ve	0.000				
Step 2	Innovation	(constant)	-	0.026	0.726	0.528	46.386	0.000
		Support for Innovation (IC1)	+ve	0.000				
		Resource Supply (IC2)	+ve	0.006				
Model A2 : Client Developers								
Step 1	Innovation	(constant)	-	0.900	0.801	0.642	26.934	0.000
		Support for Innovation (IC1)	+ve	0.000				
Model A3 : Contractors								
Step 1	Innovation	(constant)	-	0.177	0.666	0.443	25.441	0.000
		Support for Innovation (IC1)	+ve	0.000				
Model A4 : Construction Consultants								
Step 1	Innovation	(constant)	-	0.000	0.667	0.445	20.841	0.000
		Resource Supply (IC2)	+ve	0.000				

Similarly, multiple regression analysis with forward selection method is applied to investigate the association between learning transfer climate and innovation, starting from the total sample. Since the result of Pearson correlation indicates that the strength of correlation between LTC2 and innovation is the highest (refer to Table 3.4), LTC2 is selected as the first independent variable, with subsequent independent variable added to the regression analysis. The model development ends at Step 3 (Table 3.4) when all three learning transfer climate variables are included in the model. The final model (which explains 29.4% of the variance) reveals that innovation is positively predicted by openness to change, performance-outcome expectation and performance self-efficacy.

The same analysis is employed to investigate the three groups of client developers, construction consultants and contractors. LTC2 is again firstly selected as the first independent variable in the regression Model B2 for client developers. Then, LTC1 is added to the model in step 2 since it has the second-highest correlation coefficient with innovation. The model development ends at Step 2; since the significant value of LTC3 would be higher than 0.05 if it were entered into the model. The final model (Model B2) reveals that innovation in client developer firms is positively predicted by LTC2 and LTC1, explaining 43.0% of the variance.

Similarly, Model B3 is developed for contractors and Model B4 is developed for the construction consultants. In Model B3, LTC2 is selected as an independent variable in the regression and the final model reveals that innovation in contractor firms is positively predicted by LTC2, explaining 22.2% of the variance. In Model B4, LTC3 is selected as the first independent variable in the regression, and the final model reveals that innovation in consultant firms is positively predicted by LTC3, explaining 30.8% of the variance.

Table 3.4 Regression Models of Learning Transfer Climate & Innovation

Steps	Dependent Variable	Independent Variables	Path Estimates	Sig.	R	R^2	(ANOVA) F	Sig.
Model B1 : Total Sample								
Step 1	Innovation	(constant)	-	0.000	0.469	0.220	40.839	0.000
		Openness to Change (LTC2)	+ve	0.000				
Step 2	Innovation	(constant)	-	0.000	0.514	0.264	25.790	0.000
		Openness to Change (LTC2)	+ve	0.000				
		Performance-Outcome Expectation (LTC3)	+ve	0.004				
Step 3	Innovation	(constant)	-	0.000	0.542	0.294	19.804	0.000
		Openness to Change (LTC2)	+ve	0.000				
		Performance-Outcome Expectation (LTC3)	+ve	0.021				
		Performance Self-Efficacy (LTC1)	+ve	0.015				
Model B2 : Client Developers								
Step 1	Innovation	(constant)	-	0.000	0.604	0.365	23.556	0.000
		Openness to Change (LTC2)	+ve	0.000				
Step 2	Innovation	(constant)	-	0.007	0.656	0.430	15.080	0.000
		Openness to Change (LTC2)	+ve	0.000				
		Performance Self-Efficacy (LTC1)	+ve	0.039				
Model B3 : Contractors								
Step 1	Innovation	(constant)	-	0.000	0.471	0.222	15.093	0.000
		Openness to Change (LTC2)	+ve	0.000				
Model B4 : Construction Consultants								
Step 1	Innovation	(constant)	-	0.000	0.555	0.308	19.183	0.000
		Performance-Outcome Expectation (LTC3)	+ve	0.000				

Again, multiple regression analysis with forward selection method is applied to investigate the association between leadership and innovation, starting from the total sample. Since the result of Pearson correlation indicates that the strength of correlation between LD1 and innovation is the highest (refer to Table 3.2), LD1 is selected as the first independent variable, with subsequent independent variable added to the regression analysis. The model development ends at Step 1 (Table 3.5), since the significant value of other variables would be higher than 0.05 if they were entered into the model. The final Model C1 (which explains 18.6% of the variance) reveals that innovation is positively predicted by charisma leadership only.

The same analysis is employed again to investigate the three groups of client developers, construction consultants and contractors. LD1 is again firstly selected as the first independent variable in the regression Model C2 for client developers. The model development ends at Step 1; since the significant value of other leadership variables would be higher than 0.05 if it were entered into the model. The final model (Model C2) reveals that innovation in client developer firms is again positively predicted by LD1 only, explaining 72.3.0% of the variance. The regression models for contractors and construction consultants could not be formulated.

Table 3.5 Regression Models of Leadership & Innovation

Steps	**Dependent Variable**	**Independent Variables**	**Path Estimates**	**Sig.**	**R**	**R^2**	**(ANOVA) F**	**Sig.**
Model C1 : Total Sample								
Step 1	Innovation	(constant)	-	0.000	0.432	0.186	19.245	0.000
		Charisma (LD1)	+ve	0.000				
Model C2 : Client Developers								
Step 1	Innovation	(constant)	-	0.561	0.850	0.723	18.237	0.000
		Charisma (LD1)	+ve	0.000				

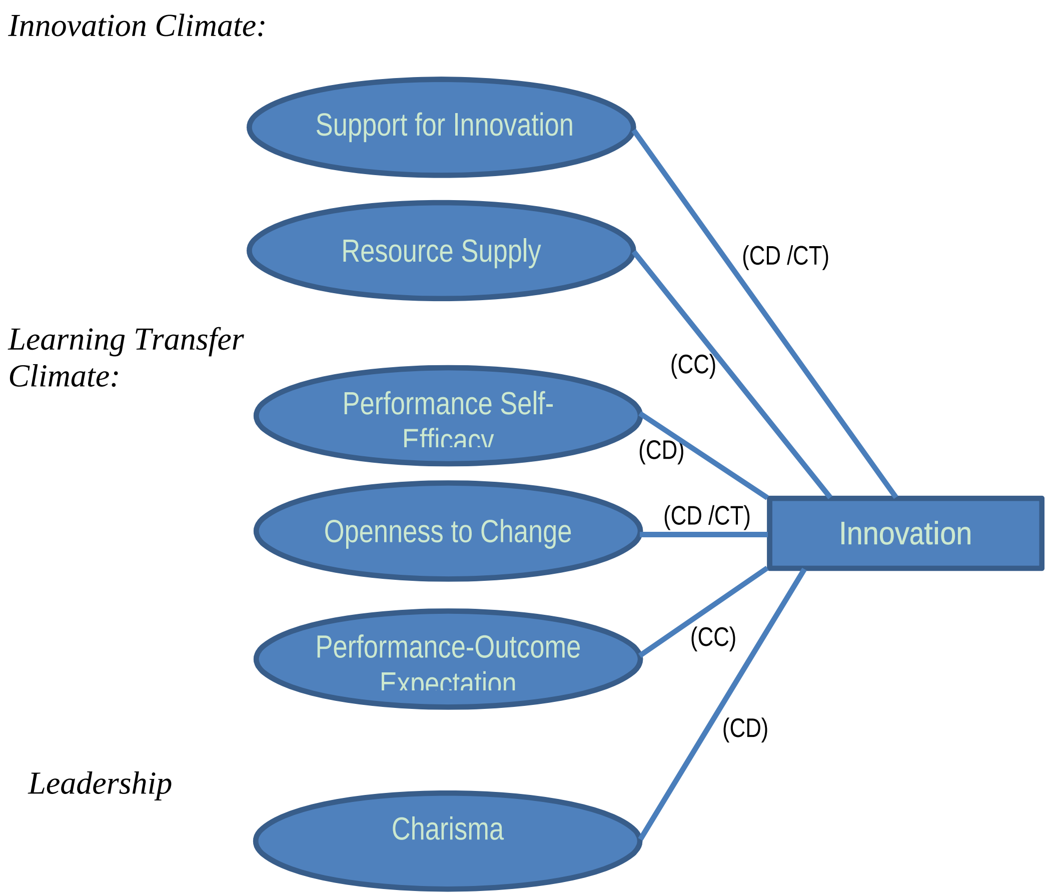

Figure 3.9 Relationships between Innovation and Innovation Climate, Learning Transfer Climate and Leadership for Client Developers, Contractors and Construction Consultants

Note: —— denotes positive and significant parameter estimates revealed in regression modellings (refer to Tables 3.3-3.5).

CD refers to Client Developers; CT refers to Contractor; and CC refers to Construction Consultants

3.5 Discussion

Given the findings, this study provides two essential contributions to the innovative 5D-BIM implementation in construction. Firstly, the current research results conform to previous studies that innovation climate, learning transfer climate and leadership are all key factors of innovation in construction. For innovation climate, both support for innovation and resource supply are found to be antecedents of innovation, confirming the study results of Scott and Bruce (1994). For learning transfer climate, previous studies conducted for general industries indicate that all learning transfer climates appears in the LTIS model are influential to innovation (e.g., Bates and Khasawneh, 2005). The results of the current study indicate that not all learning transfer climate influences innovation in construction, although the involved factors cover both task-support and individual cognition related factors. The three learning transfer climate factors found to influence innovation in this study involve openness to change (task support related), performance to outcome expectation and performance self-efficacy (individual cognition related). When comparing with individual cognition related learning transfer climate, task support related climate is lower in the construction sector (refer to Figure 3.4). Even though quantities surveyors perceive themselves having the ability to adopt 5D- BIM after training and that they expect that changes in job performance brought by the adoption will lead to valued outcomes, 5D-BIM implementation can still be hindered by the prevailing group norms which discourage innovative skills or knowledge. To foster 5D- BIM implementation, openness to change of construction personnel should not be ignored.

For leadership, the results of this study conform to previous research findings that transformational leadership has a positive association with innovation of an organization (e.g., Basu and Green, 1997; Jung et al., 2003). While other previous studies found that transformational leadership as a whole fosters innovation in the general sector, the current study finds that charisma, out of the three transformational leadership styles, is the key antecedent of innovation in construction. When comparing with projects in other industries, like manufacturing, construction projects tend to have a high degree of complexity and larger capital investment. For this type of large-scale project, a leadership style which encourages participation and ideas from followers is expected to be more effective in facilitating project success (Naoum, 2001). Charismatic leaders nurture the intrinsic development of followers by demonstrating a strong sense of purpose and displaying a sense of power and confidence. A charismatic leader motivates followers to try and adopt an innovation by nurturing their personal value systems (e.g., openness to change and /or uncertainties) and facilitating their creative ways of thinking, fostering organizational innovation. Although top management in the construction industry tend to adopt transformational rather than transactional leadership (Giritli and Oraz, 2004; Butler and Chinowsky, 2006), construction stakeholders are still recommended to promote charisma leadership, out of the various transformational leadership, amongst construction leaders in order to foster innovative 5D-BIM adoption in construction.

On the other hand, the research results also indicate that adoption of the innovative 5D-BIM in the construction sector can be fostered by the heterogeneity of construction parties. In fact, the essential roles of client developers and contractors in fostering innovation in construction are often overlooked in the sector (CIOB, 2007). One of the common arguments is that contractors seldom have a research and development department (Slaughter, 1993). However, as indicated in Tangkar et al. (2000)'s project and product knowledge pyramids model, client developers and contractors play a leading role in fostering innovation in a project-oriented domain, since they have the most enriched information and knowledge of the project, when comparing with other parties down the supply stream. In other words, the client developers and contractors can be regarded as the pulling forces in innovation in construction, while construction consultant can be regarded as the pushing forces (this can, to certain extent, explain why the innovation climate of client developers and contractors is found to be higher than that of the construction consultants as shown in Figure 3.3; and as motivated by client developers and contractors, construction consultants is found to be the most innovative one amongst the three as shown in Figure 3.1).

Therefore, conforming to the study results, openness to change and support for innovation of both client developers and contractors are essential to innovation. Openness to change and support for innovation of client developers facilitates an initiation of an innovative design, which can stimulate contractors to create new construction techniques to overcome the challenges (as demonstrated in the case study by Boland et al. (2007)). Meanwhile, openness to change and support for innovation of contractors is also essential in facilitating client developers to put an innovative design forward. In addition, since client developers play a leaders' role in a construction project, they often demonstrate charismatic leadership by demonstrating a strong sense of purpose, emphasizing the importance of having a collective sense of mission of various parties, and display a sense of power and confidence in the project. However, an innovative idea may sometimes be risky. Feasibility, which is closely associated with risk and budgeting, of an innovation adoption, is thus the main concern of client developers. Since client developers are the initiator of a construction project, their performance self-efficacy should be the most essential factor fostering innovation in a project. Under this circumstance, construction consultants, by applying their specialist expertise, ensure the efficacy of a proposed innovation of the client developers. However, since consultants are positioned at the lower stream of the supply chain, they are usually motivated by performance to outcome expectations and resource supply (e.g., incentives provided by client developers or contractors).

Hence, the results of this study move the innovation theories forward by postulating the sequence and interaction of client developers, contractors and construction consultant in the innovation process (refer to Figure 3.10).

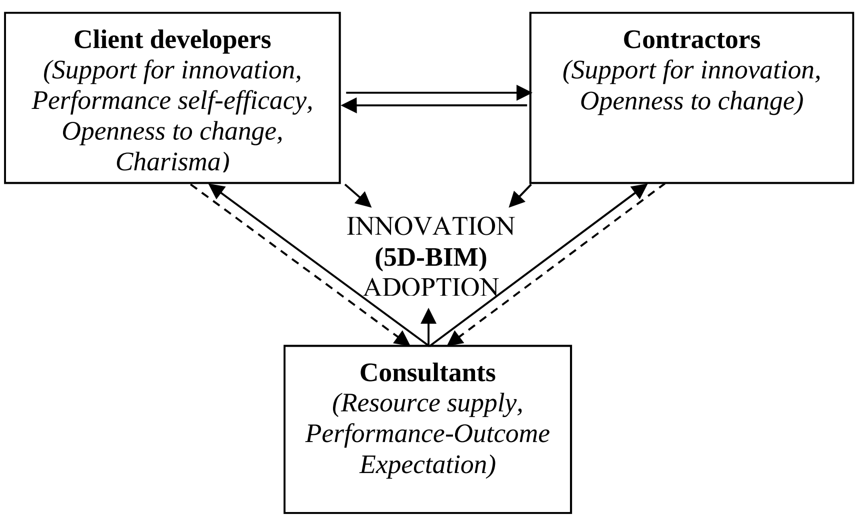

Figure 3.10 The Postulated Interactive Roles of Construction Parties in Fostering Innovation (5D-BIM) Adoption

Since a successful construction project demands the interactions of multiple wakes of innovation contributed by different construction parties throughout the project lifecycle, it is important to foster innovation of individual construction parties. The study results indicate that construction parties are motivated by different innovation climate, learning transfer climate and leadership factors to innovate. Instead of following practices /strategies of firms which are successful in innovation in general, construction parties are recommended to have a thorough understanding on their specific positions in the industry, the resources and capabilities they have, and their potential competitive advantages first. Innovation can then be fostered by various organizational strategies (e.g., nurturing a charismatic leadership for client, culture /value of openness to change and innovation support for client developers and contractors, and provision of resource supply to consultants) and training (e.g., focusing on how individual's cognition on learning transfer can be enhanced for client developer and consultant) can then be developed and managed in sustainable ways, which fits the needs of particular construction parties.

3.6 Summary

The implementation of BIM has long been recognized as an adoption of innovation in construction. Since innovation evolves, a more sustainable way to investigate the adoption of BIM in construction is to escalate the study to the level of innovation adoption, followed by grounded case studies for BIM adoption in construction (refer to Section 4). This section presented a series of empirical studies for the development of a model indicating what and how different management strategies foster innovation (5D-BIM) adoption of various construction parties. In summary, innovation (5D-BIM) adoption can be fostered by support for innovation , performance self-efficacy, openness to change and charismatic leadership of client developers, support for innovation and openness to change of contractors, and resource supply and performance-outcome expectation of consultants. It is worth noting that, client developers play the most essential role in the 5D-BIM adoption process.

4. Identification of Key Drivers, Obstacles and Consequences of 5D-BIM Implementation - Case & Questionnaire Survey Studies

Authors: Gao, J.; Chan, I.Y.S.

4.1 Three 5D-BIM Implementation Cases

Case 1 : 5D-BIM from the Perspective of Client

The Hong Kong Housing Authority (HKHA) is the main provider of public housing in Hong Kong. HKHA has adopted BIM since 2006. Up to now, BIM has been used for 3D visualization, clash detection, and 4D simulations. The success of initial adoption of BIM in HKHA prompted the HKHA's Quantity Surveying Section (HKHA's QS) to investigate using BIM to generate detailed quantity take-offs. HKHA's QS section started from a study of integrated 5D BIM for cash flow simulation and interim payment processing, to integrated 4D (program optimization) and 5D (quantity take-off), and currently, the development of Standard Approach of Modeling (SAM) for concrete, plumbing, and drainage works for BIM measurement.

- Why (Modeling Purpose)

HKHA's QS Section started the experiment of 5D-BIM in a new public rental housing development in Shui Chuen O Phase 1 in Shatin of Hong Kong. The HK$1.3 million project involves the construction of five housing blocks with 3,039 domestic flats.

On this project, one team was working on BIM related issues; the other team was the project QS team. For the BIM team, the major scope of study was to use quantities extracted from BIM to carry out cash flow simulation and interim payment assessment. The bi-product during the process of study was the identification of problems with the current modeling approach.

- When (Timing of Modeling)

R&D project lasted from April 2012 to December 2012. The BIM consultant created the building information model during the construction stage.

- Whom (Stakeholder Involvement)

The HKHA decided to undertake this 5D-BIM R&D project in partnership with the general contractor (GC) China State Construction Engineering (Hong Kong) Ltd. and the BIM consultant is BIM Limited. The BIM consultant for the project was employed by the GC. HKHA issued a variation order (VO) to the GC to use BIM data and carry out cash flow forecast and payment simulation.

Within the HKHA's QS Section, there were five people involved in the 5D-BIM R&D project, including one senior QS, one QS, and three technical staffs. As with the BIM consultant, there were three people involved – two responsible for creating models, and one for quantity take-off and cost estimation.

- What (Modeled Scope and Level of Detail)

To fit with the site progress, four work sections were identified and modeled in BIM. The four work sections are piling, excavation, concrete works (excluding rebar) and underground drainage. The reason for establishing the four work sections in the modeled scope is that the four trades are the first few steps of the construction process. Among the four trades, concrete works are always difficult to model and measure through BIM.

- Which Tools (Modeling Software)

5D-BIM software, such as EXactal, Vico, and RIB, provides good functions with feasibility study, tender preparation, quantity take-off (QTO) module, etc. However, one challenge is how to localize thes software and make it consistent with the Hong Kong Standard Method of Measurement of Building Works (HKSMM).

The BIM consultant's proprietary software (characterized with a organized BIM data in a single-source database) was used to integrate isolated quantities, cost, method of measurement, construction schedule, and element location. The database is updated automatically when there are design changes, which saves tremendous non-value-adding work for QSs who, often, have to link the updated quantities in the revised models with the changed construction schedule and costing manually.

Based on the proprietary software, the BIM consultant developed a plug-in called "QSBIM add-on". Using "QSBIM add-on", the BIM consultant created material quantity take-offs in Revit and then handed them on to the quantity surveyors.

- How (Workflow)

The project took a new approach to quantity measurement as follows. This new approach aims at boosting efficiency and productivity by automated quantification, increasing accuracy by reducing data variability, and facilitating sharing of data among stakeholders.

1. BIM consultant/modelers created BIM models according to HKHA's BIM modeling guidelines.
2. Quantity surveyors put labels that contain the HKHA Construction Electronic Measurement Standard (HACEMS) code on every element in the model using QSBIM add-on.
3. Information was extracted automatically according to the HKSMM measurement rules.

When the BIM consultant received the 2D drawings, they built BIM in Revit. When building the Revit 3D model, the BIM consultant set out their methods of how to build BIM models for the four work trades. Afterwards, labels which contain the newly drafted HA Construction Electronic Measurement Standard (HACEMS) code were put on every element in the models. Coupled with standardized guidelines based on the Hong Kong Standard Method of Measurement of Building Works Fourth Edition (HKSMM4), information was then extracted automatically according the measurement rules in the HACEMS and formed a list of Bills of Quantities (items with quantities).

- What benefits and barriers

  - Benefits

The quantities from the new BIM approach and the quantities from manual measurement were compared and counter-checked with each other for the accuracy of quantities generated from BIM. For concrete works, the initial discrepancies by value were found to be around 10% and could be improved to 5% with some manual adjustments according to HKSMM4.

In addition, the GC found the BIM Quantity takeoff (QTO) helps in extracting quantities of work progress for interim payment applications.

  - Barriers

One of the challenges in extracting quantities is the requirement to follow the measurement rules in HKSMM. Part of the integration includes a reconstitution of the building data within the costing solution – linking cost geometry, attributes, and pricing. Another challenge is that different methods of building up BIM models produce different quantities.

The BIM team in HA QS section had to investigate the discrepancies between BIM measurement and manual measurement and identify ways to minimize the discrepancies. The BIM team found this task was the most difficult during the whole process.

Due to the lack of experience, the BIM team was not checking the model. They were just checking the quantities from BIM measurement. The adjustments made to fit HKSMM are still being investigated.

Case 2 : 5D-BIM from the Perspective of a Contractor

The Anderson Road project at contract value $4.7 billion has nine housing blocks providing 7,146 domestic flat. The Anderson Road Sites Phases A and B will be delivered with Integrated Procurement Approach (IPA) contract, in which the contractor proposed the development of 5D model-based QTO and schedule optimization.

- Why (Modeling Purpose)

The contractor started to implement BIM initially because of the client's requirement. Another reason was that, due to the complicated structural design of the project, it could not be built without use of BIM.

- When (Timing of Modeling)

The contractor first thought that a BIM could be built before the stage of construction drawings, but later found that what they expected was not realized since the design was changing all the time.

- Whom (Stakeholder Involvement)

The contractor employed its own architectural and structural design team and BIM modelers to carry out the design and modeling work. With input from contractor's own QS staff, models were created taking into account the rules in HKSMM4. Since the designers, modelers, and QSs are all working for the contractor, the teamwork is coordinated, collaborative, and coherent. This is an indispensable factor that led to the satisfactory result on the model based QTO on foundation works.

The basic BIM requirement in the contract was to have 1 BIM manager and 4 modelers. The modeling work was outsourced to a BIM consultant. For 5D BIM, a 5D BIM team has been set up by the contractor including QS, Engineers, BIM adviser and modelers.

- What (Modeled Scope and Level of Detail)

The level of detail (LOD) of model evolved as the project progressed. For example, during the tender stage, BIM was built on LOD 100 (a mass and form concept model for the purpose of pricing); and between tendering and construction stage, BIM was built on LOD 200 with all the major systems modeled.

- Which Tools (Modeling Software)

The contractor chose Revit for 3D modeling and Vico as a 5D BIM management tool which can provide both quantity take-off and scheduling functions. The contractor also expected to take advantage of quantity take-off from BIM for the purpose of project schedule planning so that GC and subs could work together to evaluate what-if scenarios and to determine the best solutions.

On this project, the way of getting quantities and material definitions out of a building information model into a cost estimating system was through “Application Programming Interface” (API) to estimating program. This approach uses a direct link between the costing system and Revit. From within Revit, the BIM consultant exported the building model using the costing program’s data format and sent it to the estimator, who then opened it with the costing solution to begin the costing process.

- How (Workflow)

i. Integrated 5D BIM Workflow (Figure 1).

This integrated 5D BIM workflow leverages its integration between the 3D model, the 4D schedule, and the 5D estimate. From the 3D model geometry, the contractor derives the construction-caliber quantities. These take-off items each have a special assembly of material, labor, and equipment. These priced take-off items and resources are then organized by location for an optimal schedule. The result is a cost- and resource-loaded schedule. Due to the tight integration, a design change in the model is immediately evaluated with a new schedule and new estimate.

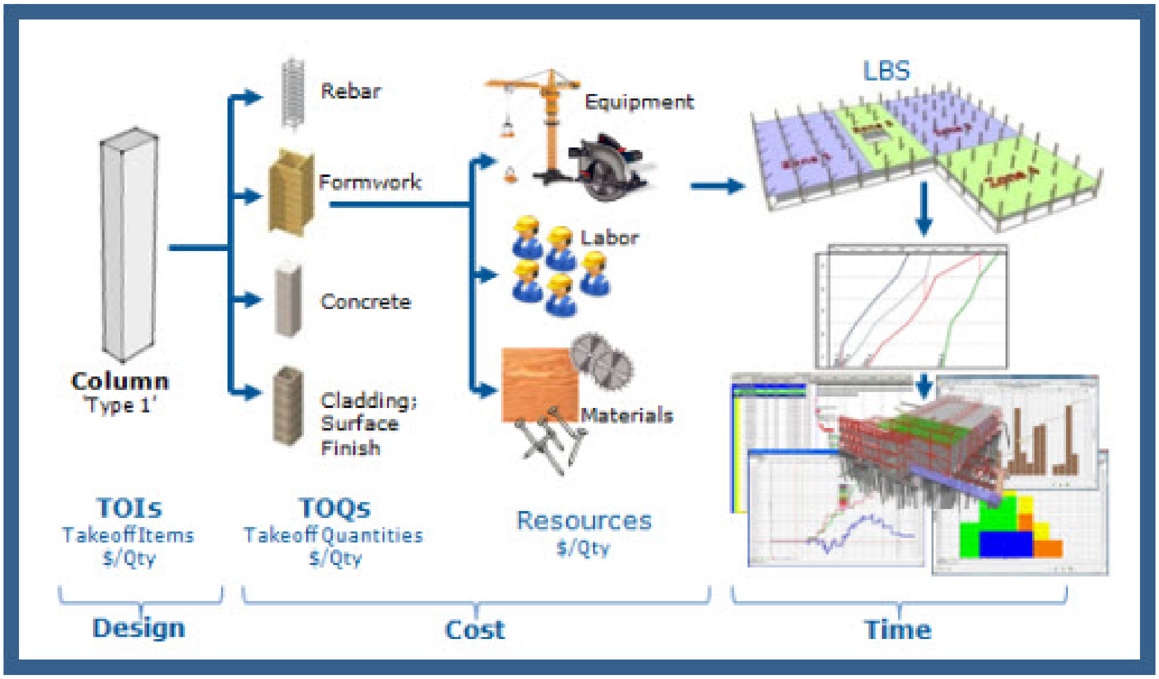

Figure 1: Integrated 5D BIM Workflow Overview (image source from Trimble VICO Office - http://www.vicosoftware.com/0/vico-office-R3-BIM-software-for-construction/tabid/229424/Default.aspx)

a) Modeling

BIM modelers followed modeling guidelines when developing each model. Communication and collaboration among engineers, QSs, and modelers is the key to BIM modeling accuracy and consistency. The model naming convention is to facilitate the HKSMM classification of materials for QSs to generate formulas for model based QTO. Each 3D component contains information such as material, size, number, length, width, height, area, and volume that can be linked to cost data for the purpose of interpreting project costs.

b) Model-based QTO

The refined 3D model then was imported to Vico Office to perform the automated quantity takeoff. The model based QTO is to link each individual 3D component with the cost breakdown structure database. The database is a crossover product between New

Rules of Measurement (NRM), HKSMM3, and HKSMM4. Quantity, cost, and specifications are all linked and formulated in the customized cost breakdown database

The approach transforms 3D BIM into construction-caliber quantities by location, 4D scheduling data, and 5D cost estimating data. The workflow allows the contractor to automate the task of generating location-based quantities both for their estimates and for schedules. The contractor can assess the schedule and cost impact of changes accurately and rapidly.

This approach requires that the creation of 3D BIM be integrated with the construction means and methods knowledge contained throughout the contractor firm, e.g., business development, preconstruction teams, estimators, schedulers, operations teams, and the field teams.

Afterwards a coordinated 3D BIM model feeds quantities to the different teams. Those detailed quantities feed cost estimates, and the line items in an estimate feed the project schedule. Subcontractors were brought into the process to assess and plan proper crew and resource sizing to produce a project plan.

ii. BIM Execution Plan (Figure 2).

In addition to the integrated 5D BIM workflow, BIM Execution Plan (BEP) is fundamental to the success of 5D BIM implementation. The goal for developing this structured planning procedure is to stimulate and direct communication and planning by the project team during the early phases of a project. BEP helps the project team to design a tailored execution strategy by 1) understanding the project goals, project characteristics, and the capabilities of the team members, and 2) dealing with questions and providing answers to protocol, procedure, and technical details.

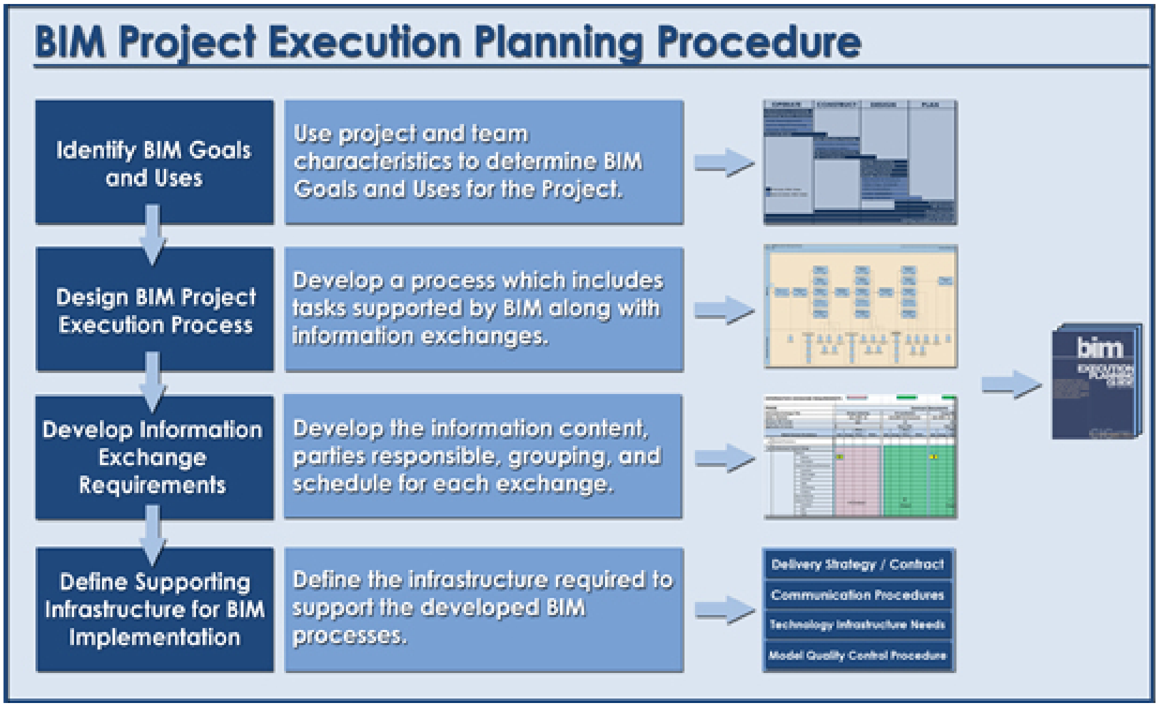

Figure 2: BIM Project Execution Planning Procedure (source from Penn State - http://rcd.typepad.com/rcd/2009/11/psu-bim-project-execution-planning-guide.html)

This diagram shows that the four steps within the procedure comprise:

- Defining high value BIM uses during project planning, design, construction and operational phases;
- Using process maps to design BIM execution;
- Defining the BIM deliverables in the form of information exchanges; and
- Developing a detailed plan to support the execution process

iii. BIM modeling guidelines

Apart from BEP, modeling guidelines also play an important role in the 5D BIM workflow. They describe how a model should be developed, e.g., how to define the graphical presentation of building components, what the naming principles, how to link the QTO in relation to HKSMM rules.

To facilitate faster and more accurate cost estimation, the QS from the contractor has developed standard modeling guidelines based on an international modeling standard. The standard modeling guidelines specifiy how the model should be built so as to suit the cost breakdown structure. The BIM consultant built BIM in Revit following the contractor's standard modeling guidelines and then published Revit models to a 5D BIM Management tool to generate construction-caliber quantities.

By combining model-derived quantities with the contractor productivity rates by trade and standard formulas for deriving labor and material resource requirements, the contractor was able to calculate costs for project estimates automatically.

- What benefits and barriers

  - Benefits

The quantities can be measured automatically according to HKSMM4 in Vico Office. Cost estimation can be generated more effectively and accurately also, as compared to the traditional measurement method.

  - Barriers

The workforce lacks the BIM-related skills. The contractor wishes that institutions would provide more BIM education programs. In addition, the value design and cost information created and collected during the BIM development process is difficult to transform into a BIM library for future project developments.

Case 3 : 5D-BIM from the Perspective of a BIM Software Developer

- Why (Modeling Purpose)

Glodon New HQ Building used BIM to:

a) Visualize the design and make decisions more efficiently
b) Check design consistency
c) Reduce clashes of different building systems
d) Reduce annual energy consumption by 16% through BIM-based energy simulation
e) Estimate project budget and manage project costs by using BIM5D

- When (Timing of Modeling)

This project used the traditional design-bid-build contract. BIM was built after the tender was awarded. BIM was built not only for quantity take-off but also for 4D simulation and other purposes.

- Whom (Stakeholder Involvement)

Unlike Hong Kong ,the government is not the **initiator** in implementing BIM. Often it is the major, general contractors who initiate the experiments with 5D-BIM. They carry out 5D-BIM R&D on their own projects, such as residential projects and institutional buildings.

There are two different kinds of parties take the role of BIM **modelers**. One is general BIM consultants including independent BIM consultants, design firms, and software companies. Often BIM consultants will create BIM and software companies to give advice on how to build the model for the purpose of 5D-BIM. The second kind is in-house BIM teams inside client's or contractor's organizations.

On the Glodon New HQ project, the executives from the owner company were deeply involved in project management from the beginning. The 3D models were not only shown in desktop PCs but could be reviewed in a tablet PC and a mobile phone. Those arrangements proved to be very convenient for executives (decision makers) to view, review, and comment on the project.

- What (Modeled Scope and Level of Detail)

Architecture models and structure models were built with a BIM platform with a high level of detailed information on building properties. The near zero-energy building was designed with detailed analysis and simulations to achieve the green building standards. With rich information embedded in BIM, the designers could analyze the sun exposure situations (light intensity) in each room and determine solutions in the design phase. Besides sunlight, the designers also measured and analyzed energy consumption accurately using model-based simulation. In addition, room temperature, humidity, air quality, and other properties were quantified accurately.

90% of quantity take-off for architecture and structure can be realized by the approach of 5D-BIM. However, only 20%-30% of MEP components needed for quantity take-off can be reflected in current models. This is because many small MEP components such as certain pipelines were not modeled.

- Which Tools (Modeling Software)

BIM technology has been applied in China for some time, but more applications are still in the design stage. Until recently, foreign software companies had little market share in the area of cost estimation in Mainland China. The difficulty lies in localization. In Mainland China, different provinces have different standards for construction cost estimation. In January 2013, a new standard was announced by the Ministry of Housing and Urban-Rural Development of People's Republic of China (MOHURD).

Around 50% of quantity surveyors in Mainland China use specialized QS software to do quantity take-offs. As early as 2000, 3D model based quantity take-offs emerged. With the development of BIM technology, R&D construction projects using BIM based cost management have emerged in Mainland China.

Glodon and Luban are the two primary domestic 5D-BIM software companies in Mainland China. Glodon have developed 5D-BIM software such as architecture and structure software GAS2011 as well as mechanical and electrical software GME2011. Luban has developed Project Data Providing Services (PDPS) based on BIM technology.

- How (Workflow)

i. Traditional workflow

Traditional QTO software recognizes 2D CAD drawings and provides a one-stop solution from quantity takeoff to cost estimation. The outcome of quantity take-off is presented in Excel format. There are different QS standards in different provinces in Mainland China. Software companies have localized their QTO software so as to suit the QS standards at the provincial level.

ii. 5D-BIM workflow

There are two approaches to BIM-based QS. The first is to add required information for cost estimation into the model; the second is to exact cost-related data from BIM to existing cost management system. Table 2 compares the advantages and disadvantages of the two approaches.

Currently, BIM-based QS will not begin until the construction stage. Models built before the construction stage, often, will not take the requirements of QS into consideration. Due to this constraint, BIM consultants have to rely on the second approach. Take Golden for example, they first converted a Revit model into Golden QS software and then revised the model within their software. The following process for quantity take-off and cost estimation is the same as the traditional workflow.

Table 1: Pros and cons of two approaches for BIM-based cost management

Approach	**Advantages**	**Disadvantages**
Adding required information for cost estimation into the model	Information highly integrated Cost will change automatically after design is changed.	Large size of BIM High hardware requirements High coordination requirements among designer, contractor, and quantity surveyor
Extracting cost-related data relating to cost management from BIM model to existing cost management system	Easy to realize	Cost cannot be changed automatically following design changes.

4.2 Key Drivers, Obstacles and Consequences of 5D-BIM identified in the Cases

4.2.1 Drivers of 5D-BIM Implementations

- Leadership of Client Developers

5D-BIM implementations can take many approaches but AEC professionals' motivation to adopt is the key to successful implementation. One of the major motivators is that AEC professionals are trying to keep up or respond to a mandate requiring BIM (client's requirements). As shown in the cases in Hong Kong, contractors and consultants are often required by the *clients* to adopt BIM (Case 2), while AEC professionals in client firm are self-motivated (Case 1). Hence, conforming to the results of the survey study (refer to Section 3), leadership of client developers are the key motivation of 5D-BIM implementation in construction in Hong Kong. For the Mainland case (Case 3), although the contractor took the initiating role in 5D-BIM implementation, it was also indicated that the involvement of executives from the client firm is also a key to the successful implementation. Hence, all the three cases support that the initiation and leadership of client developers are the key motivators of 5D-BIM implementation in the construction sector.

- Complicated Project Design

On the other hand, AEC professionals in the contractor firm in Case 2 also expressed that the complicated structural design is one of the factors motivating them to adopt 5D-BIM in their project. Innovation is often created or diffused in the interfaces of change and challenge. The professionals implemented 5D-BIM in the case because of the anticipated positive outcomes of this innovation. They wanted to and did create quick cost estimations from BIM as well as to update cost variations quickly.

- Project Team within the Organizational Boundary

Due to the different organizational cultures, structures and work practices, information processing across organizational boundaries has long been found to be complex and complicated. The adoption of 5D-BIM in construction project is a demonstration of information processing (e.g., the interchange of design and quantity information) between various AEC professionals who belong to different construction organizations (e.g., surveyors from QS firms and structural engineers from designers firm). Informers from Case 2 indicated that the project team in their project, composed of designers, modelers and QSs, is formed within their organizational boundary, the contractor firm. This was recognized as one of the successful factors of the 5D-BIM implementation in this case.

4.2.2 Obstacles of 5D-BIM Implementations

- Inadequate Training & Poor Learning Transfer (Incapable and inexperienced project team members)

Professionals, who are competent in both BIM and QS, are rare in Hong Kong. Often, QS professionals do not have experiences in modeling and experience difficulties in understanding BIM software. Meanwhile, architects who can design with BIM are few in Hong Kong. Most architects produce 2D drawings instead of BIM. In addition, architects know little about QS. Hence, they have difficulties in taking HKSMM's requirements into consideration when creating BIM. Training of 5D-BIM for AEC professionals is essential. Incapable and inexperienced project team is recognized as the barrier to 5D-BIM implementation in all the three cases.

In addition, even though the project team has received certain training on BIM, they are not used to, nor, willing to adopt BIM since they are not familiar with it. As mentioned by informers in Case 1, even though the quantity is ready in BIM model, the BIM team still followed their old practices and checked quantities from BIM measurement, instead of the model. Hence, in addition to training, a learning transfer conducive climate is also important for fostering professionals' adoption of an innovative technology.

- Lack of Support to Innovation

In addition to the above mentioned problems, the implementation of 5D-BIM was also hindered by inadequate support to the innovative quantity take-off (i.e., 5D-BIM). The above cases study unveiled two general types of support in need, the hard and soft support. For the hard support, it focuses technically on both i) the lack of fit between BIM model and HKSMM, and ii) the lack of standard approach for modelling. Often, BIM platforms are developed overseas and applied for design purposes mainly. The platform's capability for exporting quantities according to the rules of HKSMM4 has not been programmed. Architects and structure engineers do not consider the requirements of HKSMM when they design in BIM. Along with the development of BIM model from 3D to 5D, the design of BIM platform should evolve and innovate to incorporate HKSMM.

On the other hand, usually, different modelers create BIM in their own way. It is not uncommon to find different modeling methods applied in the same model. Different methods of building up BIM will lead to different sets of QTO. The differences between the way of creating BIM and the way of calculating quantities often lead to data discrepancies. To proceed to a more reliable BIM QTO, it is necessary to develop a Standard Approach of Modeling (SAM) to ensure: a) consistent modeling approach; b) identifiable building components; and c) sufficient object information to fit current QS measurement practices in different regions (e.g., HKSMM4 in Hong Kong). Only after BIM is created with a standard modeling approach that is consistent with the requirements of HKSMM, will discrepancies between BIM QTO and manual measurement decrease. When the data discrepancies are minimal, clients can use the same BIM QTO for measurement/ tendering, and contractors can use the same BIM QTO for quantity take-off/ sub-contracting. Regarding the issue whether we need a BIM QTO to pull for a SAM or a SAM to push for a BIM QTO, neither are current in Hong Kong. Both practice and standard are developing in parallel.

Lastly, soft support is also needed to resolve the conflicts between QSs and upstream parties, such as designers and engineers. Design intent and cost data often are separated and isolated in different digital environments, which makes it difficult and timeconsuming to extract and to link data among fragmented data sources. Due to the current industry practice, architects and engineers (or modelers) seldom take the advice and comments from QS professionals into account when they start BIM. The reason is that architects and engineers (modelers) think it takes more time and effort to build BIM if following the standard approach of modeling (SAM). Hence, an integrated project cooperation approach should be encouraged amongst various project parties, in which 5D-BIM can be used as a solid platform.

4.2.3 Consequences of 5D-BIM Implementations

- Increased Accuracy and Effectiveness

Some large construction companies use project management IT systems to improve their project performance. However, the project management IT systems may not work well in reality. Despite problematic functioning within the IT system and inappropriate business process set up alongside the IT system, one of the most important issues is the lack of accurate and timely cost and schedule data input to the IT system. Enterprise and project decision makers need to make judgments and decisions based on accurate and timely data. However, reports generated from real-time data on a project site, often, are out of touch with the day-to-day construction operations. For cost estimation, cost engineers need to spend a lot of time and effort to calculate quantity and price of a project. 5D-BIM was found to count the amount of materials quickly, which frees the cost engineers from such tedious work and allows them to focus on management of the cost.

- Integrated Project Delivery Approach (BIM-based Multi-disciplinary Collaboration Platform)

It should also be noted that the implementation of 5D-BIM does not only smoothen the quantity take-off process, but also brings the collaboration practice in construction to the next stage. The collaboration between different construction parties, including architects, structural engineers, and quantity surveyors, have been based on the frequent exchange of

2D drawings and documents traditionally, in which different parties participate in the information exchange process in different stages of the project. The fragmented project team cooperation has resulted in various project complications and delays. The wider-spread of BIM adoption in the past decade has resulted in a change in the existing collaboration practice and provided a solid platform for multi-disciplinary collaboration in construction projects, since the development of an integrative, centralized 5D-BIM model requires greater collaboration and information exchange between multi-disciplinary construction parties in the early project stage. Although previous studies indicated various benefits of the practice of multi-disciplinary collaboration (e.g., increased benefits to client and cost reduction, etc.; Akintoye et al., 2000), there are still various factors inhibiting the collaboration approach, such as the goal conflicts, lack of experience and varied roles and responsibilities, and so on (Singh et al., 2011).

4.2.4 Summary of Case Study

To summarize the findings of the three case studies, Table 2 was compiled. In general, the drivers of 5D-BIM include i) the initiation and leadership of client developer, ii) complicated project design, and iii) project team within the organizational boundary. The obstacles include i) lack of training /poor learning transfer (inexperienced /incompetent project team members), and ii) lack of support to innovation. The consequences of 5D-BIM implementation include i) increased accuracy, ii) enhanced effectiveness, and iii) integrated project delivery approach.

Table 2: Summary of the Case Study

Cases	**1**	**2**	**3**
Project details	Public rental housing development in Shui Cheun O Phase 1 in Shatin 5 housing blocks with 3,039 domestic flats	Anderson road project 9 housing blocks providing 7,146 domestic flats	New HQ project?! (not much details of project found, more like a national-based one, rather than project based case)
Contract sum	HK$1.3 million	HK$ 4.7 billion	-
Contract type	-	Integrated Procurement Approach (IPA)	Design-Bid-Build contract (DBB)
Party Studied	Housing Authority	The Contractor	Glodon (Software developer)
Party-based in	HK	HK	Mainland China
The BIM team	HA in partnership with China State Construction (HK) and the BIM consultant (employed by the China State)	A 5D BIM team comprising QS, engineers, BIM adviser and modelers set up by the contractor	-
5D-BIM Implementation			
Drivers	Self-initiation (Ada Fung) [Leadership of client]	Client's requirement [Leadership of client]	Involvement of executives from the client company [Leadership of client]
	-	-	Initiation of main, general contractor [Initiation of contractors]
	-	Complication of structural design	-
	-	Project team (designers, modelers and QSs) within the contractor's organizational boundary	-
Barriers	Working team in lack of BIM-related	Workforce in lack of BIM-related skills	Workforce in lack of technical

	experience (the BIM team checked quantities from BIM measurement, instead of BIM model) [Learning transfer]	[Training]	knowledge-how in implementing 5D-BIM [Training]
	Lack of technical support (linking cost geometry, attributes and pricing; different quantities resulted from different model dev. methods, reducing discrepancies) [Innovation]	Lack of technical support (transferring design & cost information to BIM library for future projects) [Innovation]	Lack of technical support (current BIM developed without details of construction method, procedures, etc; a lack of material coding) [Innovation]
Consequences	↑ Accuracy (10% discrepancies, can be improved to 5%)	↑ Accuracy	↑ Accuracy
	↑ Effectiveness (time & productivity)	↑ Effectiveness (time & productivity)	↑ Effectiveness (time & productivity)
	Multi-disciplinary Collaboration [Innovation]	Multi-disciplinary Collaboration [Innovation]	Multi-disciplinary Collaboration [Innovation]

4.3 The Questionnaire Survey Study

In this section, a questionnaire survey is conducted to cross-validate the case study results. Based on extensive literature review, the questionnaire was designed to involve two major scales, namely consequences and barriers of BIM implementation. Purposive and convenience sampling was adopted again by sending out questionnaires to quantity surveyors who had i) direct experience in quantity take-off in various construction projects, ii) worked in major construction sectors, including developers, contractor firms and consultant firms, and iii) amassed at least one year working experience in his /her current organization at the time the surveys were issued.

The questionnaires were distributed by fax, email, or in person. Out of 500 distributed questionnaires, 127 were returned, representing a response rate of 25.4%. Since four returned survey was found to be incomplete, only 122 questionnaires were included in the following analysis. The respondents were working in the private sector, in which 42.6% of them were working with BIM, while 57.4% are not (refer to Figure 4.1). This, to certain extent, reflects the spread of BIM adoption in the construction industry nowadays. On the other hand, 30% of those who were not working with BIM indicated that there was plan(s) for implementation BIM in their organizations (refer to Figure 4.2). The scales of benefit and barrier of adopting BIM were measured using a 5-point Likert scale ranging from 1 to 5, in which 1 stands for "very insignificant" and 5 stands for "very significant".

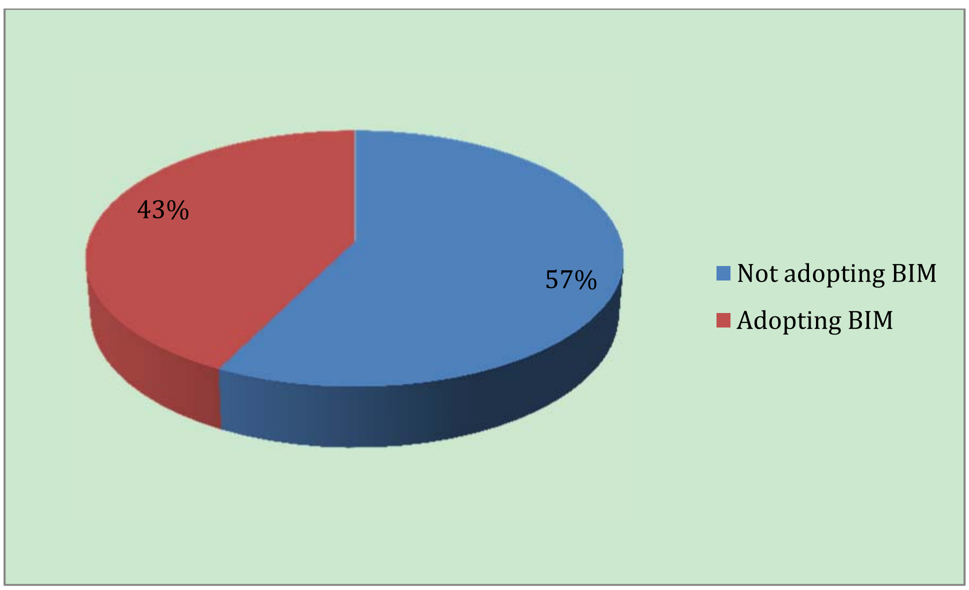

Figure 4.1 BIM Adoption in the Construction Sector

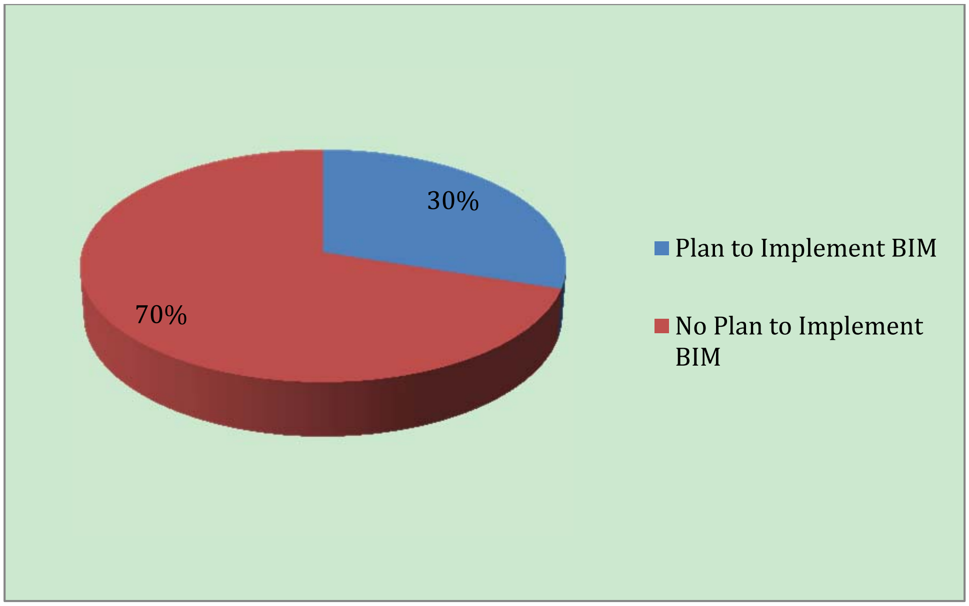

Figure 4.2 Plan to Implement BIM in the Future (respondents who are not adopting BIM)

4.3.1 The Consequences of BIM Implementation (Drivers)

The case study resulted in three main consequences of BIM implantation in construction, including enhancing accuracy, improving effectiveness and enhancing collaboration. The literature review also indicates other possible consequences, namely, minimizing error (e.g., errors detected by clash analysis), lowering cost (e.g., reducing workload of quantity surveyors), increasing quality (e.g., optimization of design in the early construction stage) and reducing time (e.g., automatic change in estimation in accordance to design change), in addition to the abovementioned three (Kubba, 2012). Hence, there are eight consequences included in the survey in total. As shown in Figure 4.3, the mean scores obtained for all the eight consequences are higher than 3, which mean that they were believed to be significant. Amongst these consequences, minimizing error (mean score = 3.81), improving collaboration (mean score = 3.68) and lowering cost (mean score = 3.49) were found to be the most significant benefits of implementation BIM.

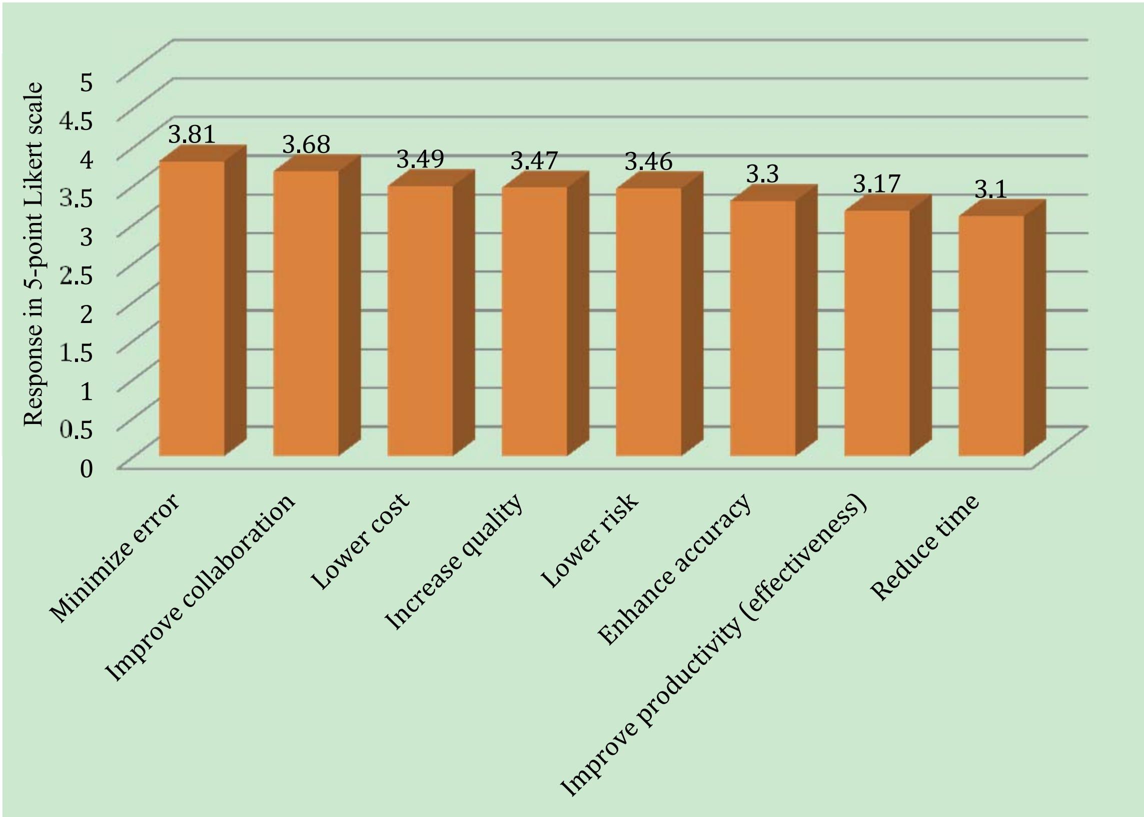

Figure 4.3: Consequences of BIM Implementation (all respondents)

However, not all respondents involved in this study were adopting BIM. Due to their different experience, a further analysis was conducted to compare their views on BIM implementation benefits. As shown in Figure 4.4, respondents who were adopting BIM rate higher in all of the BIM implementation benefits. The differences in rating between the two groups are the highest amongst minimizing error (difference in score = 0.9), improving collaboration (difference in score = 0.7) and enhancing accuracy (difference in score = 0.5). This, to certain extent, reflects that quantity surveyors who have no experience in BIM implementation tend to underestimate the benefits of BIM. The results provide indications to construction stakeholders who wish to promote BIM adoption in the construction sector, in which particular focuses should be paid on BIM's positive contributions in minimizing error, improving collaboration and enhancing accuracy. Promoting the beneficial consequences of BIM can, in turn, act as drivers of construction firms to adopt BIM, fostering the adoption and diffusion of BIM in the construction sector.

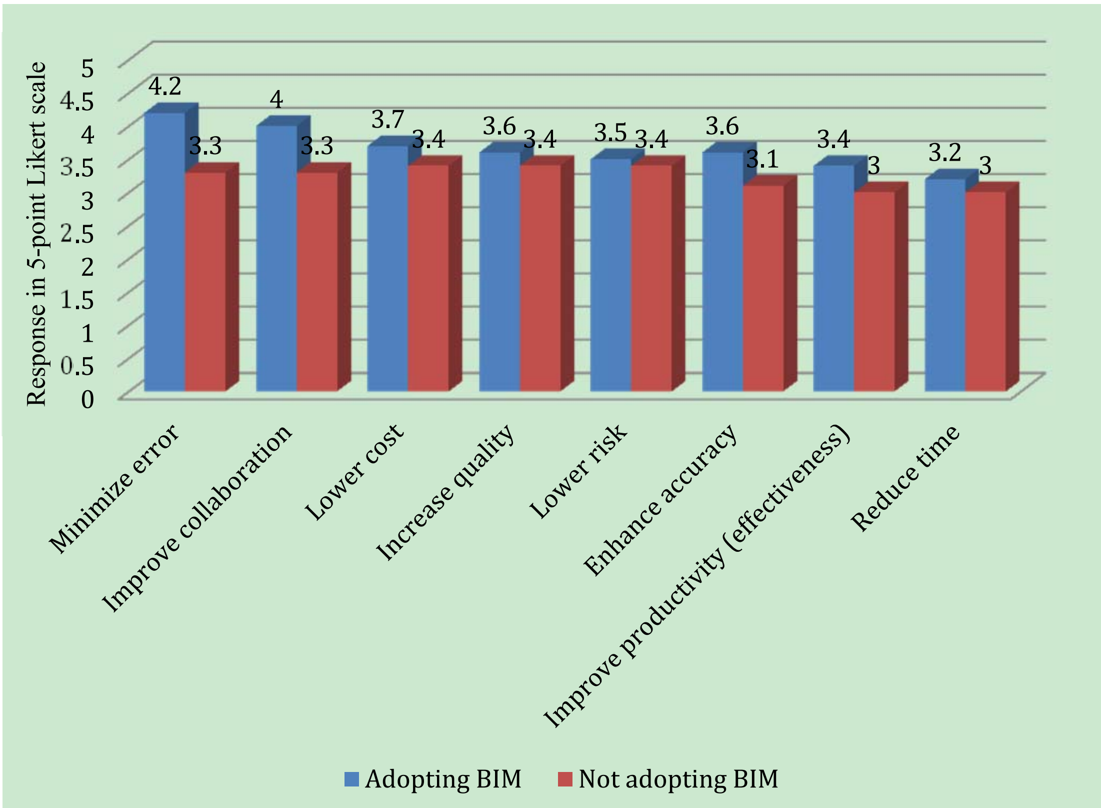

Figure 4.4: Consequences of BIM Implementation (respondents adopting vs. not adopting BIM)

4.3.2 The Barriers to BIM Implementation

Regarding barriers to BIM implementation, the case study has resulted in two main factors, namely, inexperience /incompetent working team (lack of training and /poor learning transfer) and lack of technical support. The literature review further indicates other possible barriers, namely lack of financial support (results in inadequate hardware support, such as high quality computer, and software support, such as training), lack of organizational strategy (adoption and implementation plan in an organization), reluctance to change work practice (lack of openness to change), poor software compatibility (between different BIM software), low adoption rate (inconvenient or even complicated information exchange process between parties adopting and not adopting BIM), high digital illiteracy rate (lack of BIM expertise in the construction sector), liabilities for data reliability (unclear allocation of responsibility of data transmission and verification), data ownership (sharing of data influenced by data ownership by project clients vs. other project parties), lack of clear distribution of work (responsibility of model development, operation, costing, etc.), and lack of computable design data (drawing data as common design data, rather than computable data) (Associated General Contractors of America, 2005; Bernstein and Pittman, 2004; Gilligan and Kunz, 2007; Gu and London, 2010; Hongqin et al., 2010; McGreevy, 2011). The survey, therefore, involves eleven barriers in total.

As shown in Figure 4.5, the mean scores obtained for all the eleven barrier factors are higher than 3, which mean that they were believed to be significant. Amongst these consequences, lack of financial support (mean score = 3.84), lack of organizational strategy (mean score = 3.82) and reluctance to change work practice (mean score = 3.71) were found to be the most significant barriers to BIM implementation in the construction sector. It is interesting to note that the top three barriers are all different from those found in the case study. Perhaps, the barriers revealed in the case study are secondary, surface barriers, which were caused by these primary, key barriers found in the survey study – lack of financial support, lack of organizational strategy (→incompetent project team due to lack of training & inadequate technical support) and reluctance to change (→ poor learning transfer).

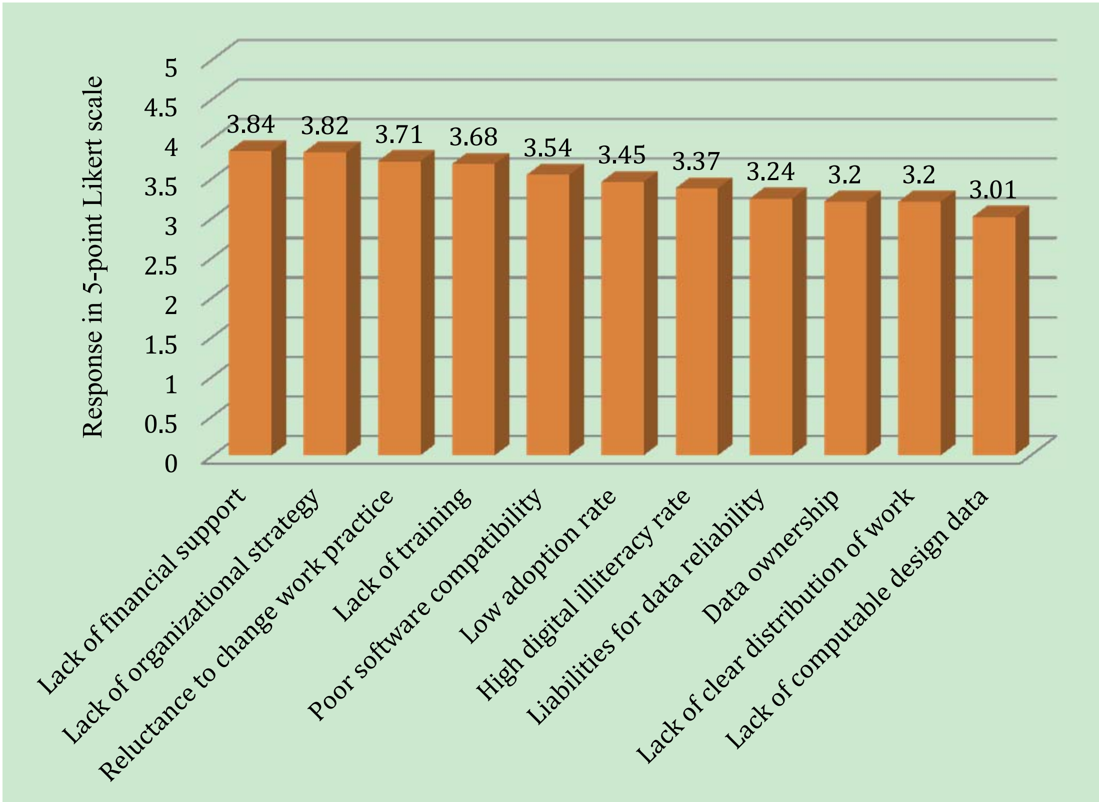

Figure 4.5: Barriers to BIM Implementation (all respondents)

Again, since not all respondents involved in this study were adopting BIM, a further analysis is conducted to compare their views on barriers to BIM implementation. As shown in Figure 6, respondents who were adopting BIM tended to rate the four key barriers including lack of financial support, lack of organizational strategy, reluctance to change work practice and lack of training (support or background barriers ranked the highest as shown in Figure 4.4) lower, while respondents who were not adopting BIM rated all the rest of the barriers (operational barriers in general) higher. This, to certain extent, indicates that the four anticipated key barriers are the most essential yet solvable barriers, in which firms generally overcome before they adopt BIM.

On the other hand, the differences in rating between the two groups are the highest amongst reluctant to change work practice (respondents adopting BIM rate 1.0 higher than their counterparts), poor software compatibility (respondents adopting BIM rate 0.7 lower than their counterparts), liabilities for data reliability (respondents adopting BIM rate 0.6 lower than their counterparts) and data ownership (respondents adopting BIM rate 0.6 lower than their counterparts) (refer to Figure 4.6). This, to certain extent, reflects that quantity surveyors who have no experience in BIM implementation are more reluctant to change their work practice and tend to underestimate the operational barriers of BIM. The results provide indications to construction stakeholders who wish to promote BIM adoption in the construction sector, in which particular focuses should be paid on individuals' openness to change (for BIM to be diffused into a firm) and the realistic operational barriers (for BIM to be implemented smoothly into a firm).

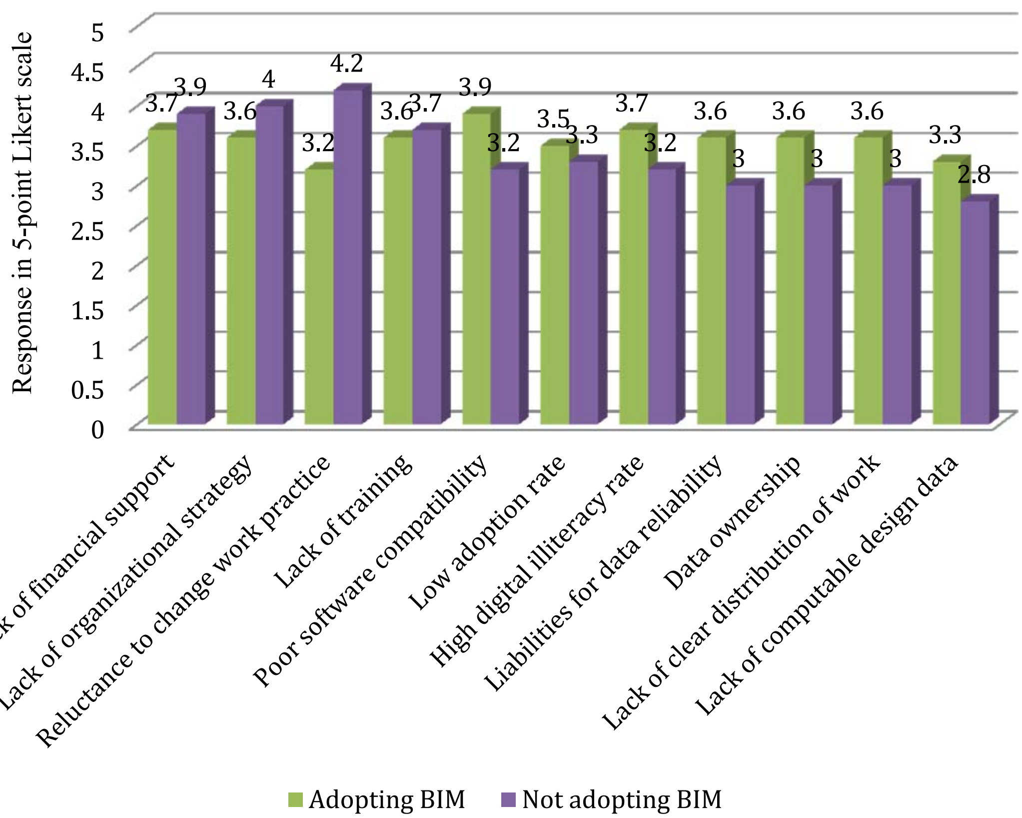

Figure 4.6: Barriers to BIM Implementation (respondents adopting vs. not adopting BIM)

4.3.3 Summary of Questionnaire Survey Study

The results of the survey study indicate that: i) Amongst the different benefits of adopting BIM, minimizing error, improving collaboration and lowering cost were the most significant ones, while respondents who were not adopting BIM tend to under-estimate the benefits of BIM in minimizing error, improving collaboration and enhancing accuracy; ii) Amongst the various barriers to BIM implementation, lack of financial support, lack of organizational strategy and reluctance to change work practice were found to be the most significant, while respondents who have no experience in BIM implementation are more reluctant to change their work practice and tend to underestimate the operational barriers of BIM.

4.4 Cross-Validation of Case and Survey Studies

To cross-validate the findings of both the case study and the survey study, Table 4.3 was compiled. As revealed in the case study, positive consequences of BIM will, in turn, become drivers of BIM implementation. Therefore, they are grouped under the same category in the summary table. For drivers and consequences of 5D-BIM implementation, factors identified by both case and survey studies include: i) improve collaboration, ii) enhance accuracy, iii) improve productivity, and iv) reduce time. For barriers, factors identified by both case and survey studies include: i) lack of training, ii) poor software compatibility, iii) high digital illiteracy rate and iv) lack of computable design data. Since the three cases in the study are all successful adopters of 5D-BIM, they, like respondents who were adopting BIM in the survey study, tend to put more emphases on operational barriers, rather than the background barriers, such as financial support, organizational strategy and openness to change in work practice. Perhaps, they have already overcome those barriers at the first stage before BIM could diffuse into their firms.

Table 4.3: Summary of Findings in Case Study and Survey Study

5D-BIM Implementation	Case Study	Survey Study
Drivers and Consequences		
Minimize error	-	Y (ranked 1st)
Improve collaboration	*Y (3 cases)*	*Y (ranked 2nd)*
Lower cost	-	Y (ranked 3rd)
Increase quality	-	Y (ranked 4th)
Lower risk	-	Y (ranked 5th)
Enhance accuracy	*Y (3 cases)*	*Y (ranked 6th)*
Improve productivity (effectiveness)	*Y (3 cases)*	*Y (ranked 7th)*
Reduce time	*Y (3 cases)*	*Y (ranked 8th)*
Self-initiation (leadership of client)	Y (3 cases)	-
Complicated structural design	Y (1 case)	-
Project team within organizational boundary	Y (1 case)	-
Barriers		
Lack of financial support (resource support)	-	Y (ranked 1st)
Lack of organizational strategy (support for innovation)	-	Y (ranked 2nd)
Reluctance to change work practice (openness to change)	Y(1 case)	Y (ranked 3rd)
Lack of training (training & learning transfer)	*Y (3 cases)*	*Y (ranked 4th)*
Poor software compatibility	*Y (1 case)*	*Y (ranked 5th)*
Low adoption rate	-	Y (ranked 6th)
High digital illiteracy rate	*Y (3 cases)*	*Y (ranked 7th)*
Liabilities for data reliability	-	Y (ranked 8th)
Data ownership	-	Y (ranked 9th)
Lack of clear distribution of work	-	Y (ranked 10th)
Lack of computable design data	*Y (1 case)*	*Y (ranked 11th)*

Note: 'Y' denotes factors supported by the stud(ies) (rating > 3 in the survey study).
Italic items denote factors identified in both case and survey studies.

5. BIM Implementation Strategies for Quantity Surveying

Authors: Liu, A.M.M.; Fellows, R.

5.1 Industrial & Professional Pushes for BIM Implementation

The practice of quantity surveying (QS) in Hong Kong remains firmly rooted in procedures, practices and standards of QS in UK. Since the return of Hong Kong to China in 1997, emphasis has shifted focus towards China. Developments in globalization and the internet are additional, major impacts. The current profile of QS in Hong Kong continues to be highly diversified from a few major, international, corporates firms to a large number of small practices; the workloads undertaken are, similarly, varied. Procurement processes are diverse and continually evolving (e.g., multi-stage work award; PPP) alongside performance assurance requirements (e.g., PASS; ISO certifications). Technologies are advancing at an increasing rate – regarding construction itself and information technologies. Thus, the entire construction industry is in a state of perpetual flux. Quantity Surveyors, in their central role of value and commercial/financial management, must be cognizant of and equipped to cope with all those changes to continue to provide professional service to clients.

In the face of the prolific and rapid changes, it is impossible to practice and provide excellent service through ‘traditional’ (person and paper-based) processes – advanced information technology is essential.

The necessity of standardized data which may be used in common throughout an integrated project realization process has been a rhetorical goal and debated for decades. Today’s context renders that goal an imperative. BIM (building information modelling – preferably, management) is critical to integration of data and information, alongside overcoming organizational and human fragmentation to achieve integrated project realization (design and construction) teams to deliver projects with significantly improved performance.

5.2 From Informational Technology to Boundaries Issues

Information technology (IT) began to impact the construction industry, and QS, during the 1960s (pre-level 0 of BIM – see Johnson (2014)). Architects and structural engineers pioneered the use of IT in design and calculation in moving from paper to 2D and, somewhat later, 3D systems (almost always, proprietary packages); BIM emerged during the last decade. Currently, BIM is being extended into Building Information Modelling and Management [BIM(M)] which is a managed approach to the generation, collection and use of information for a project's life cycle. The core is the digital model of the project comprising graphical and tabular data regarding the design, construction, and operation (sometimes disposal also) of the project. It is the management of the data, usually with a focus on value achievement through cost effectiveness and efficiency, which concerns quantity surveyors.

In common with other arenas of IT use, construction has to deal with three interfaces (boundaries and consequent issues) – person-person; IT system-IT system; person-IT system. Those interface issues are far from trivial and give rise to numerous problems of resistance, mis-understanding, clashes of various types, etc., which cause delays, quality/performance problems and cost increases on projects. Education and training are of great help but must be accompanied by developing compatibility of IT systems and 'user friendliness'. Human attitudinal change requirements may be the most problematic.

Attitudinal issues comprise two major types – individual and organizational. The individual pertain to a person's 'comfort' with using IT systems and particular packages. The organizational pertain to organisations' goals and objectives, tactics and so, behavior in the project environment. Commonality and integration yields teamwork, while ('traditional' and all-too-common) fragmentation leads to opportunism, conflicts and reduced performance (see, e.g., Latham, Egan, Tang).

Commercial and regulatory forces are moving practices in the industry along the path of BIM (towards level 3). Whilst that may be regarded as a logical, desirable development, numerous issues, of all three types, remain to be resolved (such as language/translation issues between the different Chinese characters used on drawings, etc. in Hong Kong and mainland China).

5.3 The Changing Industrial Environment

Quantity surveyors are in a particular situation within the myriad of the developments. Although not primary designers, they are far from the historic 'cost police' role. Quantity surveyors use primary design data and information generated by others to produce information vital to the financial/commercial viability of (proposed) projects – traditionally, regarding capital cost but, now, concerning life cycle value – and act, post-contract, to maximize project performance realisation. Some practices are extending their services to incorporate programming and life cycle environmental evaluations. As economic/financial and contractual/procedural/process specialists in construction, the analytic and advisory role of quantity surveyors from the earliest phases of possible projects is vital.

Clearly QS is nested within the construction industry. The industry is largely nested in its home country socio-political economy; thence, for Hong Kong, in China, Asia, and global (and beyond – environmentally). In an increasingly privatized world, emphasizing free-markets, metrics of ('bottom line') performance regarding profitability and growth are imperative; arguably, other business criteria, technological factors, and relationships are important (only) as means for achieving the bottom line performance requirements. Those contextual considerations must be addressed adequately for survival and prospering.

Generically, driving forces for all economic agents, notably businesses, are survival, growth and profitability which are pursued in various ways depending on the context (industry, location, etc.) and internal forces (the desires of powerful and active owners and managers). Given the highly competitive nature of construction, demand side factors are paramount – through price and quantity signals of market trends, and governmental policies and actions. Thus, practice initiatives by government and agencies in Hong Kong have great impact on practice in the construction industry – notably, the BIM initiative of the Housing Authority (see http://www.housingauthority.gov.hk/en/business-partnerships/resources/building-information-modelling/) and of the Construction Industry Council (see www.hkcic.org/WorkArea/DownloadAsset.aspx?id=10628...1033).

Clients' requirements for cost reductions, faster realistion of projects, enhanced value of buildings through better in-use performance, and improved life- cycle environmental effectiveness and efficiency of buildings are global drivers of change. In Hong Kong, quality assurance of suppliers is a common tendering qualification and environmental certification of buildings acts as an important demand determinant. In UK, as a trend indicator, government has included four major targets: 33% reduction in both construction and whole life costs of built assets, and 50% reduction in each of time from inception to completion, greenhouse gas emissions, and improvement in exports in its strategy document "Construction 2025". BIM is identified as an imperative for achievement of those targets. Thus, by 2016, all UK government contracts, large and small, must use BIM at, minimum, level 2. By 2025, UK government and industry anticipate general adoption of level 3 BIM, and so, be embedded in the wide arena of digital technology, thereby reaping considerable benefits throughout construction supply networks.

5.4 Current Practices and Obstacles of BIM Implementation

Today, CAD programs are extending in scope through 3D, 4D, and 5D versions, as in level 2 BIM, which greatly assist management of organisational interfaces and understanding work of other disciplines through visualisation and appreciation of components, processes and their consequences – such as safety issues during construction, adaptation and disposal. Such 'boundary objects' operate as common information spaces used by project participants who, thereby, can interact and coordinate their activities whilst maintaining their own goals (Bartel and Garud, 2003) in application to the overall project. That requires appropriate access protocols (trusting behaviour) and trustworthy behaviour by participants – which have given rise to widespread governance concerns over the use of BIM.

In analysing processes in different project design consultancy practices (single- and multi-discipline) which adopt different arrangements for project working (discipline-, project-, or team-based), Day and Faulkner (1988) and Day (1996) find differing attitudes and behaviours as well as different protocols to access the designs. Those result in varying levels of integration and coordination and so, impact project performance.

Whilst the legal issues, such as intellectual property rights, are of concern to users of BIM, the basic issues are similar to those embodies in traditional (paper) equivalent processes but with the important difference of BIM using a common design model. Thus, the issues, in essence, concern access protocols and transparency and traceability of inputs (which should be readily incorporated in the BIM IT packages). (see, e.g., http://www.fenwickelliott.com/files/insight_issue_7.pdf). Reassuringly, the Building Information Modelling (BIM Working Party (2011: 6) states "…little change is required in the fundamental building blocks of copyright law, contracts or insurance to facilitate working at level 2 of BIM maturity. Some essential investment is required in simple, standard protocols and service schedules to define BIM-specific roles, ways of working and desired outputs."

Some technical obstacles in BIM implementation remain. Those, primarily, involve compatibility between IT packages – as in incorporating additional dimensions into models 2D – 3D – 4D – 5D (at BIM level 2). Even at constancy of dimensions, compatibility between packages remains. Notoriously errors are most prevalent at points of conversion between media – input errors (e.g., digitising hard copy drawings).

Major BIM design packages tend to be architecturally-oriented (e.g., Revit) which, coupled with requirements of quantity surveyors to have data and information in formats compatible with the appropriate standard method of measurement (and, hence, cost and price databases) for cost / price forecasting and control, is a drawback. Usually, that drawback is overcome either by exiting the BIM system and performing QS functions manually or, increasingly, by securing 'plug-ins' to the BIM system to produce the data required from the design. (Often, 4D requirements – time – are secured in similar ways to the 5D requirements.) Clearly, for effectiveness and efficiency, 4D and 5D requirements must be incorporated into the BIM system to yield data and information in appropriate formats automatically, including incorporation of design changes. That is essential in progressing to level 3 BIM in which web located databases of many forms and purposes may be accessed – for materials and components, duration and sequencing, costing and pricing, etc.

Success, as an outcome, is achievement of expectations (and targets) of performance, as a minimum, which should lead to satisfaction of the focus participant / stakeholder. Often, due to differences in goals amongst participants, success is viewed differently by the various participants – traditionally, a zero-sum-game (trade-off model) has operated in which one participant gains at the loss of another. Various initiatives have been adopted in endeavours to change the situation to one of mutual gain (win-win), a non-zero-sum-game) in which gains arise from an enlarged 'cake'. Through early participation and enhanced clarity of visualisation of product (the building and its components) and processes of realisation (assembly, etc.), BIM facilitates elimination of many forms of waste (component clashes, assembly delays, etc. – and resultant, likely conflicts) to 'enlarge the cake' and to preserve / enhance relationships – with well known, consequential benefits!

5.5 Developing Key Performance Indicators (KPIs) for BIM

The more tangible objectives of BIM are securing performance improvements for both the product (building, etc.) and its realisation process (project performance and project management performance). Governments continually admonish the industry for its performance and lack of innovation and press it to 'improve' through policy documents and performance improvement targets – usually cost reduction, duration reduction, quality improvement, environmental protection; sometimes accompanied by quantity targets – e.g., housing units in Hong Kong). Many countries have 'key performance indicators' (KPIs) which include time, cost quality metrics plus predictability, client satisfaction, profitability, safety, workforce turnover, etc. (see, e.g., http://www.constructingexcellence.org.uk/news/pdf_news_articles/KPIv6.pdf). The KPIs are numerous and while each one is important, they are also of differing importance to different parties and so, weighting of them, in the context of other performance requirements – n.b., corporate objectives – is problematic. An agglomerate measure of several metrics invokes 'regression to the mean' (an average, overall measure) which diminishes its usefulness. Managers need to identify and focus on a small number of essential performance indicators and use metrics which are easy to use, accurate and reliable, and transparent.

Perhaps the main hallmarks of QS work are consistency and accuracy. However, it is widely acknowledged that no two quantity surveyors will produce identical take-offs from the same set of design documents (drawings and specifications). That variability will be eliminated through use of a common BIM package. Thus, the issue is to ensure the accuracy of the automatic take-off within BIM; as such assurance will be achieved through comparisons with take-off done by hand, minor inaccuracies are likely to persist but may be ignored through their being insignificant and consistent.

Since 5D-BIM implementation is still in its early stage, performance indicators specifically developed for it is still rare. However, some criteria developed by the RICS (2014a) for the selection of BIM estimating tools, which aims as facilitating the BIM process, can be borrowed as a base for KPI development. The key performance indicators can include:

- **Information exchange**

  The capacity and quality of information exchanged through various organizational, project and software boundaries

- **Model visualization**

  The adoption and functioning of model visualization by various project parties across various project stages

- **Quantification process**

  The efficiency and accuracy of the estimation process, usually determined by

  i) the speed and reliability of information transfer, extraction and production;

  ii) the speed and reliability in recognizing and recording changes in models

  iii) the capability of incorporating certain measurement standards within the tools and to map with other standards, and

  iv) the generation and export of report

5.6 Other BIM Implementation Strategies

BIM strategies occur in two categories – push (commonly through system suppliers), and pull (from members of the industry and owners / users of construction products – 'clients') (see http://www.bimtaskgroup.org/wp-content/uploads/2012/03/BIS-BIM-strategy-Report.pdf). The two, generic strategies operate differently and yield different capability contents of BIM packages. The push approach produces BIM packages with capabilities determined by IT producers, using expectations, information eliciting and performance feedback from users – the resultant BIM is driven by producers' commercial considerations of what is included; hence, specialist add-on plug-ins are likely to be common. The pull approach is customer-centric and so, driven by users of BIM regarding their own (commercial) requirements concerning their own requirements in endeavouring to satisfy their customers (clients, etc.); again, that may lead to BIM packages biased towards particular activities and requiring plug-ins for others.

5.6.1 Changing Attitudes and Behavioral Consequences via Various Management Strategies

From the perspective of the construction industry and its clients / customers – and everybody uses buildings and structures daily – the immediate objective of BIM, at any level, is integration – of components and (realisation) processes and, cooperative collaboration amongst project participants and wider stakeholders. Integration is pursued differently at progressive levels of BIM and so, industry standard protocols must be adapted. Whilst the widely criticised fragmentation in the industry is a consequence of increasing specialisation, it has fostered self-oriented, silo mentalities which have proved detrimental to performance through opportunistic behaviour and conflicts. The widespread use of price competition, often in quite 'raw' forms for work allocation to and within supply chains has exacerbated the problems. As illustrated in Figure 3.10, the adoption of innovative 5D-BIM requires the contributions and interactions of all the client developers, contractors and construction consultants. It is the time for construction stakeholders to move from the traditional concept of transaction market to the innovative co-creation one, which is based on collaborative perspective.

As with 'partnering' initiatives (and QA / TQM initiatives before them), a fundamental issue is peoples' attitudes and their behavioural consequences. Changing attitudes or beliefs is very difficult and requires diversified management strategies. As shown in Figures 3.9, 3.10, and Table 4.3, innovative climate (i.e., support for innovation and resource supply), learning transfer climate (i.e., openness to change, performance-self efficacy and performance-outcome expectation) and leadership (i.e., charisma) are all found to have positive impact in fostering 5D-BIM adoption in construction. The adoption of 5D-BIM is grounded to the levels of individuals – merely changing the rules is insufficient.

5.6.2 Development of International BIM Standards

As indicated in the case study (refer to Section 4.2.2), one of the key obstacles of 5D-BIM implementation in construction is lack of standardization. The obvious solution is for standards to be developed, advisedly globally – a process which is under-way in various countries. The international perspective is vital, given globalisation of construction. Initiatives of importance in standardisation include those of ISO and COBie (Construction Operations Building Information Exchange – see, e.g., http://www.wbdg.org/resources/cobie.php) (COBie 2012 – UK) as well as many concerning BIM systems themselves. Hong Kong, and its quantity surveying profession lies at a confluence of construction industry developments from China and major Western countries – their standards, products procedures, languages, etc. are markedly different (e.g., methods of measurement) which, for global BIM require rationalisation to a common, accepted library. This rationalisation will, inevitably, require some compromises.

At present, despite some dominance in certain areas, there are many BIM packages used by different participants, for different purposes at different stages of a project; often compatibility of the packages is limited, occasionally non-existent. Quantity surveyors, given their central role regarding commercial aspects of a project must deal with the various types, and accuracies, of data and information to effect sound commercial judgements in advising clients. Thus, each data set must be evaluated for input to that function – suggested criteria are:

- Completeness of the data, appropriate structuring, and with correct parameters
- Consistency and coordination of the data
- Data availability at appropriate stages of the project to support the decisions necessary, and for follow-on activities
- Data relevance to KPIs etc.
- Indications of effectiveness and efficiency in design and design (and construction, etc.) processes by tracking data development trends

5.6.3 The Importance of International Construction Measurement Standards

As indicated in the BIM for New rules of measurement (NRM1) report (RICS, 2014a), the mismatch between BIM based cost estimating software tool and the regional practices and standards of measures is the key reason for the limited adoption of BIM amongst quantity surveyors. To fill up this gap, the RICS (2014a) has conducted a research investigating the required information from a BIM model to support the estimating process according to the RICS standard of NRM1. However, NRM1 is not, or yet, universal. BIM software tools developed to specifically fit NRM1 may still not be applicable to projects in regions which are applying other measurement standards, like the Standard Method of Measurement (SMM7) and the Standard Form of Cost Analysis (SFCA).

In fact, construction measurement approach deviates from region to region and from standards to standards. For instance, land and finance costs are included in construction costs in Switzerland, which is different from that in the UK (RICS 2014b). The inconsistency of quantity surveying standards and practices resulting from different standards does not only make it very difficult to develop a universal 5D-BIM software, but also hinder the information exchange process between project participants, making decision making more difficult. This is especially true for mega, international projects which involve construction parties from all over the world. In addition, one of the key benefits of BIM is that it can be connected as an integrated library for massive construction and building related data, which is a key to sustainability in the construction sector. Without international construction measurement standards, data and experience amassed can hardly be transferred from project to project. Hence, international construction measurement standards are essential platform for 5D-BIM implementation in construction.

For the above reasons, the RICS has worked to develop a coalition of partners to establish the shared international construction measurement standards. There are currently more than 30 organizations participated, including the Council of European Construction Economists (CEEC) (RICS, 2014b). The following strategies are proposed for the quantity surveying discipline:

- Identifying key areas related to QS in a 5D-BIM project (e.g., cost, risk and technology) (RICS, 2014b)
- Based on the identified areas, reviewing international standards worldwide (e.g., Different national codes could have led to various wrong decisions in the past. The international standards should highlight the differences and prevent the previous mistakes from happening in the future (CEEC, 2008))
- Deciding what items to be included in the standards (e.g., land and financing costs) (RICS, 2014b)
- Finalizing structured standards (e.g., a structured list of costs) (RICS, 2014b)
- Standardizing form of cost analysis (CEEC, 2008)
- Setting up a documentation format (CEEC, 2008)

By standardizing measurement approach in terms of cost, risk and technology (the BIM technology), the adoption of international construction measurement systems will provide consistent and transparent measuring, reporting and management standards (RICS 2014). By reducing risks in data accuracy and waste in time, decision making can be improved, which can further enhance project efficiency and performance.

5.6.4 Development of In-house Expertise

Moving (further) into BIM may affect the expert power structuring within an organisation sue to increasing reliance on IT as the medium for execution of technical, professional expertise tasks. Practicality determines that practices obtain packages from IT specialist suppliers which are likely to require add-ons for particular, specialist purposes (5D aspects for QS and compatibility with SMM and, hence cost / price databases). Selection of the package must address own requirements and, importantly, wide compatibility with other project participants' packages (in the existing and future sphere of operations) – that suggests an industry standard package. The add-ons may be (developed and) provided by the package producer, by another IT specialist, or developed in-house; the choice, in part, depends on the size of the firm and the add-on IT requirements. In any case, development of IT expertise in-house, through recruitment, training and education is a sound strategy.

NBS (2014) notes the five main barriers to implementation of BIM are (approximate hierarchy):

- Lack of in-house expertise
- Lack of client demand
- Cost
- Relevance of BIM for the project(s)
- The projects undertaken are too small for BIM

The NBS survey also found that Autodesk Revit is the usual BIM platform (package) and that most BIM objects are generated in-house and then re-used on future projects, although objects included in packages and obtained from libraries are widespread.

Adoption of BIM is perceived to yield competitive advantage. Particular benefits are:

- Changes in workflow, practices and procedures
- Improved visualisation
- Improved coordination of construction documents
- Enhanced productivity through easy retrieval of information
- Cost efficiencies
- Increased speed of delivery
- Increased profitability

Further, most respondents to the NBS survey believed that both clients and contractors will insist on the use of BIM in the (near) future. Building Information Modelling (BIM) Working Party (2011: 92) report that US research indicates that using BIM produces savings in the order of 5% of construction cost for new build projects and 1.5% on refurbishments; further savings may be expected through use of BIM(M); BIM(M) system investments are expected to achieve return in investment (ROI) "greater than

60%”. For UK projects, around 9% reduction in construction costs is expected through use of BIM(M).

5.7 Summary

5D-BIM is an inevitable trend in the construction sector. Although various construction firms have started acquiring BIM knowledge or implementation BIM, they are still in the early stage. The obstacles to 5D-BIM are not only knowledge inefficiency (at individual and /or organizational level), but also involve the lack of support from the industry (e.g., various standards on implementations). With reference to both the study results and the international trends and practices worldwide, five implementation strategies are proposed: 1) changing attitudes and behavioral consequences of construction professionals via various management strategies (especially those which foster or innovation climate, learning transfer climate and leadership); 2) developing international BIM standards for fostering experience collection and information exchange; 3) establishing international construction measurement standards as a platform for 5D-BIM adoption; 4) developing key performance indicators for BIM implementation; and 5) e in-house expertise rather than out-sourcing to BIM consultants.

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