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Knowledge, Skills and Functionalities Requirements for Quantity Surveyors in Building Information Modelling (BIM) Work Environment: An International Delphi Study

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Abstract

Previous research studies have identified a lack of skilled personnel and a lack of Building Information Modelling (BIM) knowledge and training as one of the major challenges hindering the adoption of BIM in the Architecture, Engineering, and Construction (AEC) industry. Despite the significance of these challenges, there is a dearth of research studies to identify the necessary skills and knowledge to overcome these challenges. A few extant studies in this area focused on general domain skills and knowledge which may not sufficiently suit each domain. This study aims to identify a series of knowledge domains, domain-specific skills, and domain-specific functionalities needed for quantity surveyors to function in a BIM environment and for maintaining sustainable quantity surveying practice in the AEC industry. Delphi survey technique was adopted to aggregate the consensus of experts on knowledge, skills, and functionalities identified from the literature review coupled with experts' collective reviews and opinions. The survey findings underscored the need for quantity surveyors to be BIM compliant and identified 8 knowledge areas, 7 domain-specific skills, and 9 domain-specific BIM functionalities for the quantity surveyors along with the industry required level of expertise using the cognitive domain of Bloom's taxonomy. The survey findings will help mitigate possible fears of quantity surveyors as regards BIM adoption in practice and will be useful in the training and assessment of quantity surveyors to efficiently work in a BIM environment.

Keywords: Quantity Surveyors; Building Information Modelling (BIM); knowledge; skills; functionalities

Background of Study

There have been emerging paradigms and technologies aiding the development of the Architecture, Engineering, and Construction (AEC) industry over the years. Paradigms and technologies such as lean practice, sustainability, Building Information Modelling (BIM), Artificial Intelligence (AI), Big Data, and Internet of Things (IoT), among others, are gaining widespread awareness and adoption in the construction industry. These are channelled towards maximizing and optimizing the performance and value generated by the AEC industry and towards a more integrated industry (Egan, 1998; Latham, 1994). However, the transition from the traditional approach to these innovative approaches is highly complex and the AEC industry is slower in adopting innovations when compared to other industries such as the manufacturing industry (Gledson et al., 2012).

The Building Information Modelling (BIM) is an interrelation of policies, processes, and technologies for the digital-enabled management of buildings from inception to demolition (Succar, 2009). It enables digital construction of accurate virtual models of building for use throughout the whole lifecycle and for a safer and productive environment (Eastman et al., 2008). BIM enables access and sharing of building data for different functionalities such as clash detection, energy analysis, structural analysis, quantity takeoff, and space management, etc. (Singh et al., 2011). Several perceived benefits such as raising productivity, saving time, saving cost, improving project collaboration, design visualization, lifecycle management, among others, have been reported by early adopters of BIM. Thus, there have been a myriad of BIM studies on areas such as adoption and implementation (Gray et al., 2013; Gu and London, 2010; Olawumi and Chan, 2019b; Poirier et al., 2015; Saka and Chan, 2019a), application (Becerik-Gerber et al., 2012; Karan et al., 2016; Olawumi et al., 2018), framework

(Kouch, 2018; Porwal and Hewage, 2013; Singh et al., 2011), challenges and benefits (Azhar, 2011; Sun et al., 2015), among other areas.

Recent research has revealed that the adoption of BIM in the AEC industry is still slow and not as envisaged (Saka et al., 2019b). Also, BIM is changing the modus operandi of firms from the traditional fragmented approach to a collaborative and integrated approach. However, the implementation of BIM goes beyond learning new software (Arayici et al., 2011), and it involves a significant change in the operation of the firms and different business strategies (Olatunji, 2011). Thus, there exists a pressing need to change the traditional work process of the professionals (e.g. quantity surveyors, architects, engineers, etc) in the AEC industry.

Quantity Surveying is a global profession saddle with the responsibility of providing services across various industries. Quantity surveyors are involved in all stages of the project lifecycle and are crucial to the success of construction projects; making them indispensable to the construction industry and the clients (Perera et al., 2007). Dada and Jagboro (2012) opined that the primary function of quantity surveyors is to add value to the financial and contractual management of construction projects throughout the whole project lifecycle. Ashworth and Hogg (2002) and Leveson (1996) corroborated that quantity surveyors serve as financial advisors, construction advisors and contract administrators.

Despite the immense benefits such as good decision making, automatic quantification, consistency and accuracy of cost estimating, automatic quantities reflection with design changes, lifecycle costing, and more time for alternative services (Goucher and Thurairajah, 2012) that BIM holds for the quantity surveying profession, myriads of challenges are encountered as the profession is still entrenched in the traditional work setting. Babatunde et al. (2018) assessed the BIM drivers and barriers to the quantity surveying profession and concluded that the desire to be competitive, trained staff, government support, clients' demand, etc are some of the key drivers of BIM; while improved efficiency, cost saving, clash detection, central data storage, rapid identification of changes in design are some of the concomitant benefits. Boon and Prigg (2012) argued that quantity surveyors need to improve their job skills from the traditional approach of making use of 2D from the 3D. Aibinu and Venkatesh (2014) reported on some significant challenges such as lack of BIM knowledge, the high cost of implementation, and lack of client's demand, etc as the reasons for the low status of BIM in quantity surveying practice in Australia and this was corroborated by Zhou et al. (2012) in the UK and Stanley and Thurnell (2014) in New Zealand. Similarly, P. Smith (2016) opined that the full potential of BIM implementation in quantity surveying profession is not yet realized and there is a need for quantity surveyors to be BIM compliant (P. Smith, 2014).

The fear that BIM would usurp the quantity surveying practice is enshrined in some professionals and firms leading to resistance to change and adoption. However, Olatunji et al. (2010) asserted that BIM only challenges the traditional process of the practice and recommended improvement on the quantity surveyors' training. As the adoption of BIM has the capability to enhance quantity surveyors' work performance, and improve the project performance (Wong et al., 2014); and enhance the effectiveness of the services offered by quantity surveyors (Kulasekara et al., 2013). Consequently, Harrison and Thurnell (2014) opined that there is a genuine need to identify the necessary pre-requisites/skills to tackle the challenges of lack of BIM knowledge, lack of skilled personnel, and lack of awareness in quantity surveying practice for proper adoption and implementation of BIM in future.

Extant research studies have established the lack of skills/knowledge as one of the major impediments of BIM in the AEC industry. However, there is a scarcity of studies focusing on domain-specific skills and knowledge to curb this major challenge. This paper aims to determine the domain-specific skills, domain-specific BIM functionalities and knowledge domains by means of Delphi survey technique in order to equip quantity surveyors and quantity surveying practice in the BIM environment. Also, the expertise levels of the skills, knowledge, and functionalities as required in practice will be assessed and discussed. The research findings will mitigate the fear of BIM intimating the quantity surveying roles by revealing some of the pre-requisites needed to make them capable of functioning in the BIM environment. The practical implications of the results will lead to the identification of required domain-specific skills, knowledge and functionalities of BIM that would be beneficial in the training of quantity surveyors; assessing the current status of training and identifying possible deficiencies; and providing useful guidelines for the employers of quantity surveyors to upgrade their employees' capability.

Knowledge, Skills and Functionalities Requirements for Quantity Surveyors in Building Information Modelling (BIM) Environment

Lack of knowledge and skills have been identified as one of the major bottlenecks for the proliferation and use of BIM in the construction industry (Sacks and Barak, 2010). This can only be solved by training professionals to have the required knowledge, skills, and be proficient in BIM capabilities related to their disciplines (Barison and Santos, 2011; Gu et al., 2010). However, there has been no universally accepted set of skills and knowledge for the professionals and it is unclear what exactly are their BIM roles and competencies (Barison et al., 2011; Inguva et al., 2014). Firms have resorted to the hiring of specialized companies to equip their staff with the requisite skills for them to function in a BIM work environment as the higher institutions of learning are unable to meet this demand in a short term (Smith and Tardif, 2009).

Barison et al. (2011) differentiated between skills and knowledge which are often mixed in extant studies. The study then identified competencies necessary for the role of a BIM specialist by performing content analysis using inputs from BIM specialists' job descriptions and technical papers. A list of general knowledge, attitudes, and skills was then identified with no quantitative or qualitative feedback from BIM experts. Similarly, Inguva et al. (2014) adopted a survey method to rank the identified BIM/VDC skills of construction professionals. A total of 14 skills across four categories of general, cognitive, technical, and affective competency were used. However, the identified competencies are not domain specific and the study concluded that there is a significant difference between the perceptions of BIM/VDC users and non-users.

Ku and Taiebat (2011) reported on the status of BIM adoption, implementation, strategies and training requirement of construction companies in the United States and examined their expectations of university graduates as regards BIM skills and knowledge. BIM knowledge domain areas and skills that were identified as important are model access management, model specification, model validation and interoperability. The model access management relates to the storing and sharing of information; model specification refers to the model progression for shared collaboration; model validation is making sure that the model received is of the right standard, and interoperability deals with sharing of model between different BIM software and tools. Sacks and Pikas (2013) adopted the use of cognitive Bloom’s taxonomy to rank 39 topics for the training of construction engineering graduates. The Bloom’s taxonomy adopted has been widely used in the literature of education, training and skilling because it provides measurable levels and goals. The identified topics by

Sacks et al. (2013) were then grouped into three main areas of competency (process, technology and application).

Extant studies on BIM skills and knowledge in quantity surveying domain have often focused on the BIM capabilities. Succar et al. (2012) defined BIM capability as the 'basic ability to perform a task or deliver a BIM service/product' which is synonymous to BIM functionalities in this study. Ali et al. (2016) developed a BIM educational framework for quantity surveying students. The QS BIM framework was divided into four objectives (visualization, quantification, planning & scheduling, and management) which are QS BIM capabilities/functionalities. Similarly, Kamaruzzaman et al. (2016) identified the BIM capabilities of quantity surveyors in cost estimating practice. The capabilities were categorised into data visualization (e.g. bill of quantities preparation, whole lifecycle costing, contractual documentation), reliable database (e.g. estimating, quantity takeoff), and data coordination (e.g. storing, sharing, and accessing of information). Fung et al. (2014) adopted a desktop literature review and in-depth interviews to identify 11 BIM capabilities in quantity surveying practice during preconstruction stage of projects. Wong et al. (2014) then examined the relationship between the 11 identified BIM capabilities in quantity surveying practice and project performance in terms of cost, time and quality. The study concluded that BIM holds potentials for the quantity surveying practice with regards to project performance.

The identified knowledge, skills, and functionalities as related to quantity surveyors from the literature are summarized in Table 1. This study reviewed and identified domain-specific skills and functionalities as against general domain in extant studies. Also, similar studies from quantity surveyors' perspective focus on BIM capabilities, this study thus stresses BIM capabilities/functionalities, knowledge, and domain-specific skills with experts' feedback.

Table 1: List of knowledge domains, skills and functionalities of BIM for quantity surveying practice

Identified Knowledge, Skills and Functionalities of BIM for Quantity Surveying Practice

The 8 knowledge domains identified consist of knowledge about construction design and contracting procedures, knowledge about BIM, BIM model progression & specifications, data security, information management, contractual & legal aspects, BIM standardization and BIM implementation. These are some of the knowledge areas considered germane for quantity surveyors to function efficiently in a BIM compliant environment in the literature. The knowledge of construction design and contracting procedures is necessary as BIM does not operate on its own but within the construction design and contracting process in the AEC industry. Contracting process such as the Integrated Project Delivery (IPD) which ensures early collaboration of all major project stakeholders is efficient for BIM environment, and knowledge of the key attributes (e.g. shared risks, multi-party agreement and early collaboration) and its process are necessary for the proper functioning of the stakeholders. Sound knowledge about BIM benefits for design, construction and operation is indispensable to enable compliant and implementation of BIM. This would enable quantity surveyors to be aware of the immense benefits and some of the likely bottlenecks of BIM implementation. The BIM model progression & specification relates to the richness of the information of the BIM model which is often referred to as the level of details or level of development (LoD). The LoD varies through the life cycle of the project and the LoD determines the type of estimating and costing that quantity surveyors can produce from the model. LoD can varies from LOD 100, 200, 300, 400 to 500 or can be referred to as as-designed, as-built, and as-used or approximate geometry, precise geometry, fabrication level (Leite et al., 2011) or schematic design, detailed design, shop model (Eastman et al., 2008). Data security and information management are also identified as one of the key knowledge areas as a result of data/information being the strength of B'I'M. Quantity surveyors should be able to manage data effectively and their outputs (e.g. bill of quantities, preliminary estimate, schedules of quantities) would serve as inputs for other stakeholders. Issues relating to BIM implementation such as the contractual & legal aspects, BIM standardization and BIM implementation are also required for quantity surveyors who are part of projects and firms. These knowledge areas would enable them to be relevant and contribute effectively in a BIM compliant environment.

A total of 7 domain-specific skills areas of BIM identified in the literature review include basic BIM operating skills, central databases, interoperability, storing & sharing of information, interaction with BIM model, change analysis, and extraction of BIM information. These are some of the necessary skills that a quantity surveyor needs to possess for better discharge of their duties and responsibilities in a BIM compliant environment. Quantity surveyors should have basic BIM operating skills and should be able to store and share information with other professionals across various software platforms based on knowledge and skills to interoperate. Quantity surveyors are also expected to be able to interact with the BIM model based on their knowledge of BIM progression & specifications to extract both geometric and non-geometric information.

Domain-specific functionalities of BIM are either inherent in BIM or attached to the BIM as independent expert applications (Volk et al., 2014). It involves using the BIM data to perform various tasks such as auto-quantity take off, structural analysis, clash detection, space management, etc. The functionalities identified for quantity surveyors are auto-quantity generation, schedule of quantities, cost checking and planning, estimation, contract documentation, whole life cycle costing and bill of quantities preparation. These are some of the applications that quantity surveyors should be able to perform using the BIM data/information more efficiently as compared to the traditional approach.

Research Methodology

The research approach adopted consist of three stages. The first stage involved an extensive review of desktop literature about the skills/knowledge/functionalities required of a professional in a BIM environment. These were streamlined to specific skills/knowledge/functionalities for quantity surveyors; then experts' opinions and review was sought about the identified skills and knowledge. The second stage involved designing a survey questionnaire using cognitive Bloom's taxonomy (Bloom, 1956). The questionnaire consists of four sections: the first section is the demographic information of the respondents, the second, third and fourth sections consist of the identified knowledge, skills and functionalities, respectively. A pilot survey was carried out by administering the questionnaire to four well-experienced experts (two academic researchers and two industrial practitioners). Each of these experts has more than 11 years of hands-on experience in the construction industry. Valuable suggestions about modifying some of the essential skills, additional items and the format of the questionnaire from the four experts were received, considered and included in the final survey form. The final questionnaire (as shown in Appendix A) covered 8 knowledge domains, 7 domain-specific skills and 9 domain-specific functionalities. The third stage involved the Delphi survey of both academics and practitioners with abundant hands-on BIM research or working experience to rank the identified skills/knowledge/functionalities using the Bloom's taxonomy (scale ranging from 1 to 6) as required for the effective practice of quantity surveyors in the construction industry. The Delphi survey was adopted in this study because: (a) the required knowledge and information can be obtained from experts; (b) it focuses on the quality of the responses and respondents rather than the quantity; (c) it allows for dissenting voices and opinions that are relevant to the study; (d) collective decisions made by experts are better and less likely to be wrong as compared to those of individuals; and (e) it provides a better group decision than a physical meeting where the respondents might not have enough time to decide and might be under pressure to agree with others on the spot (Hasson et al., 2000; Livesey, 2016)

The outline of the research design is portrayed in Figure 1.

(Figure 1: Outline of Research Design)

Bloom's Taxonomy

This was developed by Benjamin Bloom in the 1950s (Bloom, 1956). It categorized and ordered thinking skills and objectives (Krathwohl, 2002). The six levels of measurement scale (1-6) were used as a scale for ranking the identified knowledge, skills, and functionalities by the experts as required for practice in a BIM environment. The six levels are:

(a) Knowledge (1): This involves knowing about the domain without no understanding of what it entails; (b) Comprehension (2): This involves having an understanding of the domain but with no skills to apply it; (c) Application (3): This involves having knowledge and being able to apply knowledge; (d) Analysis (4): This involves having knowledge, being able to apply knowledge and being able to infer result of their use; (e) Synthesis (5): This involves developing new knowledge, understand, apply and analyse, and develop new information; (f) Evaluation (6): This involves developing new knowledge, apply, analyse, synthesis and being able to evaluate critically.

Delphi Survey Technique

Delphi survey is a form of group assessment to reach agreement on an issue (Hsu and Sandford, 2007). Thus, it is suitable for achieving experts' consensus (Yeung et al., 2007) on multidisciplinary issues like BIM and quantity surveying (Olawumi et al., 2018). It involves non-probabilistic sampling method using purposive sampling technique (Hasson et al., 2000), as panellists/experts were invited based on some pre-set selection criteria (knowledge about the construction industry, BIM expert, and quantity surveying experience) from diverse fields such as academic researchers, consultancy firms and contracting organizations. A total of 25 target experts were invited but only 17 agreed and completed the two rounds of the Delphi survey. This was considered acceptable as a minimum of 7 is deemed sufficient for the Delphi survey (Hon et al., 2011). Also, two to three rounds are preferable, and the salient issue is the consensus of the experts (Hasson et al., 2000).

However, the issue of consensus has been a very contentious one as there is no universally accepted definition of consensus in the literature (Duffield, 1993; Hasson et al., 2000). Studies need to define what 'consensus' means to make sense of the findings (Williams and Webb, 1994). The consensus determines when to stop the rounds of the survey and when to go for more. This is very crucial because stopping 'too soon' would provide results that are not meaningful and 'not soon enough' may cause respondents' fatigue, spurious result and may lead to bandwagon effect (Schmidt, 1997; Walker and Selfe, 1996). Extant studies often use Kendall's coefficient of concordance (W) and quartile deviation (QD) to determine consensus (Ab Latif et al., 2017; Chan and Chan, 2012; Olawumi et al., 2018; Raskin, 1994; Yeung et al., 2007), however, the use of Kendall's coefficient of concordance (W) has been criticized as not sufficient enough when the experts are more than 10 (Schmidt, 1997). McKenna (1994) suggested that consensus should be measured by the percentage of agreement amongst the experts and opined 51% as consensus. Sumsion (1998) opted for 80% level as consensus. Usage of these percentages as a yardstick of consensus was criticised by Crisp (1997) and suggested that the consensus should be determined by the stability of the responses through the round as this is a more reliable indicator of consensus. Goodman (1987) corroborated that it is the stability of the group response on the items that should be of utmost importance rather than 'an apparent consensus which may mask a bimodal or flat response distribution'. In addition, Okoli and Pawlowski (2004) opined that when the mean ranking of successive rounds is not significantly different, the iteration should be stopped. Thus, this study defines consensus as to when there is stability or consensus in the responses of successive rounds and when the quartile deviation is less than or equal to 1 ($QD \leq 1$).

The anonymity of the experts was maintained to facilitate the credibility and reliability of the survey (Olawumi and Chan, 2019a). The experts were from 9 different countries (Australia, Canada, Malaysia, South Africa, Nigeria, United Arab Emirate, Ghana, Hong Kong, and the United Kingdom) across the globe. Nine (9) of the experts are industrial practitioners and 8 are university academics to facilitate a balanced view of the study's findings across boundaries and disciplines. 80% of the experts have more than 11 years of practical experience in the construction industry and have been utilizing BIM over the years with adequate hands-on experience. The demographic distribution of the survey respondents is shown in Table 2.

(Table 2: Demographics of the Delphi experts)

Figure 2 portrays the adapted Delphi technique sequence model (Couper, 1984). Worthy of note is that in the classic Delphi survey, the first round starts with open, simple questions and seek for the experts' opinions on the issues raised. The responses would then be analysed and used to develop a questionnaire for experts' ranking in the second round. However, this has been criticized as it could be easily influenced by the researcher’s bias. Over time, this approach has been modified and the first round often starts with a list of questions/items for the experts to rank or respond to. Although this has been said to be advantageous as the experts are already responding to questions in the first round of the survey; and the first round is in fact ‘second-round’ of the survey. Also, it would reduce the number of rounds and might improve the quality of the responses (less respondents’ fatigue) (Jenkins and Smith, 1994). It has also been criticised for not giving rooms to dissenting voices which is one of the key characteristics of the Delphi survey. Thus, this study started with a list of identified items from the literature and presents it to selected experts during the pilot survey. The experts suggested modification of the items and additional items that are relevant to the list. These were reviewed and incorporated to improve the quality of the study. Also, during each round of the survey, the experts were given the option of adding additional items that they considered important. In this manner, this study benefits by starting with the ‘second round’ of classic Delphi and avoids the criticism by allowing for dissent voices.

(Figure 2: Delphi Technique Sequence Model (Adapted from Couper, 1984))

Statistical tools for analysis

The statistical methods of analysis include the Cronbach’s alpha reliability test, mean score ranking, the Mann-Whitney U test and Quartile deviation. The Cronbach’s alpha value was used to test the reliability of the set of questions for each section of the questionnaire and for each round of the survey. The value ranges from 0-1 and a value of at least 0.7 is acceptable for further statistical analysis (Saka et al., 2019c). The Cronbach's alpha value does not indicate the stability or consistency of the test over time, however, it does indicate the reliability of the questionnaire survey for each round (Bolarinwa, 2015). The mean score is the average of the responses (on Bloom's scale) of the experts which are then rounded up to the nearest Bloom's taxonomy level. The Mann-Whitney U test was used to assess if there is a statistically significant difference between the median value of the same item between any two survey groups (Chan et al., 2010). If the actual calculated p-value is less than the allowable significance level of 0.05 from the table, the null hypothesis which states that 'no statistically significant difference in the median values of the same item between the respondents of the two expert groups' will be rejected. The Quartile deviation (QD) is used to measure if there is consensus or not, and a value of QD ≤ 1 signifies that there is a consensus (Ab Latif et al., 2017; Raskin, 1994; Tengan and Aigbavboa, 2018).

Presentation of survey results

First round of Delphi survey

The experts were presented with the list of identified knowledge, skills, and functionalities for ranking on Bloom's level of 1 to 6. This section presents the survey results from the analysis of the experts after round one of the Delphi survey. It is necessary to go for a second round to determine if the responses would vary significantly and if stability has been attained.

Knowledge requirement for Quantity Surveyors in Building Information Modelling (BIM) Environment

The experts ranked the industry level requirement for the identified knowledge domains as shown in Table 3. The Cronbach's alpha values for all the experts, for the practitioners' group and for academics' group were calculated and the values are 0.895, 0.940, and 0.794 respectively which are all larger than 0.70 which is the acceptable threshold. The MS column indicates the average value for each of the identified knowledge areas, and BL column provides the corresponding Bloom's taxonomy level. The Mann-Whitney U test was used to test for any statistically significant differences in the median values of each of the identified knowledge areas between the practitioners' group and academics' group as revealed in the 'Mann-Whitney' column. 'Knowledge about construction design and contracting procedures', 'Merits and demerits of BIM for design/construction/operation processes', and 'BIM model progression and specifications', were ranked at level 4 of Bloom's taxonomy by both the practitioners and the academics. 'Data security', 'Information management', and 'Contractual and legal aspects of BIM implementation, were ranked at level 3 of Bloom's taxonomy by the academics as compared to level 4 by the industry experts. Knowledge about BIM standardization was ranked at level 5 by the industry experts and this reflects the significance placed on standardization of BIM in the industry.

The Mann-Whitney U test as portrayed in Table 3 reflects no statistically significant differences in the median values of the ranked knowledge domains between the practitioners and the academics, with all the p-values being greater than the allowable value of 0.05 sought from the statistical table.

Table 3: Knowledge Domains of BIM (First round of Delphi survey)

Skills requirement for Quantity Surveyors in Building Information Modelling (BIM) Environment

The experts ranked the industry level requirement for the identified skills as shown in Table 4. The Cronbach's alpha values were calculated to test the reliability of the set of questions and the alpha values are 0.922, 0.960, and 0.826 for all the respondents, practitioners and academics respectively. All the identified skills were ranked by both groups at level 4 of Bloom's taxonomy with 'Storing, sharing and accessing of information' and 'Central databases' being ranked at levels 3 and 4 by the academics; and at levels 4 and 3 by the practitioners. The actual calculated p-values derived from the Mann-Whitney U test are all larger than the allowable level of significance of 0.05 manifesting no statistically significant differences in the median values of the ranked skills between the practitioners and the academics. Similarly,

Table 4: Domain-Specific Skills of BIM (First round of Delphi survey)

Functionalities requirement for Quantity Surveyors in Building Information Modelling (BIM) Environment

The industry level requirement for the identified functionalities is as shown in Table 5. The Cronbach's alpha value calculated for all the respondents is above the threshold value of 0.7. The identified BIM functionalities were ranked at level 4 of Bloom's taxonomy depicting the need for quantity surveyors to have gained adequate knowledge about these functionalities and they should be able to perform them and infer results of their use. The Mann-Whitney U test shows that there are no statistically significant differences in the median values of the identified functionalities between the practitioners and the academics.

Table 5: BIM Domain-Specific Functionalities (First round of Delphi survey)

Second round of Delphi survey

This section presents the survey results from the analysis of the experts after the second one which is the final round of the Delphi survey. The decision to stop at the second round was based on the consensus defined for this study. Also, there seems to be respondents' fatigue as it took a longer period for some experts to respond when compared to the first round.

Knowledge requirement for Quantity Surveyors in Building Information Modelling (BIM) Environment

The Cronbach's alpha values for the second round of Delphi survey were calculated and all the values are well above the minimum acceptable value of 0.70. There are no significant differences between the responses in the first round and second round as most of Bloom's taxonomy levels are still the same. This signifies stability or consensus in the successive rounds. Also, the calculated QD for the items are all ≤ 1. Mann-Whitney U test shows that there is no statistically significant difference in the median values of the knowledge domains between the practitioners' group and the academics' group. Thus, the quantity surveyors need to be at level 4 (i.e. have the knowledge about these domains and be able to infer results) of Bloom's taxonomy as regards the identified knowledge domains except for 'Data security' at level 3 as shown in Table 6.

Table 6: Knowledge Domains of BIM (Final round of Delphi survey)

Skills requirement for Quantity Surveyors in Building Information Modelling (BIM) Environment

The Cronbach's alpha values were calculated for the second round and they are all above 0.70 threshold which is acceptable. The overall responses of the experts did not change significantly as revealed in Table 7. This signifies stability or consensus in the successive rounds. Also, the calculated QD for the items are all ≤ 1. The 'Central databases' (S2) changed from level 4 in the first round for the academics to level 3 to be in concordance with the practitioners. Similarly, there is no statistically significant difference in the median values of the identified skills between the two experts' groups in the second round as advocated in the p-values. Thus, the level required for all the identified skills was agreed to be at level 4 of Bloom's taxonomy except for S2 'Central databases' at level 3.

Table 7: Domain-Specific Skills of BIM (Final round of Delphi survey)

Functionalities requirement for Quantity Surveyors in Building Information Modelling (BIM) Environment

The Cronbach's alpha values for these set of items in the second round of Delphi survey were calculated and they are all above the threshold value of 0.70. All the identified functionalities were later ranked at level 4 of Bloom's taxonomy as shown in Table 8. The responses in round 1 are consistent with those in round 2 which connotes stability or consensus and the calculated QD for the items are all ≤ 1. Also, no statistically significant differences in the median values of the functionalities between the two expert groups as reflected in the Mann-Whitney U test; with all the p-values above 0.05.

Table 8: BIM Domain-Specific Functionalities (Final round of Delphi survey)

Discussion of survey findings

Altogether 8 knowledge areas, 7 domain-specific skills, and 9 domain-specific BIM functionalities were identified from the desktop literature review and refined with experts' opinions and reviews. The identified knowledge areas/skills/functionalities were incorporated to constitute an empirical questionnaire for the pilot survey before inviting the group of Delphi experts. Modifications were made as suggested by the experts during the pilot survey.

The experts ranked knowledge areas related to construction & contracting procedures, BIM, model progression & specifications at level 4 of Bloom's taxonomy which corresponds to 'Analysis' as used in this study. Thus, quantity surveyors should have a clear understanding of these knowledge areas and should be able to infer and draw conclusions/references via these knowledge areas as far as applicable. Only 'Data security' was ranked at level 3 of Bloom's taxonomy and this reflects the importance placed on quantity surveyors as regards data security. The role of quantity surveyors is to make use of data from other professionals to perform their duties as required, the outputs of which would serve as inputs for use/processing during the life cycle of the project. Thus, there is no stringent requirement on quantity surveyors to be an expert in data security but to have knowledge about it and be clear in its understanding. This is in tandem with the findings of Sacks et al. (2013).

All these identified skills were ranked at level 4 of the Bloom's taxonomy except 'Central databases' which was ranked at level 3. This is in tandem with the fact that a quantity surveyor is not in charge of central databases. Albeit, having to exchange information through it, he needs to have a clear understanding of how to work with such for delivering efficient service. These are similar to the findings of Ku et al. (2011) which were from constructors' perspective. Also, it is in concordance with Inguva et al. (2014), but the present study went further to provide quantitative feedback from BIM experts.

The functionalities were ranked at level 4 of Bloom's taxonomy as required for quantity surveyors to function efficiently in a BIM environment. Thus, quantity surveyors should have requisite knowledge and skills to perform these activities and infer results from there. They should be able to infer inferences from the results and convert it into inputs for use by other stakeholders during the life cycle of the project. These resonate with the findings of Fung et al. (2014), Kamaruzzaman et al. (2016) and

(Ali et al., 2016). However, the industry requirement levels were not provided in these extant studies.

The responses of the experts in round 1 and round 2 are stable and in concordance as reflected by the calculated QD which is ≤ 1 for all the items. The Mann-Whitney U test reflected that there are no statistically significant differences in the median values of the identified attributes between the two groups of experts (i.e. practitioners vs. academics). This discerns that the two survey groups are generally in consensus about the level of requirement for the identified factors under study for quantity surveyors in a BIM compliant environment.

The knowledge, skills and functionalities are interwoven as conceptualized in Figure 3. The BIM knowledge domains are necessary for the skills and functionalities; the skills are necessary for carrying out the functionalities and helps to improve the knowledge of quantity surveyors, and the functionalities are basically built on knowledge and skills.

Figure 3: Relationship between Knowledge, Skills and Functionalities Requirements for Quantity Surveyors in BIM Environment

Conclusions

This study identified a total of 8 knowledge domains, 7 domain-specific skills and 9 domain-specific functionalities for quantity surveyors to function effectively in a BIM coordinated environment. Albeit, the knowledge areas/skills/functionalities needed are inexhaustible, but these were identified as some of the important ones to allay the fear of quantity surveyors to practice in a BIM environment and for the sustainability of the practice in the AEC industry. Quantity surveyors who are used to the traditional working style of the AEC industry are often unwilling to adopt and implement innovations in their practice. There is the fear of the BIM usurping the roles of quantity surveyors in the industry which is unfounded. The fear is often a result of lack of knowledge and awareness of quantity surveyors. The BIM would change the firms and make them more efficient and productive in their workplace. However, one of the major challenges, as identified in the literature, is the lack of trained and skilled personnel in their firms. Thus, there is a pressing need for quantity surveyors to be informed and skilled in order to be able to collaborate with other professionals and for survival in the AEC industry nowadays.

The findings of this study have several implications. First, the study underscores that BIM would not usurp the roles of quantity surveyors, however, quantity surveyors need to be equipped with the necessary knowledge and skills to function in a BIM environment. Second, the findings indicate that quantity surveyors do not need to be a BIM specialist or proficient/knowledgeable in all BIM domains to function effectively, the major emphasis should be on their domain-specific skills, knowledge and functionalities to a reasonable expertise level. Lastly, the identified knowledge, skills, and functionalities would serve as a useful guide for training and assessment of quantity surveyors in the AEC industry. It would enable employers to assess their quantity surveyors and to train them to be BIM compliant.

It is recommended that educational institutions should equip and offer sufficient training of quantity surveying practice to ensure that their graduates are BIM compliant as this would serve as a long-term solution to the issue of lack of trained professionals. The quantity surveyors' professional bodies should assess the professional competency of the practising professionals and to help with organising various CPD workshops & seminars targeting at these knowledge domains, domain-specific skills, and domain-specific functionalities of BIM on a regular basis.

The few identified knowledge areas/skills/functionalities may serve as a limitation of the study as the list is inexhaustible, however, these are some of the important knowledge areas/skills/functionalities of BIM and they can be served as the basis for the development of BIM compliant quantity surveyors in future. The experts were invited from 9 different countries only; however, due attention was paid to the countries to secure an international representation and reflection. Also, despite the experts being from 9 different countries, the roles and duties of quantity surveyors in the AEC industry and profound challenges facing them are similar irrespective of the country. Thus, the survey findings of this study are still applicable and useful to quantity surveyors regardless of the location.

It is worthy of note that the identified knowledge areas/skills/functionalities of BIM are domain-specific of quantity surveyors, a further area of research may consider other disciplines of professionals (e.g. architects, structural engineers, building services engineers, project managers, etc) to identify their specific knowledge areas/skills/functionalities needed to function in a BIM environment and to assess the industry level requirement in a similar way. Also, these identified essential knowledge areas/skills/functionalities of BIM may be adopted in further studies to assess the current level of training of quantity surveyors to determine what is lacking and the key areas that need immediate attention for improvement.

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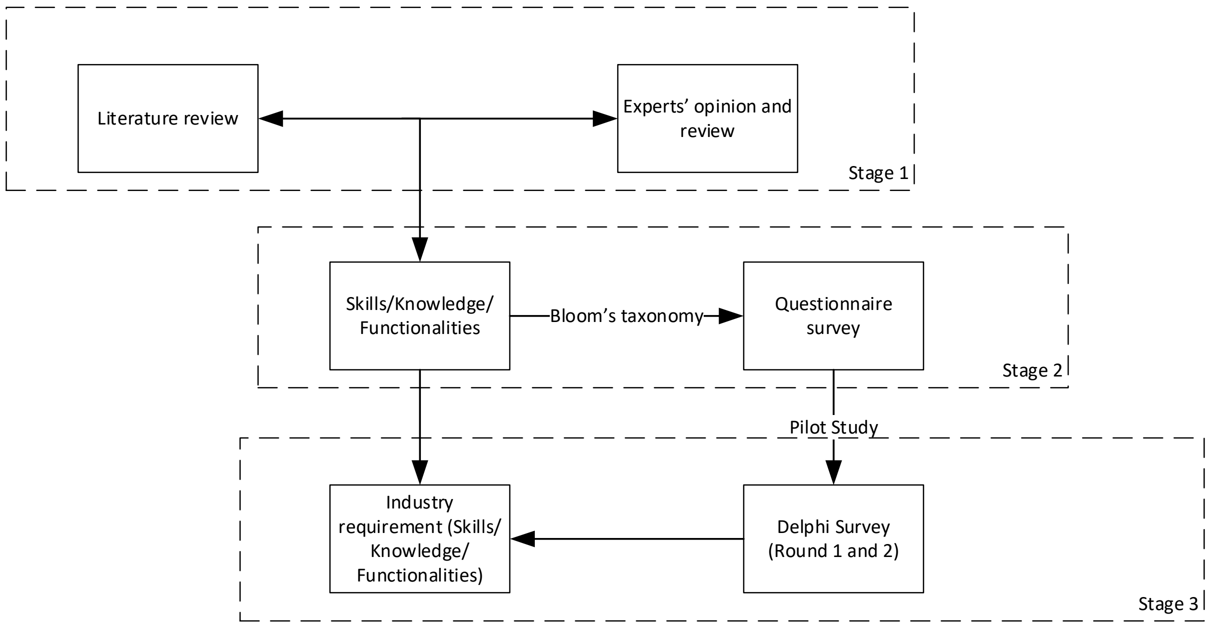

Figure 1. Outline of Research Design

Table 1. List of identified knowledge, skills and functionalities of BIM for quantity surveying practice

Code	Knowledge/Skills/Functionalities	Sources
K1	Knowledge about construction design and contracting procedures	(Barison et al., 2011; Inguva et al., 2014; Quek, 2012; Sacks et al., 2013)
K2	Merits and demerits of BIM for design/construction/operation processes	(Ali et al., 2016; Barison et al., 2011; Sacks et al., 2013)
K3	BIM model progression and specifications	(Barison et al., 2011; Ku et al., 2011; Sacks et al., 2013)
K4	Data security	(Sacks et al., 2013)
K5	Information management	(Barison et al., 2011; Fung et al., 2014; Inguva et al., 2014; Kamaruzzaman et al., 2016; Quek, 2012; Succar and Sher, 2014; S. Wu et al., 2014a)
K6	Contractual and legal aspects of BIM implementation	(Barison et al., 2011; Sacks et al., 2013)

K7	BIM standardization	(Ali et al., 2016; Sacks et al., 2013; Succar et al., 2014)
K8	BIM Implementation procedures	(Ali et al., 2016; Barison et al., 2011; Sacks et al., 2013; Succar et al., 2014)
S1	Basic BIM operating skills	(Barison et al., 2011; Inguva et al., 2014; Ku et al., 2011; Sacks et al., 2013)
S2	Central databases	(Fung et al., 2014; Sacks et al., 2013)
S3	Interoperability from one tool to another	(Ali et al., 2016; Barison et al., 2011; Ku et al., 2011; Sacks et al., 2013)
S4	Storing, sharing and accessing of information	(Fung et al., 2014; Kamaruzzaman et al., 2016; Ku et al., 2011; Sacks et al., 2013; Succar et al., 2014)
S5	Ability to interact with model in 3D interface	Experts
S6	Change analysis	Experts
S7	Ability to extract specifications and information from the BIM model	(Inguva et al., 2014; Kamaruzzaman et al., 2016; Sacks et al., 2013)
F1	Auto quantity take-off	(Goucher et al., 2012; Kamaruzzaman et al., 2016; Liu and Hatipkarasulu, 2014; Sacks et al., 2013; S. Wu et al., 2014a)
F2	Rapidly generate and evaluate multiple cost alternatives	(Fung et al., 2014; Goucher et al., 2012; Sacks et al., 2013; S. Wu et al., 2014a)
F3	Auto generation of schedule of quantities	(Goucher et al., 2012; S. Wu et al., 2014a)
F4	Cost checking and planning	(Fung et al., 2014; Quek, 2012; R Stanley and Thurnell, 2013)
F5	Integration with project partner (supply chain) databases	(Sacks et al., 2013)
F6	Whole life cycle costing	(Kamaruzzaman et al., 2016; Sabol, 2008)

F7	Bill of Quantities preparation in line with a specific standard method of measurement with the specifications	(Fung et al., 2014; Kamaruzzaman et al., 2016; R Stanley et al., 2013; S. Wu et al., 2014a)
F8	Approximate estimate preparation	(Barison et al., 2011; Fung et al., 2014; Inguva et al., 2014; Kamaruzzaman et al., 2016; Liu et al., 2014; Quek, 2012; Sabol, 2008; W. Wu and Issa, 2014b)
F9	Contract documentation	(Barison et al., 2011; Goucher et al., 2012; Kamaruzzaman et al., 2016)

Table 2. Demographics of the Delphi experts

Demographics	Categories	Frequency	Percentage (%)
Level of Education	First (Bachelor's) Degree	4	23.53
	Postgraduate Degree (MSc)	4	23.53
	Postgraduate Degree (PhD)	9	52.94
Type of Expert	Researcher / Academic	8	47.06
	Practitioner	9	52.94
Years of working experience in construction	< 5 years	-	
	6 – 10 years	3	17.65
	11 – 15 years	8	47.06
	> 15 years	6	35.29
BIM experience	< 5 years	-	
	6 – 10 years	10	58.82
	11 – 15 years	7	41.18
	> 15 years	-	

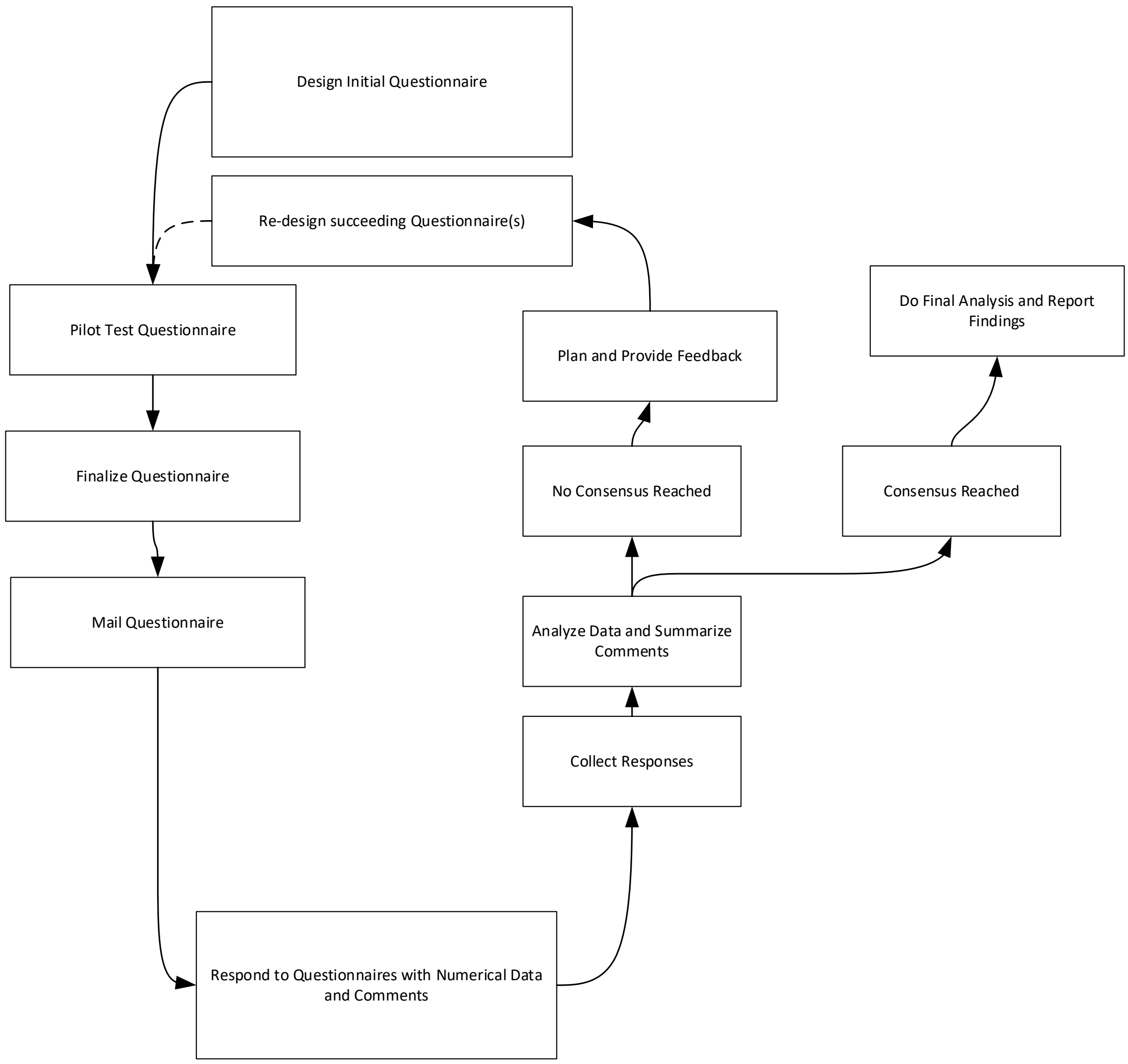

Figure 2. Delphi Technique Sequence Model (Adapted from Couper, 1984)

Table 3. Knowledge Domains of BIM (First round of Delphi survey)

ID	Knowledge Domains	ALL		Practitioners		Academics		Mann-Whitney U test	
		MS	BL	MS	BL	MS	BL	Z-value	P-value
K1	Knowledge about construction design and contracting procedures	4.29	4	4.33	4	4.25	4	0.000	1.000
K2	Merits and demerits of BIM for design/construction/operation processes	3.94	4	4.00	4	3.88	4	-0.298	0.766
K3	BIM model progression and specifications	3.82	4	4.00	4	3.63	4	-0.750	0.453
K4	Data security	3.18	3	3.56	4	2.75	3	-1.648	0.099
K5	Information management	3.94	4	4.44	4	3.38	3	-1.922	0.055
K6	Contractual and legal aspects of BIM implementation	3.59	4	3.89	4	3.25	3	-1.485	0.138
K7	BIM standardization	4.24	4	4.56	5	3.88	4	-1.085	0.278
K8	BIM Implementation procedures	4.11	4	4.44	4	3.75	4	-1.031	0.303
	Number of respondents	17		9		8			
	Cronbach's alpha value	0.895		0.940		0.794			

Table 4. Domain-Specific Skills of BIM (First round of Delphi survey).

ID	Domain-Specific Skills	ALL		Practitioners		Academics		Mann-Whitney U test	
		MS	**BL**	**MS**	**BL**	**MS**	**BL**	**Z-value**	**P-value**
S1	Basic BIM operating skills	3.94	4	4.22	4	3.63	4	-0.843	0.399
S2	Central databases	3.24	3	3.44	3	3.00	4	-0.502	0.616
S3	Interoperability from one tool to another	3.59	4	3.67	4	3.50	4	0.000	1.000
S4	Storing, sharing and accessing of information	3.59	4	4.11	4	3.00	3	-1.514	0.130
S5	Ability to interact with model in 3D interface	4.00	4	3.89	4	4.13	4	-0.556	0.578
S6	Change analysis	3.76	4	3.67	4	3.88	4	-0.154	0.878
S7	Ability to extract specifications and information from the BIM model	4.24	4	4.22	4	4.25	4	-0.149	0.881
	Number of respondents	17		9		8			
	Cronbach's alpha value	0.922		0.960		0.826			

Table 5. BIM Domain-Specific Functionalities (First round of Delphi survey).

ID	Domain-Specific Functionalities	ALL		Practitioners		Academics		Mann-Whitney U test	
		MS	BL	MS	BL	MS	BL	Z-value	P-value
F1	Auto quantity take-off	4.47	4	4.56	5	4.38	4	-0.099	0.921
F2	Rapidly generate and evaluate multiple cost alternatives	4.35	4	4.44	4	4.25	4	-0.247	0.805
F3	Auto generation of schedule of quantities	4.29	4	4.44	4	4.13	4	-0.345	0.730
F4	Cost checking and planning	4.35	4	4.33	4	4.38	4	-0.099	0.921
F5	Integration with project partner (supply chain) databases	3.88	4	4.00	4	3.75	4	-0.732	0.464
F6	Whole life cycle costing	4.29	4	4.11	4	4.50	4	-0.639	0.523
F7	Bill of Quantities preparation in line with a specific standard method of measurement with the specifications	4.29	4	4.33	4	4.25	4	-0.098	0.922
F8	Approximate estimate preparation	4.12	4	4.33	4	3.88	4	-0.897	0.370
F9	Contract documentation	3.71	4	3.89	4	3.50	4	-0.562	0.574
	Number of respondents	17		9		8			
	Cronbach's alpha value	0.960		0.962		0.967			

Table 6. Knowledge Domains of BIM (Final round of Delphi survey).

ID	**Knowledge Domains**	**ALL**			**Practitioners**		**Academics**		**Mann-Whitney U test**	
		MS	**BL**	**QD**	**MS**	**BL**	**MS**	**BL**	**Z-value**	**P-value**
K1	Knowledge about construction design and contracting procedures	4.29	4	1.00	4.33	4	4.25	4	0.000	1.000
K2	Merits and demerits of BIM for design/construction/operation processes	3.94	4	1.00	4.00	4	3.88	4	-0.298	0.766
K3	BIM model progression and specifications	3.82	4	1.00	4.00	4	3.63	4	-0.750	.453
K4	Data security	3.18	3	0.75	3.56	4	2.75	3	-1.648	0.099
K5	Information management	3.94	4	0.75	4.44	4	3.38	3	-1.922	0.055
K6	Contractual and legal aspects of BIM implementation	3.59	4	0.75	3.89	4	3.25	3	-1.485	0.138
K7	BIM standardization	4.24	4	1.00	4.56	5	3.88	4	-1.085	0.278
K8	BIM Implementation procedures	4.12	4	1.00	4.44	4	3.75	4	-1.031	0.303
	Number of respondents	17			9		8			
	Cronbach's alpha value	0.895			0.929		0.794			

Table 7. Domain-Specific Skills of BIM (Final round of Delphi survey).

ID	Domain-Specific Skills	ALL			Practitioners		Academics		Mann-Whitney U test	
		MS	BL	QD	MS	BL	MS	BL	Z-value	P-value
S1	Basic BIM operating skills	3.94	4	1.00	4.22	4	3.63	4	-0.843	0.399
S2	Central databases	3.24	3	1.00	3.44	3	3.00	3	-0.502	0.616
S3	Interoperability from one tool to another	3.59	4	0.50	3.67	4	3.50	4	0.000	1.000
S4	Storing, sharing and accessing of information	3.59	4	0.50	4.11	4	3.00	3	-1.514	0.130
S5	Ability to interact with a model in 3D interface	4.00	4	1.00	3.89	4	4.13	4	-0.556	0.578
S6	Change analysis	3.76	4	0.50	3.67	4	3.88	4	-0.154	0.878
S7	Ability to extract specifications and information from the BIM model	4.24	4	0.75	4.22	4	4.25	4	-0.149	0.881
	Number of respondents	17			9		8			
	Cronbach's alpha value	0.922			0.953		0.826			

Table 8. BIM Domain-Specific Functionalities (Final round of Delphi survey).

ID	Domain-Specific Functionalities	ALL			Practitioners		Academics		Mann-Whitney U test	
		MS	BL	QD	MS	BL	MS	BL	Z-value	P-value
F1	Auto quantity take-off	4.47	4	1.00	4.56	5	4.38	4	-0.099	0.921
F2	Rapidly generate and evaluate multiple cost alternatives	4.35	4	1.00	4.44	4	4.25	4	-0.247	0.805
F3	Auto generation of schedule of quantities	4.29	4	1.00	4.44	4	4.13	4	-0.345	0.730
F4	Cost checking and planning	4.35	4	1.00	4.33	4	4.38	4	-0.099	0.921
F5	Integrate with project partner (supply chain) databases	3.88	4	0.50	4.00	4	3.75	4	-0.732	0.464
F6	Whole life cycle costing	4.29	4	1.00	4.11	4	4.50	5	-0.639	0.523
F7	Bill of Quantities preparation in line with a specific standard method of measurement with the specifications	4.29	4	1.00	4.33	4	4.25	4	-0.098	0.922
F8	Approximate estimate preparation	4.12	4	1.00	4.33	4	3.88	4	-0.897	0.370
F9	Contract documentation	3.71	4	0.50	3.89	4	3.50	4	-0.562	0.574
	Number of respondents	17			9		8			
	Cronbach's alpha value	0.961			0.958		0.967			

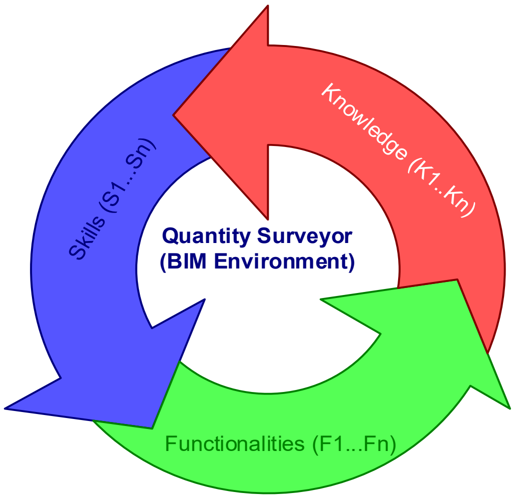

Figure 3. Relationship between Knowledge, Skills and Functionalities Requirements for Quantity Surveyors in BIM Environment.

Appendix A - Template of Delphi Survey Form

Knowledge, Skills and Functionalities Requirements for Quantity Surveyors in Building Information Modelling (BIM) Work Environment

This study aims to assess the knowledge/skills/application required of a Quantity surveyor in a BIM compliant construction industry. Bloom's taxonomy which categorised levels of learning into six (6) is used. You are requested to pick a level for each of the knowledge/skills/functionality as you deemed required of a Quantity Surveyor to function in a BIM compliant environment. Thank you for your time.

Section A: Expert's Background Information

1. Highest Educational Qualification: a) First (Bachelor's) degree ☐ b) Postgraduate degree (MSc) ☐ c) PhD ☐ d) others ___________ (Please specify)
2. Area of expertise a) Researcher/ Academic ☐ b) Industry practitioner ☐ c) others ___________ (Please specify)
3. Years of working experience in the construction industry a) < 5yrs ☐ b) 6 – 10yrs ☐ c) 11 – 15yrs ☐ d) >15 years ☐
4. Years of BIM experience a) < 5yrs ☐ b) 6 – 10yrs ☐ c) 11 – 15yrs ☐ d) >15 years ☐
5. Country: ___________ (Please specify)

Section B: Knowledge Domains of BIM

Kindly rank the identified knowledge domains using the Bloom's taxonomy (scale ranging from 1 to 6) as required for the effective practice of quantity surveyors in the construction industry. The six levels are: (a*) Knowledge (1)*: This involves knowing about the domain without no understanding of what it entails; (b) *Comprehension (2)*: This involves having an understanding of the domain but with no skills to apply it; (c) *Application (3):* This involves having knowledge and being able to apply knowledge; (d) *Analysis (4):* This involves having knowledge, being able to apply knowledge and being able to infer result of their use; (e) *Synthesis (5):* This involves developing new knowledge, understand, apply and analyse, and develop new information; (f) *Evaluation (6)*: This involves developing new knowledge, apply, analyse, synthesis and being able to evaluate critically.

ID	Domains	1	2	3	4	5	6
K1	Knowledge about construction design and contracting procedures						
K2	Merits and demerits of BIM for design/construction/operation processes						
K3	BIM model progression and specifications						
K4	Data security						
K5	Information management						

K6	Contractual and legal aspects of BIM implementation						
K7	BIM standardization						
K8	BIM Implementation procedures						
	Any other important knowledge domain? (Kindly list and rate below)						

Section C: Domain-Specific Skills of BIM

Kindly rank the identified skills using the Bloom's taxonomy (scale ranging from 1 to 6) as required for the effective practice of quantity surveyors in the construction industry.

ID	Skills	1	2	3	4	5	6
F1	Auto quantity take-off						
F2	Rapidly generate and evaluate multiple cost alternatives						
F3	Auto generation of schedule of quantities						
F4	Cost checking and planning						
F5	Integrate with project partner (supply chain) databases						
F6	Whole life cycle costing						
F7	Bill of Quantities preparation in line with a specific standard method of measurement with the specifications						
F8	Approximate estimate preparation						
F9	Contract documentation						
	Any other important skill? (Kindly list and rate below)						

Section C: Domain-Specific Skills of BIM

Kindly rank the identified functionalities using the Bloom's taxonomy (scale ranging from 1 to 6) as required for the effective practice of quantity surveyors in the construction industry.

ID	Functionalities	1	2	3	4	5	6
F1	Auto quantity take-off						
F2	Rapidly generate and evaluate multiple cost alternatives						
F3	Auto generation of schedule of quantities						
F4	Cost checking and planning						
F5	Integrate with project partner (supply chain) databases						
F6	Whole life cycle costing						

F7	Bill of Quantities preparation in line with a specific standard method of measurement with the specifications						
F8	Approximate estimate preparation						
F9	Contract documentation						
	Any other important functionality? (Kindly list and rate below)						