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The State of BIM-Based Quantity Take-Off Implementation Among Commercial General Contractors

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ABSTRACT

The State of BIM-Based Quantity Take-Off Implementation
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Building Information Modeling (BIM) plays an important role in today's construction industry. Models are tools that help stakeholders communicate, visualize building geometry, perform trade coordination and clash detection among others. A less popular aspect of BIM that shows high potential is the quantity take-off (QTO) feature. Yet, its implementation among commercial general contractors (GC) has not received as much attention. The purpose of this study was to identify how the BIM QTO features were being implemented among commercial general contractors, what challenges they faced and how they worked to overcome those challenges.

Through a three-step process including semi structured interviews with estimators, preconstruction, BIM and Virtual Design Construction (VDC) managers, valuable insights on the BIM QTO implementation state among general contractors were gathered and analyzed. Links between BIM QTO benefits, project design phases and delivery methods, software, training, leadership and jurisdictions were discussed. The data indicated that BIM QTO's benefits were best leveraged through early general contractor involvement, the adequate contract framework, trained BIM QTO estimators, and early and strategic communication between owners, designers and estimators. The conditions for increased efficiency were discussed along with the solutions to the common BIM-based QTO challenges.

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1   INTRODUCTION

1.1   Background

The rapid technological improvements of the past years have driven change in many industries (Basu, 2015). Although they were not the sole driver of change and progress, their influence was seen everywhere. The construction industry was no different. Architects, engineers and construction managers embraced new tools as they became available. Computer technology brought flexibility and speed with Computer Assisted Design (CAD). Over the past 10 years, the use of Building Information Modeling (BIM) has shown rapid growth, influenced and challenged the traditional design, project management and relationship aspects of the construction industry (Jones, 2012).

As practitioners adopted BIM in their work, they quickly understood that its features reached beyond 3D modeling and visualization. Although this aspect was essential and helpful, the power of the model lay in the ability of the user to assign the virtual objects with specific data such as weight, dimensions, cost, product, and maintenance information. Thus, a single digital document held extremely large quantities of information, both graphical and parametrical.

The National Building Specification for the UK (NBS) defined BIM as:

> "A process for creating and managing information on a construction project across the project lifecycle. One of the key outputs of this process is the Building Information Model, the digital description of every aspect of the built asset. This model draws on information assembled collaboratively and updated at key stages of a project. Creating a digital Building Information Model enables those

who interact with the building to optimize their actions, resulting in a greater whole life value for the asset." (NBS, 2017)

Several of BIM's features were used in construction projects by different stakeholders, namely in the following areas (Azhar, 2012; Willis and Regmi, 2016):

- phasing and scheduling

- accompanying clients and end-users through a virtual tour of the facility

- analyzing options

- sustainability analyses

- planning site logistics

- energy performance analysis

- building management

- on-site project management

- running clash detections for various building systems

- quantity surveying

- cost estimation

All aspects of BIM, however, were not used with the same frequency. Design-related activities ranked highest "such as 'increased owner's understanding of proposed design solutions,' 'improved constructability of final design' and 'improved quality/function of final design.'" (Jones, 2015). Although general contractors (GC) were more and more involved in the design phases of construction projects, their needs tended towards the phasing, cost and project management capabilities of BIM.

It has been observed that the quantity take-off (QTO) phase of a project was tedious and time consuming (Alder, 2006). GCs would benefit from a more efficient process during quantity

take-off stages by enabling the software to automatically extract the appropriate data from the model. Although certain sources indicated that this was a commonly used functionality (Azhar, 2012; Willis and Regmi, 2016), other reports pointed to the difficulties and barriers that GCs faced with automated BIM-based QTOs (Forgues, 2012; Monteiro and Poças Martins, 2013; Aibinu and Venkatesh, 2014).

In the 2015 SmartMarket Report, contractors were asked to assess the relative impact BIM had had on several aspects of construction projects. Among the 19 topics to which GCs provided answers and appraised the impact of BIM as being "high" and "very high," the "improved process and accuracy of estimating construction costs" was ranked at the median. On the question of "improved accuracy and completeness of bids," the ranking was found below 33%, in the same category as the following other aspects: "reduced reportable safety incidents," "improved achievement of planned schedule milestone dates," "compressed schedule results in accelerated project completion," "reduced material waste," "reduced site labor due to increased offsite fabrication" and "reduced final construction cost of project" (Jones, 2015).

The tasks needed to improve "accuracy and completeness of bids" included the QTO and cost estimation processes. This showed that there was room for improvement in the efficiency of their related tasks. It is important to note that QTO wasn't only useful for estimating costs but was used in a wide variety of other project related needs. QTO was used, among others, for cost control, worksite monitoring, project scheduling, workload evaluation, productivity, budgeting, warranty, maintenance and use of cost per unit for future reference (Monteiro and Poças Martins, 2013). Moreover, as the BIM was used collaboratively to provide information to all stakeholders along the way from conception to completion, the design and quantities would evolve. Taking advantage of the automated cost estimation capabilities of BIM during the project development

phases had the potential to save considerable time that could be allocated to other important tasks.

With commercial GCs, the estimators are responsible for QTO and project cost estimation. This study considered only the QTO responsibility of the estimators, with the term QTO being defined as gathering measurements and performing calculations for construction material quantities for a project.

1.2   Research Problem and Purpose

The examined academic literature of the past 8 years did not provide evidence of an efficient use of BIM capabilities in the QTO process. Although BIM's capabilities were said to considerably enhance and accelerate the cost estimation activities through automation (Azhar, 2012; Willis and Regmi, 2016), the studies and surveys that specifically analyzed the topic of BIM-based QTO and cost estimation were not as enthusiastic as was expected in comparison to the more general descriptions of BIM's advantages (Sattineni and Bradford II, 2011; Forgues, 2012; Monteiro and Poças Martins, 2013; Aibinu and Venkatesh, 2014: Smith, 2014). Moreover, it was noted that many general contractors (GC) tended to continue either paper or on-screen take-off from 2D plans despite regular production of new or updated BIM-based QTO software. The problem was that GCs were reluctant to use BIM for QTO notwithstanding the time savings and increased accuracy potential. The purpose of the research was to identify how commercial general contractors that were comfortable in the use of BIM were taking advantage of BIM for QTO, what challenges they still faced, and what solutions they were implementing to overcome the challenges.

1.3 Research Objectives

Technology was progressing rapidly and new QTO possibilities were updated regularly. Despite the current literature that addressed the topic of BIM over the past years, little evidence was found on the current state of BIM implementation for the QTO process in the United States. The objective of this research was to find the answers from commercial GCs to the following questions:

1. What are, or would be, the efficient uses of BIM for quantity take-off among commercial general contractors?

2. What challenges are commercial general contractors facing in using BIM for quantity take-offs?

3. How are commercial general contractors overcoming the challenges?

1.4 Assumptions and Limitations

This research focused on commercial GCs in the United States who used BIM on a regular basis. Although GCs were not the only users of BIM in the AEC industry, the author assumed they needed the QTO features of BIM more than the other stakeholders because of their financial responsibilities towards owners. Therefore, the study focused on the beneficial uses and challenges of BIM in the process.

Moreover, the data was collected from a selected group of 20 GC employees selected by the researchers. The qualitative nature of this research called for the input of willing and interested participants to gather the most relevant and accurate information on the subject. This was accomplished by using the researcher's professional contacts with knowledgeable practitioners who regularly used BIM in their projects. By gathering their insight, it provided an

accurate context of the current practices and challenges faced among GCs regarding BIM-based

estimating implementation. This did not mean, however, that other GCs did not have different

views and opinions on the matter.

1.5   Definitions

Building Information Modeling (BIM):

"A BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward." (NBIMS, 2017)

Quantity Take-Off (QTO): the process of extracting quantities of material for a

construction project.

Estimating: the process of attributing costs to the different building components based on

the quantity take-off. The cost estimate provides the overall cost of the project or bid package.

2 LITERATURE REVIEW

The literature review provided an understanding of the influence of BIM as identified in today's literature with several sources that specialized in the BIM development and evolution fields. The gathered information and conclusions identified what was known on the topic at the time of the research and which aspects would require further investigation to add to the existing body of knowledge regarding the implementation of BIM quantity take off. The literature review started with BIM's definition, its evolution and use in the industry, followed by the difficulties that GCs faced as they worked to implement BIM in their regular QTO workflow.

2.1 Defining Building Information Modeling

Since the beginnings of BIM in the mid-2000s, there have been several definitions. The definition that this thesis used was the National BIM Standard (NBIMS) definition from 2017:

> "A BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward." (NBIMS, 2017)

The following was Autodesk's answer to the question "What is BIM?":

> "Building Information Modeling (BIM) is an intelligent 3D model-based process that equips architecture, engineering, and construction professionals with the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure." (Autodesk, 2017)

Moreover, the narrator of an Autodesk video answering that same question stated:

"BIM models use objects that have intelligence, geometry and data. If a model element is changed, BIM software coordinates the change in all views that display data elements because they are all views of the same underlying information." (Autodesk, 2017)

Unknowledgeable users mistook BIM for 3D CAD (NBIMS, 2017). Although 3D CAD provided a 3D graphic visualization of a project and allowed the extraction of plans, sections and elevations, it did not contain any functional characteristics, nor could it provide sequencing, maintenance or other related project life cycle information (Azhar, 2012). The essential difference between 3D CAD and BIM lay in the "information" (or parameter) component of BIM where the model contained data on spatial elements, systems, quantities, schedule and operations. It also had the capability of associating specific information to elements which provided data necessary to maintenance operations of installed machinery (Azhar, 2012). The intelligence of BIM lay in the "information" component that allowed the designers and users to define parameters and attribute specific data to each object.

2.2   Past Technological Shifts in the AEC Industry

In a study led in 1998 and 1999 on the implementation of Information Technology (IT) in AEC companies in Canada, it was noted that the transition to the Internet was very rapid. Within 3 to 4 years, 90% of the AEC industry firms were connected to the Internet, the engineers ranking first with 97% adoption followed by architects and contractors with 86% and 83% respectively. Notwithstanding this quick adoption and everyday use of e-mail communication, it was pointed out that the AEC industry was a little slower than communications industries or business services. Moreover, at the time of the survey, the author added that "the majority of AEC professionals still exchange design information by means of paper drawings and

specifications as they used to do prior to the advent of computers." The proposed explanation was that the AEC industry was "risk avert and prefers to adopt a technology that has been proven. Technological improvement in this industry is usually driven by necessity rather than by the need to be at the cutting edge" (Rivard, 2000).

It was interesting to observe that the engineers and architects accepted the new technology faster than contractors. Engineers and architects quickly accepted or were involved with greater use of IT with 82% and 70% respectively, whereas contractors were behind with 62% (Rivard, 2000).

Davis and Songer (2009) observed that resistance factors to IT change in the AEC companies were gender, level of computer understanding and experience, past IT change experience, knowledge of future IT changes and profession. The authors noted that acceptance of IT change had a direct correlation with the profession and position. Ranked from most to least accepting of IT change were the following positions: management, architects, engineers, construction managers, administrators, and construction trades.

2.3   BIM Evolution in the AEC Industry

BIM features attracted the attention of architects, engineers, owners, general contractors and trades since its creation. The level of BIM adoption in North America increased throughout the years from 28% in 2007, to 49% in 2009 on to 71% in 2012 (Jones, 2012). As of 2013, trades and GCs were rated at 38% and 39% respectively as "high" and above BIM implementers (Jones, 2014).

In 2015, the SmartMarket Report did not provide further statistics on adoption levels by the industry as in 2012 but rather analyzed the profound impact of BIM features in ten critical

construction processes. At that stage, the industry had sufficiently matured with regard to BIM implementation to deeply transform the way the industry functioned. The research suggested that BIM was not merely changing the way architects designed and modeled but rather how the overall construction industry functioned. Emphasis on areas such as collaboration between stakeholders and improving techniques such as prefabrication were driving general contractors to higher productivity and efficiency.

Figures 2-1 and 2-2 illustrate the perceived impact of BIM by contractors in several categories, based on the results of a survey conducted by McGraw-Hill SmartMarket Report in 2015 on the use of BIM in complex projects.
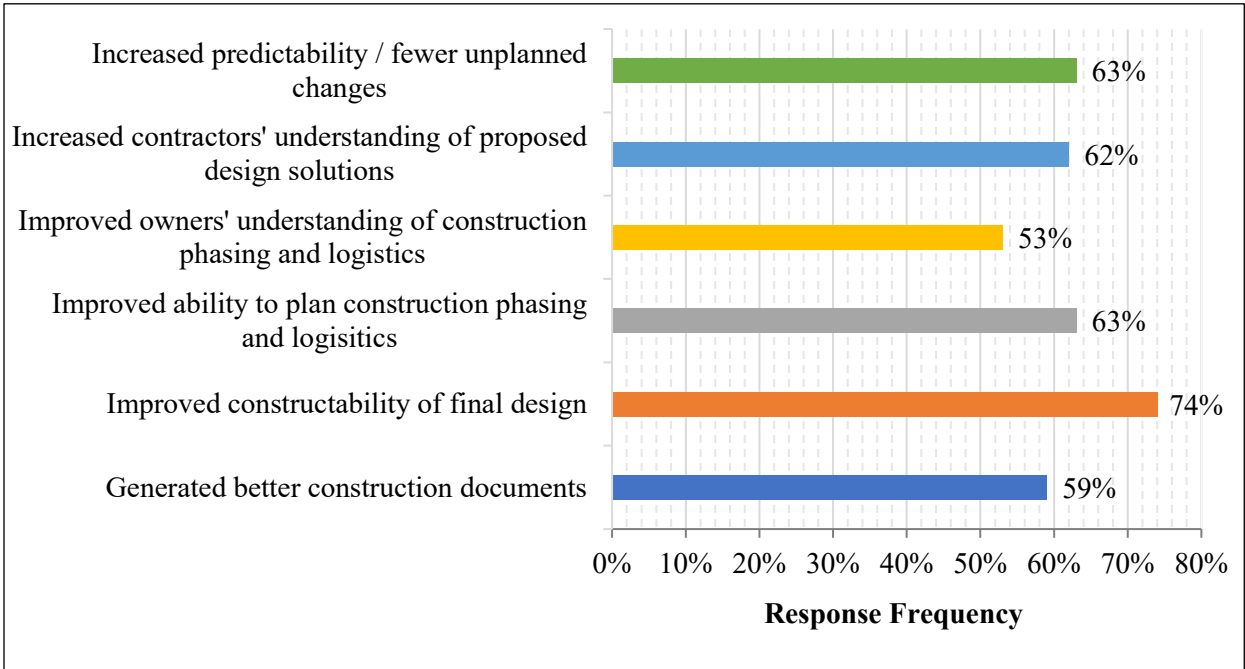
Figure 2-1 General Contractor Ratings of top BIM Impacts on Industry

The x axis represents the percentages of the GC's ratings of "high" and above to the question of the impact of BIM, stated on the y axis. As of 2015, the data in Figure 2-1 showed that BIM had a strong impact (between 53 and 73% of "high" ratings and above) on the overall quality of construction documentation, its understanding by the stakeholders and organizational potential.

However, as can be identified in Figure 2-2, the numerically quantifiable and on-site benefits of BIM received less "high" and above ratings from the survey (between 13% and 47%). Aspects such as diminished project cost, accuracy of construction costs and bidding, productivity, reportable safety incidents and other numerically quantifiable aspects have not received quite as high ratings as the documentation quality or organizational potential features of BIM.

It is important to note that although the results differed with reference to the analyzed scope of work, they nonetheless indicated a significant positive impact of BIM in many aspects of the AEC industry.

Countries outside of the US, such as Finland, Norway, Denmark, the UK and Singapore caught the vision of BIM's potential and made it a government policy to invest in its development. The shift towards this new technology grew rapidly as the governments of these countries measured the associated economic benefits (Smith, 2014).
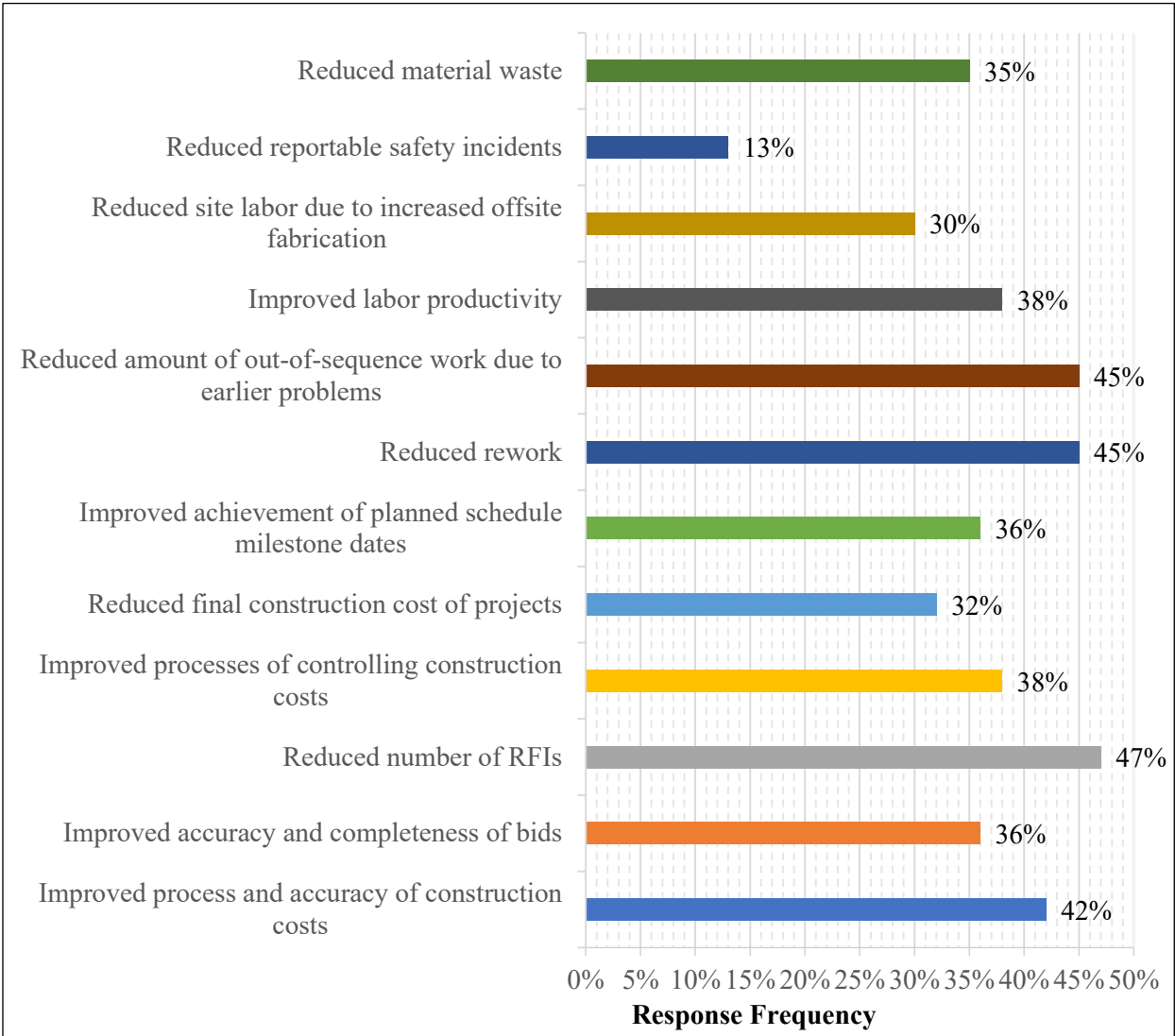
Figure 2-2 General Contractor Ratings of Lower BIM Impacts on Industry

2.4   Who Uses BIM and for What Purpose? (Successful Uses of BIM)

BIM wasn't only for designers to use. Its features benefited all the stakeholders of a construction project in several areas as discussed in the following paragraphs. The stakeholders that used the model were the designers, engineers, constructors, and facility managers as indicated in this table from Azhar (2012).

Table 2-1 BIM Applications for Project Stakeholders

BIM Application	Owners	Designers	Constructors	Facility Managers
Visualization	x	x	x	x
Options analysis	x	x	x	
Sustainability analyses	x	x		
Quantity Survey		x	x	
Cost Estimation	x	x	x	
Site Logistics	x		x	
Phasing and 4D scheduling		x	x	
Constructability analysis		x	x	
Building performance analysis	x	x	x	x
Building management	x			x

2.4.1   Traditional Construction Documentation Limitations

Two-dimensional CAD drawings provided designers with flexibility to alter, erase, add layers when drawing plans compared to paper-based drawings. However, when changing one view, all other views needed to be reviewed and edited as in paper-based drawings, "an error-prone process that is one of the major causes of poor documentation" (Azhar, 2012). Moreover, such drawings necessitated the readers to train their imagination to acquire a 3D understanding

from a series of lines and dimensions (ENR, 2005) which could result in misinterpretations of the design, especially for untrained users.

Before discussing how BIM could help solve some of the construction industries difficulties, Love (2011) explained that "one fundamental and prominent issue that continues to plague construction projects and contributes to cost and schedule growth is design changes and errors" while referencing previous studies on the topic. One of them spoke of the causes of rework in construction projects, and demonstrated that two of the most common causes for construction project rework were client directed changes and contract documentation (Love, 2009). The authors concluded that BIM could play an important role to tackle such difficulties as long as it was used as a tool and not a substitute for proper error management (Love, 2011).

2.4.2   Visualization

Previously, designers built physical models to better understand the spatial characteristics of the projected building. Often, because of time constraints and the ability to make modifications, the designers placed more importance on the 2D drawings than on the models.

3D visualization is a useful tool to show the owners and end users what the facility will look like. According to Azhar (2012), the visualization component was one of the two aspects (out of a list of ten) that touched each stakeholder, whether owner, designer, contractor or facility manager. It allowed for better communication during the design phase and helped all parties (including facility managers) obtain a better understanding of the building's use (Kerosuo, 2015). Willis and Regmi (2016) viewed this aspect of BIM as the most evident and simple form. We learned that the most impactful BIM aspects on complex construction projects were "increased owner's understanding of proposed design solutions," "improved constructability of final

design" and "improved quality/function of final design." According to the SmartMarket Report in 2015, architects generally embraced BIM before contractors and greatly benefited from its design features. It was therefore not surprising that the design aspects of BIM were more widely used and established (Jones, 2015).

2.4.3   Teamwork Among Stakeholders

Azhar (2012) emphasized that BIM was based on communication and collaboration. Willis and Regmi (2016) mentioned "collaborative platforms" when addressing the topic of software in their research. Forgues (2012) discussed collaborative design and risk sharing. These trends were also identified and marketed by software providers such as Autodesk that announced that BIM was "shaping the future of the AEC industry" by putting "the project in the center from the start." Autodesk further promised that the cloud, connected data and systems could allow project participants "to share and collaborate across the lifecycle in real time and without barriers" (Autodesk, 2017).

In a survey conducted by ENR, the authors noted that one of the contractors' "goals is to improve the information flow among project team members and between the jobsite and the office" (Jones and Laquidara-Carr, 2016). It was clear that collaboration and information sharing were central to efficient BIM use. BIM software and information technology allowed stakeholders to view and access the model and to make the necessary changes to each participant's scope of work. They then updated the central model with their adapted design and shared the latest version on the platform.

2.4.4   Clash Detection

In construction projects involving extensive coordination in the mechanical and electrical areas, clash detection played an important role in the design phase to help with construction project efficiency. In the UK, one of the reasons for implementing mandatory BIM on public projects beyond GBP 5 million pounds was to increase project efficiency through BIM-enabled processes such as clash detection, among others (Jones, 2014).

According to a study led by Hanna (2013) on mechanical and electrical contractors' use of BIM, it appeared that clash detection ranked first in the value of BIM in the project activities. Moreover, on the question of the value of BIM on ten performance indicators, the top performance indicator was "better coordination" and the second was "reduction in field conflicts" (Hanna, 2013). Additionally, in a study on the current BIM practices for MEP contractors led in 2014, the respondents indicated that they used coordination and clash detection on all the jobs that involved BIM. Most respondents to the survey indicated that the model was not worth creating if clash detection coordination wasn't to be performed (Kent, 2014).

2.4.5   Scheduling

BIM's features included scheduling and sequencing capabilities. Both terms were used interchangeably but the main difference lay in the time component (scheduling) and order component (sequencing) (Beveridge, 2012). According to a 2012 study in the US, scheduling was ranked as one of the top BIM advantages, while sequencing was ranked among the lowest in the list of BIM advantages (Beveridge, 2012). Jones (2015) reported that 68% of owners and GCs noted over a 5% schedule compression, essentially due to higher labor productivity levels and increased offsite prefabrication. Scheduling activities could be deemed a success not only

when reducing overall project duration but also by the ability to create accurate schedules and meeting the forecasted deadlines (Beveridge, 2012). Moreover, the same author noted a direct correlation between companies using BIM on a majority of projects with increased profitability and reduced schedules.

2.4.6   Prefabrication

Prefabrication was cited as among the top 3 activities used to leverage BIM (Jones, 2014). It allowed the trades to build and assemble materials off-site in a controlled environment. In the past, the most use of prefabrication was made through precast concrete for stair-cases, slabs, facades and partition walls. The use of newer technologies including BIM has extended prefabrication to more complex items such as pre-fabricated wall claddings, frames with integrated windows and doors, entire modular units such as bathroom pods and kitchen pods. Specific trades such as mechanical, electrical, plumbing and structural also used more prefabrication to their advantage because of BIM. The main benefits that came from off-site manufacturing were improved schedule, construction and labor cost reductions, increased quality (Wong, 2017), work site safety and product quality (Jones, 2014).

2.5   State of BIM Implementation in Quantity Take-Off Activities

According to Aibinu and Venkatesh (2014), who led a study on the status of BIM adoption in the cost estimation process in Australia, the use of BIM for quantity take-off was new and evolving. In their study, they found that the firms who used this technology were few and that they had very little experience. Moreover, BIM-based quantity take-off had mainly been adopted in the two years preceding the study and the technique had grown during that period.

In Australia, the results of the survey indicated that 94% of respondents still used 2D drawings for quantity take-offs, while 22% used 3D CAD models and only 20% experienced 3D BIM intelligent parametric models. These numbers showed how difficult it was for contractors to move away from traditional take-off methods. We saw that a mix of both methods (2D and 3D) were being used and that the shift towards BIM take-off was slow and uncertain (Aibinu and Venkatesh, 2014).

Additionally, Smith drew figures from the RICS 2011 survey of BIM usage by estimators in the UK and US. The main results are summarized in Figure 2-3 and Figure 2-4.
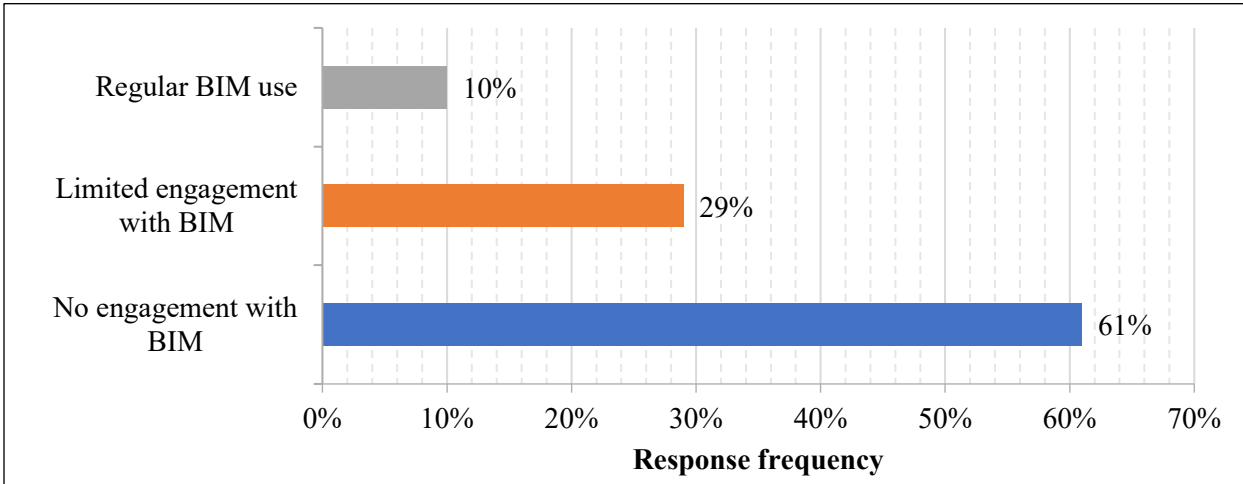
Figure 2-3 BIM Use Among Estimators in the UK and US in 2011

Another noteworthy finding was that as little as 4% of all quantity surveying firms invested regularly in BIM training and 10% actively assessed tools for potential adoption (RICS, 2011).
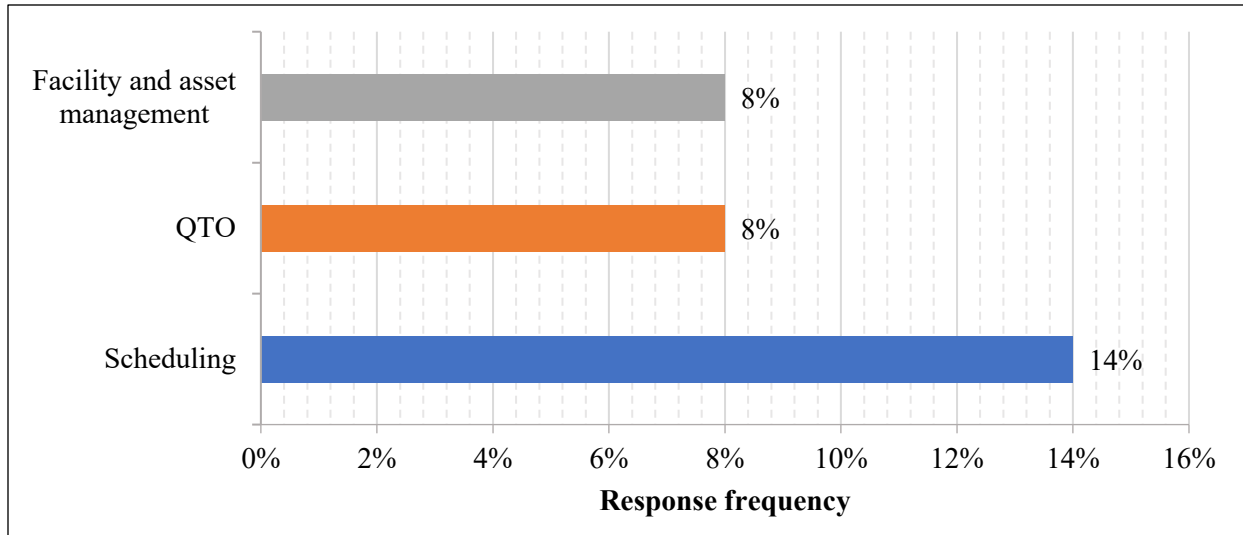
Figure 2-4 BIM Estimator Activities in the UK and US in 2011

2.6 Historical Take-Off Methods

According to Alder (2006), there were two categories of QTO, manual and electronic. Manual take-off was performed by estimators using specific colored markers for each type of material. The measurements were then recorded into a ledger or spreadsheet. This process was tedious and great care needed to be taken to keep the information accurate, especially on large and complex projects.

The QTO process could be accelerated by using a digitizer. The digitizer consisted of a tablet that the estimator used with an electronic pointing device which generated X and Y coordinates that were directly transferred to spreadsheets. This system helped estimators gain productivity in the QTO process and reduce errors.

Electronic QTO was further enhanced with solutions known as on-screen take-off, allowing the estimator to view the electronic 2D plans and measure the quantities on the

computer. The quantified parts of the plans were easily visualized and saved for comparison with the next updated version of the plan.

At the time of Alder's study, Computer Aided Design (CAD) was used regularly by designers and transferred to the estimators, allowing them to more rapidly and accurately draw the necessary information from the 2D drawings (Alder, 2006). However only minimal take-off was occurring from the 2D CAD drawings.

2.7   Difficulties General Contractors Face Using BIM for QTO

Although there have been few authors to directly address the BIM QTO benefits and challenges, there was some consensus as to where the barriers lay with regard to BIM implementation in the QTO process.

Aibinu and Venkatesh (2014) ranked 8 different challenges from the survey they conducted in Australia. Similarly, at the same period and in the same country, Smith (2014) listed 6 challenges which were related to the other study with an additional challenge being the legal, contractual and insurance aspects.

Autodesk offered a more simplistic vision of the challenges GCs faced by citing the following difficulties in BIM implementation: "retraining teams," "putting your faith in the cloud and mobility," and "making the necessary transition from you 2D comfort zone into the world of 3D models and BIM" (Autodesk, 2017). These challenges were real and were observed by practitioners. However, and notwithstanding Autodesk's active contribution to solve software difficulties over the years, the barriers to BIM implementation reached beyond the three technical aspects they identified. The current challenges were grouped into the seven following categories.

2.7.1   Design

BIM revolutionized how design was performed along with the interactions among those contributing to a given project. A major challenge related to design was the use of a single model for all stakeholders who had different needs. The architect was primarily concerned with the 3D visualization, the facility manager with as-built plans and maintenance information, the structural engineer with the adequate representation of structural elements and the MEP designers with the technical visualization and quantities. Finally, the GC needed the coordinated efforts from all the participants, with additional information in the model for scheduling, clash detection, cost estimating, site logistics and safety planning.

QTO was not the only field where collaboration issues arose between designers and general contractors. Kerosuo (2015) stressed the difficulties linked to project stakeholder's priorities and model sharing challenges in the project management process where each designer had his own needs and culture. The author added:

> "These cultures are also reflected in the work procedures, practices and the use of specific tools. Yet the tasks of the designers from each discipline are highly interdependent in terms of contents, time and practical procedures." (Kerosuo, 2015)

Monteiro and Poças Martins (2013) offered the following explanation for these discrepancies:

> "Since there is no mandatory standard, individual users will adopt the methods they are most comfortable with, which may not be the ones that best fit the overall information management and exchange. This is particularly noticeable between the designer's model and the contractor's model. Because they each have their own objectives and practices they often end up adopting different approaches to BIM. This results in models that differ not in the overall geometry or purpose of the design, but in the way information is processed and organized." (Monteiro and Poças Martins, 2013)

The authors added that contractors often chose to completely remodel the project to be able to extract the required information, instead of adapting the design model. These aspects were confirmed by Forgues, (2012) where optimal use of BIM required the model to be drawn in the same way it would be built.

Aibinu and Venkatesh (2014) also found that the information contained in the model wasn't sufficient for the estimators' needs. However, the respondents of the study indicated that this difficulty could be overcome by the estimators communicating with the designers about their needs and establishing a BIM plan with goals at the beginning of the project. The authors stressed the need for collaboration, communication and cooperation between estimators and designers.

With such extended coordination capabilities and diverging views on what a model should contain, several authors pointed to the cost implications necessary to provide a quality model. Bachman (2009) indicated that more design efforts were needed which in turn resulted in higher design costs. He then added that "costs are subsequently reduced later in the project" (Bachman, 2009) which implied that the client needed to trust that his investment would pay off. Smith (2014) pointed out the necessity for clients to be willing to pay the price for a quality model, suggesting that the designers' scope of work was limited by the consultancy fees the owner was willing to pay (Smith, 2014). In comparison to the 2D traditional workflow, this represented a change in cost allocation and overall work procedures. As BIM brought change to the work procedures, all stakeholders needed to be willing to adapt and focus on the new collaborative approach rather than continue with their usual work routines.

Monteiro and Poças Martins (2013) commented on the cost implications relative to the estimators' efforts of adapting the model to their needs. The authors noted: "the cost–benefit

ratio between modeling/configuration time and estimation benefits should be at this point taken under consideration" (Monteiro and Poças Martins, 2013). General surveys indicated that BIM-based cost estimating increased accuracy (Jones, 2015) and yielded time savings (Azhar, 2012) but the research specifically conducted on the topic provided a more conservative view. The key to avoiding model rework was for estimators and designers to collaborate, communicate and cooperate (Aibinu and Venkatesh, 2014).

2.7.2   New Skills and Training

In BIM-based projects, tasks that didn't exist in the traditional project management and cost estimation roles were emerging. These new tasks seemed to frighten those stakeholders who were not familiar with the technology. In a study led in Finland where schools were built using BIM models, the researchers found that several users and facility managers were reluctant to use BIM because of its perceived complexity. One school operations manager indicated that "BIM needs to be developed for ordinary people and not only for engineers to use" (Kerosuo, 2015). Furthermore, the same study revealed new challenges regarding who had the competence and would hold the responsibility of updating the designs. BIM brought a need for trained people who understood and were comfortable using the associated tools.

Forgues (2012) pointed out that the use of BIM QTO software required specific training and that the accuracy of the results needed to be monitored and tested to ensure that the system was reliable. Along the same lines, Smith (2014) indicated that, although software and technology were expensive, the greatest cost for GCs lay "in staff training and development."

Hiring specifically trained personnel and training employees to use BIM was necessary as an increasing number of tasks were related to manipulating models. However, change coming

solely from the general contractor was not enough. The way the models were designed needed to be constructed based on a knowledge of the future operations the model would go through. Eventually, for automated model-based QTO to be possible, the designers needed to adapt their way of designing to accommodate the estimators' needs. This new approach to design was more time consuming and a cost benefit analysis was to be made to identify which efforts in the design phase yielded the best results for the rest of the project (Monteiro and Poças Martins, 2013).

2.7.3   Implementation Costs

The costs of implementing BIM for QTO was addressed by several authors (Beveridge, 2012; Monteiro and Poças Martins, 2013; Aibinu and Venkatesh, 2014) and was divided into two main aspects: acquisition of computer equipment, both hardware and software, and employee training.

Although this aspect was mentioned in several studies, there were no figures to analyze. This could be due to the difficulty of accurately quantifying how much time estimators spent taking off quantities from the BIM in comparison to 2D take-offs. It was also difficult to evaluate the cost of employee training and the direct financial benefits of that training. This overall lack of knowledge may have contributed to the challenges GCs faced in implementing the technology. According to Beveridge (2012) on his study of BIM best practices, "the rewards obtained from using BIM greatly outweighed the costs of investing" while adding that the negative aspects (including costs) were only "a temporary setback."

A study focusing on BIM implementation for mechanical and electrical contractors provided the following BIM implementation costs as percentages of the total project costs. 61% of respondents estimated that implementing BIM cost them 2% or less of the overall project cost.

30% estimated the cost to be between 2 and 5%, and finally 9% believing it was worth over 5% of the overall project budget (Hanna, 2013).

2.7.4   Software

Several studies referred to software immaturity as one of the main limiting factors of BIM estimating. In 2011, a web-based survey on the construction industry's use of BIM in cost estimating in the United States concluded that although the technology had the potential to be more accurate and save time, it was not yet ready. The two reasons for that were the lack of information of the models and BIM software immaturity relative to QTO (Sattineni and Bradford II, 2011).

In 2012, Forgues seemed to view the lack of maturity of software as being an obstacle along with the difficulty of researching and choosing the software most appropriate for the company's ways and desired workflow (Forgues, 2012). In 2014, Smith mentioned that the uncertainty relative to software's constant evolution worried GCs. The interviewees stated that "a lot of time and expense can be spent on software and training with uncertain outcomes" (Smith, 2014).

Software companies worked on the compatibility issues between BIM and QTO. In Australia, as of 2014, 87% of the quantity surveying firms reported using BIM compatible estimation software. Although those firms ranked the "integration of the new software with BIM" as medium (3.14 on a scale of 1 to 5, with 5 being very high), it seemed that the difficulties expressed in 2011 and 2012 had been solved to some degree (Aibinu and Venkatesh, 2014).

On the study of BIM in construction project management in Canada in 2016, software incompatibility was ranked among the lowest on the list of challenges. This outcome did not surprise the authors, because of "the wider variety of software that is becoming available and reduced costs associated with collaboration platforms" (Willis and Regmi, 2016).

2.7.5   Reluctance by Employees

According to Willis and Regmi's study of use of BIM in Canadian project management in 2016, on site employees' lack of skills and abilities hindered them from collaborating with others using BIM technology and led them to insist on exchanging construction information on 2D paper drawings. The authors suggested that the work-site infrastructure may not have been adequately set up to properly use BIM but also believed that the underlying problem was the lack of training of on-site employees. Moreover, the study pointed out that beyond the technical aspects that could hinder BIM implementation and use was the need for "a cultural shift in the attitudes and expectations of project participants."

Making a radical change in a company's tools and processes was bound to create difficulty among teams. Bachman (2009) stated: "for many people, rapid change can be difficult, and nearly all culture changes take time. Implementing BIM across the firm needs to be seen as more evolutionary than revolutionary" (Bachman, 2009). This principle also applied to the transition from traditional QTO to BIM based QTO.

Aibinu and Venkatesh (2014) noted that 57% of respondents indicated employee enthusiasm for BIM in estimating. However, 15% resisted, 14% were both enthusiastic and resistant while the last 14% were very cautious on the subject. Often, resistance came from those

who were the most experienced in a certain process; "it is not a function of age as much as it is years spent practicing a certain way" (Bachman, 2009).

BIM projects required a different project methodology. It took the employees away from the traditional and fragmented workflow to a new environment of collaborative design, risk sharing and input from project participants early in the design process. In order to make the best use of BIM's features, each participant needed to change his mind set (Forgues, 2012).

Willis and Regmi (2016) supported the fact that "there must be a cultural shift in the attitudes and expectations of project participants" for the use of BIM in project management. Smith (2014) also found that the "cultural business change" was a challenge for many companies as certain staff members would not adapt to that change. However, the study revealed that attitudes had been changing in the two previous years "as professional staff realize that if they do not evolve with this technology and develop expertise they will be left behind" (Smith, 2014).

2.7.6   Legal and Ownership Issues

The model sharing and collaborative environment fostered through the BIM model use brought new challenges and uncertainties. In the construction industry, contracts were laid out to clearly define which party would be liable for a specific task. This fragmentation was helpful when trying to identify which party had the liability of an error. However, in the collaborative approach, this fragmentation was dissolved and the concept of shared risk took its place (Forgues, 2012). It appeared that the legal and ownership issues of shared documents were new to the industry and were in the process of being addressed as there was very little documentation on the subject. It was interesting to note that references to legal issues were linked to uncertainty (Aibinu and Venkatesh, 2014; Smith, 2014). The lack of knowledge and experience on how to

manage the contractual liability posed some difficulty for full implementation in the BIM

process. Moreover, insurers in construction suffered from the same uncertainty which could

potentially "lead to insurance exclusion for BIM projects" (Smith, 2014).

2.7.7   Project Delivery Methods

The implementation of BIM in projects brought a shift in the interaction methods of the

stakeholders. In order to fully benefit from BIM's features, the contract binding the parties

needed to encourage collaboration between participants. Azhar (2012) indicated that "the

foundations of BIM are laid on two pillars, communication and collaboration." According to a

study led in 2012 on BIM best practices, responses to the top 3 advantages of BIM gave

"communication" as the highest, tied with "scheduling," followed by a tie between

"coordination" and "visualization" (Beveridge, 2012).

One essential aspect of communication and collaboration was the early involvement of all

stakeholders early in the design process. Willis and Regmi (2016) found that:

> "In order for an accurate estimate to be developed using BIM technologies and
> BIM cost management processes, the general contractor must be integrated in
> the design team and provide input in the development of the building
> information model." (Willis and Regmi, 2016)

These findings confirmed the need for a collaborative type of contract which would allow

the stakeholders to work together and create the best tool to use for the project. An accurate and

well-designed model added great value to the sequencing and completion of a construction

project.

There were different project delivery methods that either encouraged BIM use or

hindered its capabilities. Azhar (2012) indicated that "traditional project delivery systems (e.g.

design-bid-build) have a very limited role in BIM-based projects." The design-bid-build (DBB)

delivery method did not make optimal use of the BIM because of its fragmented configuration. A DBB contract included a succession of distinct phases involving different stakeholders at different times and therefore, did not make an efficient use of the essential collaborative aspect of BIM. The contractor was involved in the project by the time the design had been completed and there was no incentive for collaboration between the parties.

Several studies involved BIM-based QTO in a DBB contract. Such findings in which BIM estimating was used in a DBB contract indicated that the estimator's level of maturity using BIM in the QTO process was low and that he had not yet identified the efficient uses of the model. It was probable that the model was used solely as a 3D visualization tool to supplement the 2D drawings (Aibinu and Venkatesh, 2014). Such findings of partial use of this method could explain why certain BIM users were skeptical and reluctant to use BIM in this field.

On the other hand, the most collaborative approach known as Integrated Project Delivery (IPD) seemed to best suit the BIM methodology. According to Azhar (2012):

> "IPD brings key construction management, trades, fabrication, supplier and product manufacturer expertise together with design professionals and the owner earlier in the process to produce a design that is optimized for quality, aesthetics, constructability, affordability, timeliness and seamless flow into lifecycle management." (Azhar, 2012)

IPD was not the only project delivery method that enabled participants to collaborate around the BIM model. Common methods such as Design-Build (DB), Construction Manager At Risk (CMAR) or Design-Assist provided frameworks in which the designers, owners and contractors could communicate early in the design process (Patterson, 2014, El Asmar, 2013 and Azhar, 2012).

The differences between the project delivery methods lay in the relationship between the owner, the designers, engineers and contractor. An illustration of the relationships between owner, designer and contractor for DBB, DB and IPD contracts is found in the following figure adapted from El Asmar (2013).
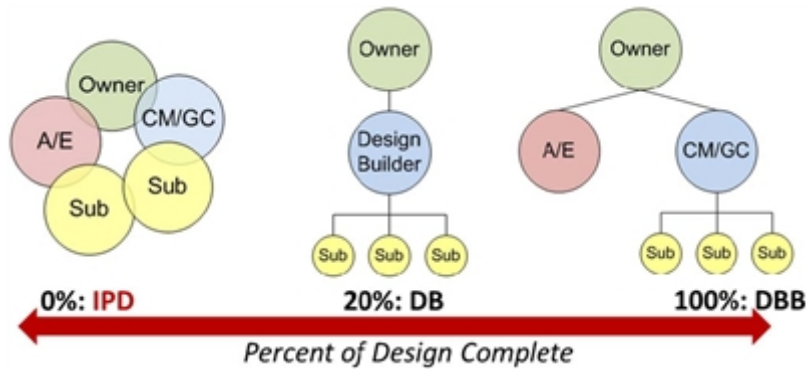
Figure 2-5 Project Delivery Method Comparison

In a DBB configuration, the owner has two sets of contracts, one with the design team and one with the contractor. The work of the designers must be completed in order for the owner to contract with the GC (El Asmar, 2013). The designers and contractor have no contractual relation and disputes between the two are mediated by the owner.

CMAR is similar to DBB in the relationship between the stakeholders. However, the difference lies in the timing. In CMAR, the GC is integrated early in the project phase to allow the designers to benefit from the construction manager's knowledge and feedback. Design-Assist is a limited version of CMAR, in which the GC is involved in the design phases but has no contract for the construction of the building (Patterson, 2014).

DB provides the owner with a single contract between himself and the contractor and design team. The GC manages the design team and is responsible for the success of the overall

project, both in design and construction. Therefore, the GC is involved early in the design process and provides valuable input throughout the design and construction phases (Patterson, 2014).

Finally, IPD involves the owner, designers, GC, subcontractors and suppliers before the design starts with a multiparty contract between all stakeholders. In this delivery method, risks and benefits are shared among stakeholders as they are all actively involved in the successive design and construction phases of the project. Definitions of IPD differ according to different authors but the most widely accepted aspects of IPD are the involvement of all key participants with a multiparty agreement and very early involvement of these participants, normally before the design phase takes place (El Asmar, 2013).

3   RESEARCH METHODOLOGY

3.1   Objectives

The principal objective of this research was to identify how commercial general contractors were taking advantage of BIM in the QTO process. Answering the three following questions would provide a general framework to understand the current state of BIM leverage in the estimating process:

1. What are, or would be, the efficient uses of BIM for quantity take-off among commercial general contractors?

2. What challenges are commercial general contractors facing in using BIM for quantity take-offs?

3. How are commercial general contractors overcoming the challenges?

These three questions defined the boundaries of the research. The purpose was to gain an understanding of the current state of BIM use in the QTO process. The study focused on what tools, processes, training, hiring and/or partnership strategies commercial GCs practiced to generate quantity take-offs more efficiently.

As identified in the literature review, there were several obstacles to the implementation of BIM in the QTO process, whether technological, theoretical, or cultural. The purpose of the study was to determine if and how those challenges had evolved and what additional knowledge

could be drawn from them. As more QTO software was developed over the years and BIM's influence continued to increase, there needed to be a base line established and an update on the current challenges to BIM based QTO. Finally, this study was designed to identify what tools or strategies the general contractors employed to overcome the current challenges.

3.2 Qualitative Research Method

Since the distinct processes and procedures were likely to be fairly specific to each company, it was determined that a qualitative research method was most appropriate to discover and analyze how GCs were taking advantage of BIM's capabilities in the estimating field. Creswell (2014) defined qualitative research as:

> "An approach for exploring and understanding the meaning individuals or groups ascribe to a social or human problem. The process of research involves emerging questions and procedures, data typically collected in the participant's setting, data analysis inductively building from particulars to general themes, and the researcher making interpretations of the meaning of the data." (Creswell, 2014)

During the first stages of this research project, open interviews with estimators and estimating department supervisors of three GCs and an architect were conducted to help gain a general understanding of how the topic was received and what thoughts were shared. The discussions brought up several interesting points. Among the three GCs, the level of BIM use in estimating differed greatly along with the employees' attitudes regarding the technology. The interview with the architect brought to light the different visions and needs between the contractors and the designers. Additionally, the lack of communication between the two entities pointed to the difficulty of finding solutions to the challenge. These interviews provided additional insights to the literature analysis and confirmed the interest and need for further research on the topic.

3.2.1 Participant Selection

This research provided a snapshot of the current implementation state of BIM estimating. To gather sufficient insight, the researchers selected 20 GC employees with experience in BIM estimating to provide a variety of points of view and a broad industry experience.

The focus of this study was to gather information from those whose jobs and responsibilities involved QTO and estimating, usually known as estimators. Since they were responsible to provide project estimates and bids to clients, they would be the most knowledgeable in BIM model use and QTO tools available. Additionally, the estimating department supervisors had an influence on the QTO methods of their teams. They most certainly participated in the decisions as whether to implement BIM or not in the cost estimation process and to what extent. They would also be in a good position to identify whether their teams' use of the technology and software was beneficial and whether it contributed to time savings and accuracy in comparison to traditional estimating methods.

In order to select the participants, the authors contacted a list of 40 potential interview candidates drawn from their industry contacts. Their selection was conditional on regular BIM use in the quantity take-off process whether as a means to quantify materials, or simply to visualize a project during the estimating process. Several of the contacted participants referred the researchers to other BIM estimators within their company. Given that the research was qualitative, it was necessary to contact and discuss the topic with knowledgeable practitioners who were willing to share their experiences and give specific, in-depth information about their current practices along with insights on successes and challenges they faced in the field. A total of 22 participants were interviewed, out of which 20 were retained. The job titles of the participants were BIM and VDC managers / directors, estimators and preconstruction managers

(see paragraph 4.3.14). The 2 participants whose data was not retained for analysis were familiar with the technology but had not been using it in their quantity take-off efforts.

3.2.2 Data Collection Procedures

The data collection method was defined in three steps: first, a general demographic information survey via e-mail, second, a semi-structured interview and third, a follow up question via e-mail based on the interview responses. The e-mailed demographic survey provided the researchers with background on the company and employees to see what relationships could be found based on the background data. This data was designed to help identify trends between the interview responses and general information such as the estimators' time spent with BIM-based QTO or the contract types they used it for. The combination of information would allow to better understand and analyze the data extracted from the interviews. Additionally, asking for the participant's job title ensured that the surveys were being sent to the appropriate employees in the company. The survey asked to provide the following information (the demographics survey is found in Appendix A):

- Types and sizes of projects taken off with BIM technology

- Types of delivery method contracts taken off with BIM technology (Design Bid Build, Design Build, Construction Manager / General Contractor, Construction Manager at Risk, Design Assist, other…)

- Years the company had been involved BIM based QTO

- Years of experience of estimator using BIM in QTO

- Number of estimators using BIM in the office and / or company

- Company yearly revenue

- Respondent's job title

After receiving the answers to the demographics survey, a second e-mail was sent to ask for a good date and time to conduct the semi structured interview. The 10 interview questions were attached to allow the respondents to give some thought to their answers before the interview took place. This provided the respondents time to reflect deeper on the questions prior to the interview.

The interviews allowed the researcher to gather respondents' thoughts, historical information and opinion on the matter. Although the set of questions were the same for each interview, the semi structured aspect allowed the researcher to ask additional questions on topics participants brought up that weren't part of the initial prepared questions. Given the qualitative nature of this paper, it was difficult to identify in advance exactly what types of responses would be given. This methodology gave some flexibility to build on the information as it was received during the interview.

It is important to note that the interviews provided data based on the interviewees' perceptions and experience. Therefore, it was possible that two estimators within the same company, working with the same procedures might have given different answers to a same question.

The interview consisted of 10 open ended questions designed to retrieve the respondent's insight on the questions. These 10 questions made no reference to the advantages and challenges of BIM relative to the cost estimation process identified in the literature review. A follow up question (question 11) was sent to gather the participant's perception on the challenges that were found in the literature review section once the interview was completed. This process was used so as not to influence the respondents in their answers to the previous questions.

The interview questions were designed to provide relevant detail on the three main questions this study wished to find answers to (see sections 1.3 and 3.1). To accomplish this objective, the following questions were posed (the interview structure is found in Appendix B):

1. What are the benefits of BIM-based quantity take-offs (QTO)?

2. Which scopes of work do you typically take-off from BIM?

3. Are there additional scopes of work that you would like to take-off from the BIM?

    a. What are they?

4. Model design phase:

    a. At which design phase do you typically receive the model from the designer?

    b. At which design phase would it be most beneficial to have the model? Why?

5. Where would you like see BIM QTO evolving in the future?

6. What challenges do you face when taking off quantities from BIM?

    a. Are the items you just provided, ranked in order of importance?

    b. If not, how would you rank them?

7. What specific strategies do you use to overcome these challenges?

8. BIM QTO training:

    a. How much BIM QTO training have you received?

    b. On average, how much time do you spend each month for QTO related professional development?

9. Which software do you use for BIM QTO?

   a. If you use multiple software packages, please assign the percentage of use of each type.

10. Any other thoughts about BIM-based QTO?

11. (Asked as a follow up question) - How would you rate today's BIM adequacy in the following aspects (on a scale from 1 to 10, 1 being inadequate and 10 meaning the aspect is perfectly suitable for your needs) :

    a. Model quality

    b. Employee training and skill

    c. Implementation costs

    d. Software availability and adequacy

    e. Employee commitment to BIM estimating

    f. Legal and model ownership aspects

    g. Other: please specify

Question 1 identified what the estimator felt was advantageous when extracting quantities from the model in the estimating process. Additionally, this retrieved information on their perception of what constitutes the successful use of BIM. This allowed for the comparison between the interviewees' responses and those identified in the literature review.

Questions 2 and 3 helped understand which scopes of work were regularly taken off and for which ones BIM take-off was the most useful. This information was designed to provide insight on the aspects of the model the estimators made the most of and what other aspects they ideally wished to use.

Question 4 brought further insight on the level of completion of the model at the time the estimator first received it. The objective was to understand if the design phase at which the estimator received the model had a positive or negative influence on his ability to extract the necessary data. This provided insight to what the ideal design phase to receive the model would be and how that would be beneficial.

Question 5 addressed the interviewees' vision of what BIM-based QTO could become in the future. It was designed as a continuation of the first four questions to understand the estimators' expectations of the technology. This question was designed to help understand how the participant felt about the system and what other aspects they hoped to gain from it.

Question 6 provided an understanding of the participants' perceptions of the current challenges. This aspect of the interview provided further understanding of the current difficulties the estimators faced. There were many challenges discussed in the literature review and this question helped identify whether identical issues were mentioned or if new ones had since been observed. The sub questions were asked after the answer had been provided in order to obtain a ranking of those challenges from the most difficult to handle to the least problematic. If the answers were close to the list of challenges mentioned in question 11, the latter question was not issued as a follow up.

Question 7 measured whether the company or the estimator had specific procedures in place to overcome the identified difficulties and if they did, to discover their solutions to the challenges of BIM QTO. This assessed how systematic their approach to problem solving was, whether each participant looked for their own solutions or if a system was in place to methodically identify and overcome the challenges.

Question 8 provided insight about the training and development opportunities the estimators received to further their skills and knowledge of the topic, whether past or ongoing. It was a way to measure their development, whether self-motivated or through company programs, to further explore and gain deeper understanding of how they could improve the processes and techniques to reach their goals.

Question 9 was intended to understand which software packages were most prevalent among those interviewed to help assess the software's role in BIM-based QTO. The assigned percentage of each software package allowed to quantify which ones were the most widely used in their BIM QTO tasks.

Question 10 allowed participants to share additional thoughts that hadn't been covered through the previous questions and gave them more freedom to address concerns, insights and other thoughts about the BIM QTO in general. It also allowed them to think about the tool in a broader and more conceptual sense.

The third and last step was the follow up question several days after the interview had taken place. It was not addressed during the interviews for two reasons. First, there was a potential for the question to influence the participants' responses if shown a list of identified challenges before they were able to give some deep thought on the difficulties they faced. This was to ensure that their responses came directly from their own experience. Second, since the question was closely related to question 6, it could sound redundant if the answers the estimators provided in question 6 already addressed the given list. Therefore, based on the question 6 answers, the 11th question was either addressed or omitted.

The ranking of the challenges exposed in question 11 was expected to provide a deeper understanding of the evolution of the BIM estimating process in comparison to earlier studies. This was to observe whether the previously identified challenges were still prevalent and just as important or whether certain issues had been solved and had been successfully implemented.

3.2.3   Data Recording Procedures

The data was gathered through surveys or interviews. The interviews took place through online meetings because of the straightforward recording possibilities. Each discussion was recorded and later transcribed for thorough analysis.

During the interviews, the researcher took notes of the given answers to better understand the topic but also as a backup in the case of electronic equipment failure. To do so, an interview protocol was created with general information such as the date, interviewee name and company along with the prepared interview questions and spaces to record the answers and thoughts that came from the discussion.

The e-mail survey was gathered electronically prior to the interviews to provide the interviewer with valuable information before the discussion. Given the data collection method, the researchers were open to any additional information independent of its format.

3.2.4   Data Analysis Method

The purpose of the analysis phase was to identify common themes in answers to the interview questions along with diverging opinions. To adequately recognize the themes, each interview transcription was reviewed and the information was coded. Coding was the process of attributing a name to specific paragraphs or other pieces of information. The coding process

identified which topics each respondent addressed during the interview. The coding was performed by a single person, which eliminated the risk of misinterpretations in the name and organization of certain data between several researchers.

The data collection and analysis phases were conducted concurrently. There was no need to obtain the information from each participant before starting the data analysis. Thus, transcriptions and coding took place shortly after the first sets of interviews. The findings were then organized in tables, graphs and other useful visual forms to best identify the common trends but also differences in the collected data. The results were interpreted and conclusions about the current state of BIM estimating implementation were drawn.

It was anticipated that several of the barriers to implementing BIM QTO already discussed in the literature review would be specific themes that would be addressed by the estimators. From this research, it was anticipated that new solutions would emerge and add to the current state of knowledge expressed in the literature.

4 FINDINGS AND DISCUSSION

The formatting of this section was adapted to more easily create academic papers on the topic of BIM QTO. Therefore, the previous three chapters were again summarized in the following pages (paragraphs 4.1 and 4.2) before exposing and discussing the findings of this research which begin in paragraph 4.3.

4.1 Introduction

The rapid growth of Building Information Modelling (BIM) over the past 10 years has influenced and challenged the traditional design, project management and relationship aspects of the construction industry (Jones, 2012). BIM is defined as:

> "A digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward." (NBIMS, 2017)

BIM's capabilities and features reach far beyond 3D modeling and visualization and include the:

> "Digital description of every aspect of the built asset. […] Creating a digital Building Information Model enables those who interact with the building to optimize their actions, resulting in a greater whole life value for the asset." (NBS, 2017)

BIM features are used by construction project stakeholders in the following areas (Azhar, 2012; Willis and Regmi, 2016):

- phasing and scheduling

- accompanying clients and end-users through a virtual tour of the facility

- analyzing options

- sustainability analyses

- planning site logistics

- energy performance analysis

- building management

- on-site project management

- running clash detections for various building systems

- quantity surveying

- cost estimation

4.1.1 Problem and Purpose of the Research

The examined literature of the past 8 years did not provide evidence of an efficient use of BIM capabilities in the quantity take-off (QTO) process. It had been observed that general contractors (GCs) were reluctant to use BIM for QTO notwithstanding the time savings and increased accuracy potential.

The purpose of the research was to identify how the current BIM-specialized GCs were taking advantage of this technology, to acquire a better understanding of the challenges that they still faced, and what solutions were being implemented to overcome the challenges.

4.1.2   BIM Evolution in the AEC Industry

BIM features have attracted the attention of architects, engineers, owners, general contractors and trades since its creation. The level of BIM adoption in North America has increased throughout the years from 28% in 2007, to 49% in 2009 on to 71% in 2012 (Jones, 2012). As of 2013, 38% of the trades and 39% of GCs were rated as "high" and "very high" BIM implementers (Jones, 2014).

In 2015, the SmartMarket Report stated that, the industry had sufficiently matured with regard to BIM implementation to deeply transform the way the industry functioned. The research suggested that BIM was not merely changing the way architects designed and modeled but rather how the overall construction industry operated. Emphasis on areas such as collaboration between stakeholders and improving techniques such as prefabrication were driving general contractors to higher productivity and efficiency (Jones, 2015).

As of 2015, it had been noted that BIM had a strong impact on the overall quality of construction documentation, its understanding by the stakeholders and organizational potential. However, aspects such as diminished project cost, accuracy of construction costs and bidding, productivity, reportable safety incidents and other numerically quantifiable aspects had not received quite as high ratings as the documentation quality or organizational potential features of BIM (Jones, 2015).

4.1.3   Uses of BIM

BIM's features were not only used by designers. Other stakeholders such as engineers, constructors and facility managers were also interested in the benefits available through BIM. Although the model was regularly used to visualize the project, other features gained popularity

such as promoting teamwork among project participants, coordinating the technical components of the building through clash detection features, establishing the schedule and sequencing of the project, and promoting prefabrication due to the accuracy and level of coordination of the model (Azhar, 2012).

4.1.4 State of Implementation in Quantity Take-Off Activities

In Australia, the results of a survey stemming from the study of the status of BIM adoption in the cost estimation process indicated that 94% of respondents still used 2D drawings for quantity take-offs, while 22% used 3D CAD models and only 20% experienced 3D BIM intelligent parametric models. These numbers showed how difficult it was for contractors to move away from traditional take-off methods. We saw that a mix of both methods (2D and 3D) were being used and that the shift towards BIM take-off was slow and uncertain (Aibinu and Venkatesh, 2014).

Additionally, figures from the RICS 2011 survey of BIM usage by estimators in the UK and US showed that only 10% of respondents used BIM regularly in QTO and cost estimation activities, in contrast to 29% of limited engagement and 61% without any engagement (RICS, 2011).

4.1.5 Historical Take-Off Methods

Two categories of QTO exist, manual and electronic. Manual take-off was performed by estimators using specific colored markers for each type of material. The measurements were then recorded into a ledger or spreadsheet. This process was tedious and great care was necessary to ensure information accuracy, especially on large and complex projects.

Electronic means were used to accelerate the process, first with the digitizer and later with software that allowed estimators to view the electronic 2D plans and measure the quantities on the computer. The quantified parts of the plans were easily visualized and saved for comparison with the next updated version of the plan.

4.1.6   Difficulties General Contractors Face Using BIM for QTO

Aibinu and Venkatesh (2014) ranked 8 different challenges from the survey they conducted in Australia. Similarly, at the same period and in the same country, Smith (2014) listed 6 comparable challenges with an additional challenge being the legal, contractual and insurance aspects.

Autodesk offered a more simplistic vision of the challenges GCs face by citing the following difficulties in BIM implementation: "retraining teams," "putting your faith in the cloud and mobility," and "making the necessary transition from you 2D comfort zone into the world of 3D models and BIM" (Autodesk, 2017). These challenges were real and had been observed by practitioners. However, and notwithstanding Autodesk's active contribution to solve software difficulties over the years, the barriers to BIM implementation reached beyond the three technical aspects they had identified. The current challenges were organized into the seven following categories.

1. Design

A major challenge related to design was the use of a single model for all stakeholders who had different needs. The architect was primarily concerned with the 3D visualization, the facility manager with as-built plans and maintenance information, the structural engineer with the adequate representation of structural elements and the MEP designers with the technical

visualization and quantities. Finally, the GC needed the coordinated efforts from all the participants, with additional information in the model for scheduling, clash detection, cost estimating, site logistics and safety planning. In order for a model to be of use to the stakeholders, it was essential that the model be drawn in the same way it would be built (Forgues, 2012).

Work around a single model required collaboration, communication and cooperation between estimators and designers. It also meant that more would be required from designers and owners. Smith (2014) pointed out the necessity for clients to be willing to pay the price for a quality model, suggesting that the designers' scope of work was limited by the consultancy fees the owner was willing to pay (Smith, 2014). In comparison to the 2D traditional workflow, this represented a change in cost allocation and overall work procedures. As BIM brought change to the work procedures, all stakeholders needed to be willing to adapt and focus on the new collaborative approach rather than continue with their usual work routines.

2. New Skills and Training

Forgues (2012) pointed out that the use of BIM QTO software required specific training and that the accuracy of the results needed to be monitored and tested to ensure that the system was reliable. Along the same lines, Smith (2014) indicated that, although software and technology were expensive, the greatest cost for GCs lay "in staff training and development." This change applied to all participants of the construction project. For automated model-based QTO to be possible, designers needed to adapt the design methods to accommodate the

estimator's needs. Additionally, GC participants and facility managers needed to be trained to be able to manipulate and work with models regularly.

3. Implementation Costs

The implementation costs were divided into two main aspects: acquisition of computer equipment, both hardware and software, and employee training (Beveridge, 2012; Monteiro and Poças Martins, 2013; Aibinu and Venkatesh, 2014). Although this aspect was mentioned in several studies, there were no figures to analyze. This could be due to the difficulty of accurately quantifying how much time estimators spent taking off quantities from the BIM in comparison to 2D take-offs. It was also difficult to evaluate the cost of employee training and the direct financial benefits resulting from that training. This overall lack of knowledge on the matter may have contributed to the challenges GCs faced in implementing the technology.

4. Software

The perceived influence of software as an obstacle evolved over the years. In 2011 and 2012, the lack of software maturity was mentioned as one of the main reasons BIM had little success in the QTO process (Sattineni and Bradford II, 2011; Forgues, 2012). Software companies worked on the compatibility issues between BIM and QTO. In Australia, as of 2014, 87% of the quantity surveying firms reported using BIM compatible estimation software. Although those firms ranked the "integration of the new software with BIM" as medium (3.14 on a scale of 1 to 5, with 5 being very high), it seemed that the difficulties expressed in 2011 and 2012 had been solved to some degree (Aibinu and Venkatesh, 2014). The improved software capabilities raised yet another challenge for BIM-based QTO where "a lot of time and expense

can be spent on software and training with uncertain outcomes" (Smith, 2014) as software

constantly changed and evolved with time.

5. Reluctance by Employees

Making a change in a company's tools and processes created difficulty among teams.

Bachman (2009) stated: "for many people, rapid change can be difficult, and nearly all culture

changes take time. Implementing BIM across the firm needs to be seen as more evolutionary

than revolutionary" (Bachman, 2009). This principle was applicable to the transition from

traditional QTO to BIM based QTO.

Willis and Regmi (2016) supported the fact that "there must be a cultural shift in the

attitudes and expectations of project participants" for the use of BIM in project management.

Smith (2014) also found that the "cultural business change" was a challenge for many companies

as certain staff members would not adapt to that change. However, the study revealed that

attitudes had been changing in the two previous years "as professional staff realize that if they do

not evolve with this technology and develop expertise they will be left behind" (Smith, 2014).

6. Legal and Ownership Issues

The model sharing and collaborative environment fostered through the BIM model use

brought new challenges and uncertainties. As traditionally fragmented tasks became

interchangeable and shared between several users, new ownership and legal issues arose. It was

interesting to note that references to legal issues were linked to uncertainty (Aibinu and

Venkatesh, 2014; Smith, 2014). The lack of knowledge and experience on how to manage the

contractual liability posed some difficulty for full implementation in the BIM process. Moreover,

insurers in construction suffered from the same uncertainty which could potentially "lead to insurance exclusion for BIM projects" (Smith, 2014).

7. Project Delivery Methods

According to Azhar (2012), "the foundations of BIM are laid on two pillars, communication and collaboration." One essential aspect of communication and collaboration was the early involvement of all stakeholders early in the design process. The contract binding the parties either encouraged or hindered teamwork and collaboration and had a direct influence on the efficient use of BIM's capabilities. For example, a DBB contract, with its succession of distinct phases involving different stakeholders at different times, did not make an efficient use of the essential collaborative aspect of BIM. The contractor was involved in the project by the time the design had been completed and there was no incentive for collaboration between the parties.

On the other hand, the most collaborative approach known as Integrated Project Delivery (IPD) seemed to best suit the BIM methodology. Other delivery methods such as Design-Build (DB), Construction Manager At Risk (CMAR) or Design-Assist provided frameworks in which the designers, owners and contractors could communicate early in the design process although they were not as collaborative as IPD (Patterson, 2014, El Asmar, 2013 and Azhar, 2012).

4.2 Methodology

4.2.1 Objectives

The principal objective of this research was to identify how commercial general contractors were taking advantage of BIM in the QTO process. Answering the three following

questions provided a general framework to understand the current state of BIM leverage in the estimating process:

1. What are, or would be, the efficient uses of BIM for quantity take-off among commercial general contractors?

2. What challenges are commercial general contractors facing in using BIM for quantity take-offs?

3. How are commercial general contractors overcoming the challenges?

These three questions defined the boundaries of the research.

4.2.2   Qualitative Research Method

The focus of this study was to gain an understanding of the current state of BIM use in the QTO process from those whose jobs and responsibilities involved QTO and estimating, usually known as estimators in commercial GCs. Since they were responsible to provide project estimates and bids to clients, they would be the most knowledgeable in BIM model use and QTO tools available.

Since the distinct processes and procedures were likely to be fairly specific to each company, it was determined that a qualitative research method was most appropriate to discover and analyze how GCs were taking advantage of BIM's capabilities in the estimating field.

In order to select the participants, the authors contacted a list of 40 potential interview candidates drawn from their industry contacts. Their selection was conditional on regular BIM use in the quantity take-off process whether as a means to quantify materials, or simply to visualize a project during the estimating process. Several of the contacted participants referred the researchers to other BIM estimators within their company. Given that the research was

qualitative, it was necessary to contact and discuss the topic with knowledgeable practitioners who were willing to share their experiences and give specific, in-depth information about their current practices along with insights on successes and challenges they faced in the field. A total of 22 participants were interviewed, out of which 20 were retained. The 2 participants whose data was not retained for analysis were familiar with the technology but had not been using it in their quantity take-off efforts.

The data collection method was defined in three steps: first, a general demographic information survey via e-mail, second, a semi-structured interview and third, a follow up question via e-mail based on the interview responses.

Following the demographic e-mail survey, a qualitative, semi-structured interview was conducted with each participant. This allowed the researcher to gather respondents' thoughts, historical information and opinion on the matter. Although the set of 10 questions were the same for each interview, the semi structured approach allowed the researcher to ask additional questions on topics participants brought up that weren't part of the initial prepared questions. Given the qualitative nature of this paper, it was difficult to identify in advance exactly what types of responses would be given. This methodology gave some flexibility to build on the information as it was received during the interview.

Finally, the follow up emailed question (question 11) was sent once the interview was completed. It contained the list of challenges that were found in the literature review section and the participant was asked to rank how well BIM QTO was suited to provide the necessary service in each of those aspects. These challenges were not shown before the interview was completed in order not to influence the responses to the interview questions.

4.3   Findings

In the following description and analysis of the findings, it is important to remember that the answers stemmed from semi-structured interviews. Therefore, there were no lists of potential answers from which to choose. All the provided answers came from the participants' experience in their field of expertise. It was interesting to note, however, that the answers fit into a relatively limited number of categories for most of the questions.

4.3.1   Question 1 – What Are the Benefits of BIM-Based Quantity Take-Offs?

The answers provided to the question "what are the benefits of BIM-based quantity take-offs?" were organized into nine response categories. The categories and frequency of the responses were summarized in Figure 4-1.

Although no ranking as to the impact of the given benefits was required, respondents regularly spoke of major and minor benefits. Some indicated only one or two benefits whereas others spoke of up to 7 of them. According to the chart, speed and visualization / project understanding were among the major benefits as they were cited 19 and 14 times respectively out of the 20 responses. These benefits were referenced more than the other seven responses by far.

However, it was worth noting that out of the 19 references to faster BIM quantity take-off in comparison to 2D take-off, 10 of the participants issued a conditional clause relative to the quality of the model or stressed the importance of the preparation work necessary to attain those time savings with phrases such as "as long as," or "depending on," and "if" the information in the model was properly labeled. Moreover, a total of seven respondents specifically spoke of the speed aspect relative to faster budget updates between model iterations.
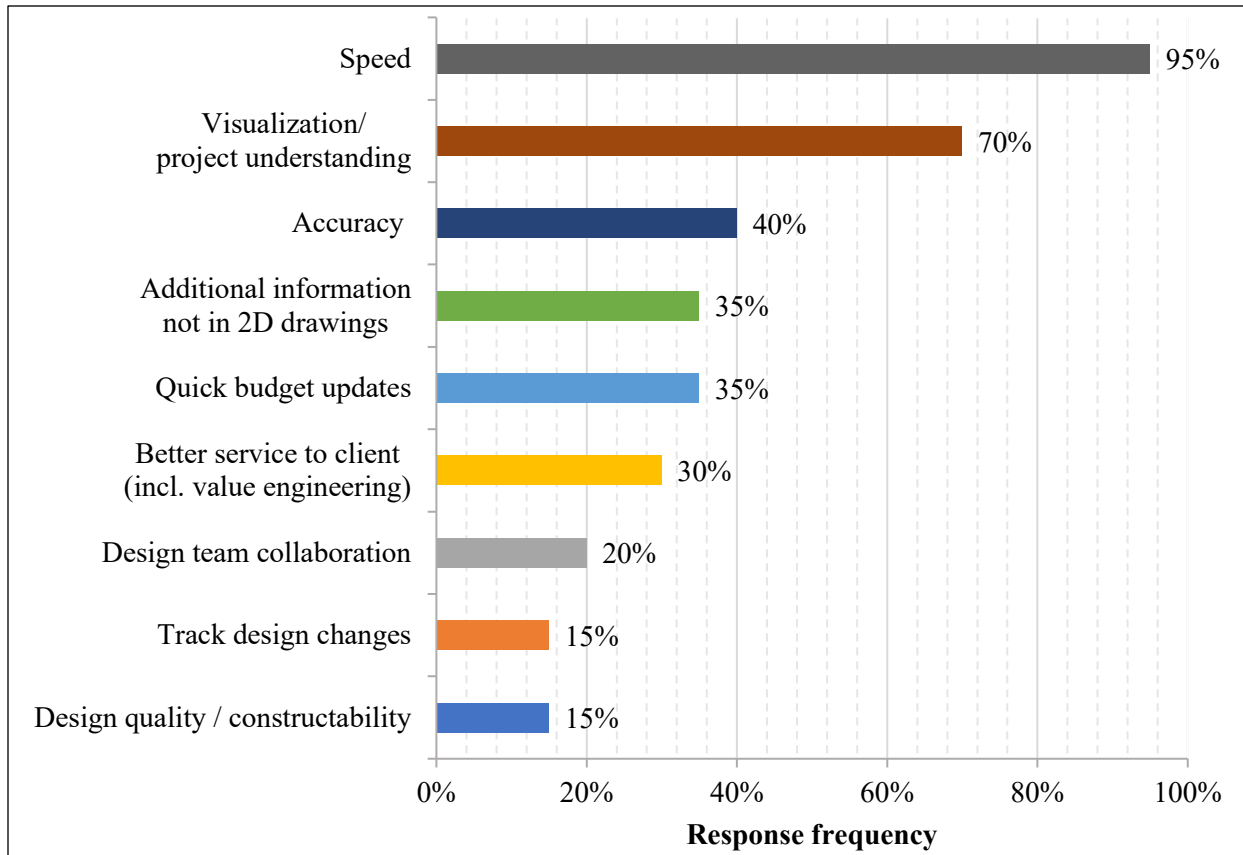
Figure 4-1 Benefits of BIM-Based QTO

On the other hand, the visualization aspect was referenced 14 times during the interviews and was not conditional on any other factors. It appeared that whatever the phase at which the model was received or however much detail was in it did not influence the estimators' ability to benefit from the model. Visualization was seen as a universal way of communicating among stakeholders, especially to help the owners understand where the costs lie. Most importantly, visualizing the project in 3D was considered of most value (based on the number of references throughout the interviews) for the estimators to gain a more thorough understanding of the project even if the majority, if not all, of the quantities were taken off the 2D drawings.

Two respondents underlined that the benefits of BIM-based QTO varied depending on the project and contract types. For example, a DBB project would not be beneficial for the quick

budget update aspect, as the project would typically be taken off only once. With the necessary preparation work to get a model ready for QTO, a single QTO would not generate time savings and would possibly lengthen the process. BIM QTO advantages were best leveraged in contracts with early GC involvement and ongoing relationships between stakeholders as the project evolved. These contracts allowed multiple iterations of the model and regular budget updates, making BIM QTO a faster alternative compared to 2D take-off methods.

4.3.2   Question 2 – Which Scopes of Work Do You Typically Take Off From BIM?

The responses regarding the scopes of work that estimators typically took off using BIM yielded 20 different answer categories as shown in Figure 4-2.

Three scopes of work were mentioned over 55% of the time. They included exterior skin, structural steel and concrete. Doors were mentioned 8 times, all possible scopes 6 times and windows 5 times, drywall and ceilings both 4 times. The remaining twelve categories were mentioned 3 times or less in the 20 conducted interviews.

It should be noted that certain categories such as item count could include doors and windows. It could be that some scopes of work were contained in several categories depending on how the respondents qualified the scope. However, there was a clear trend where the major elements such as structure and exterior envelope were among the most popular scopes to take off using BIM.
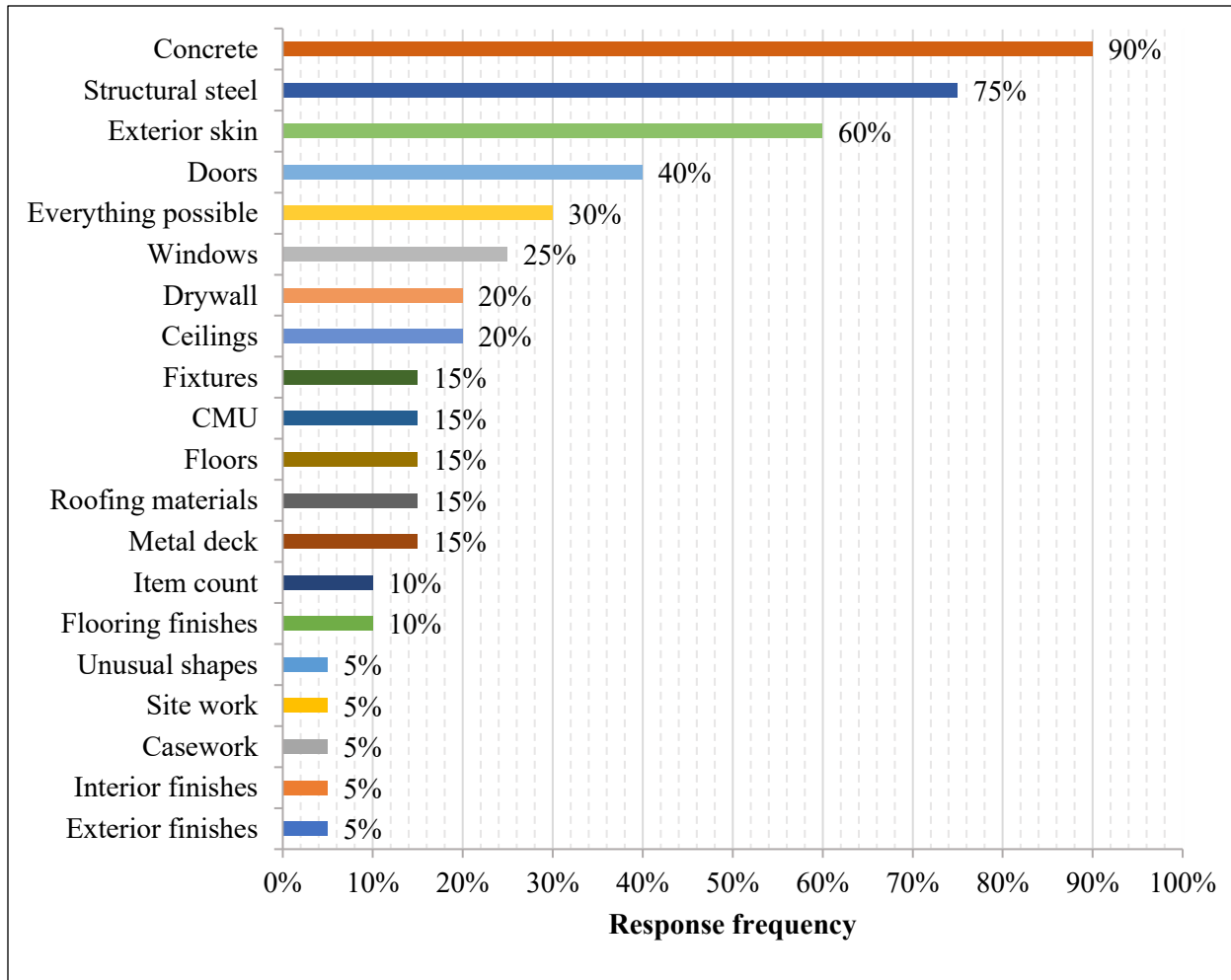
Figure 4-2 Scopes of Work Typically Taken Off Using BIM

Eight participants stressed the fact that the scopes of work taken off depended more on the reliability of the model and the quality of the information it contained than on the scopes they wished to quantify. It had regularly been reported that model-based take-offs varied for each project according to what information was available for take-off in the model. Therefore, this could imply that the structure and exterior skin were modeled in a way that was more useful to estimators than the other scopes of work. It was important to bear in mind that a few respondents only used BIM numbers to cross check values taken off from the 2D set of plans.

As estimators received models, they performed a model quality check to identify which scopes of work were reliable or not. Based on their conclusions, those identified scopes were taken off from the BIM while the other scopes were left to manual take off methods. The reliable scopes varied from one model to another. However, it had been noted by five respondents that as long as the information was available, they attempted to extract it to use what was helpful, and discarded the rest.

4.3.3 Question 3 – Are There Additional Scopes of Work That You Would Like to Take Off from the BIM? What Are They?

Responses to this question yielded 22 categories that were summarized in Figure 4-3. The most recurrent elements were "interior finishes," "MEP," "site work," and "everything possible," even if each one was brought up less than 50% of the time. Eight answer categories were cited 2 or 3 times. Another 8 categories were mentioned only once. It was difficult to identify specific scopes of work that were clearly lacking in the models and useful for most respondents. It seemed that there was no clear vision of what specific scopes would benefit estimators most.

The main reason for wanting to take off the interior finishes (paint, tile, etc.) from the model was because of the tedious and time-consuming process of manually taking off those finishes. It was also reasoned that civil and site work were expensive tasks that entailed some difficulty in accurately identifying the excavation and backfill quantities. An automated QTO could help with the earth work complex geometry.
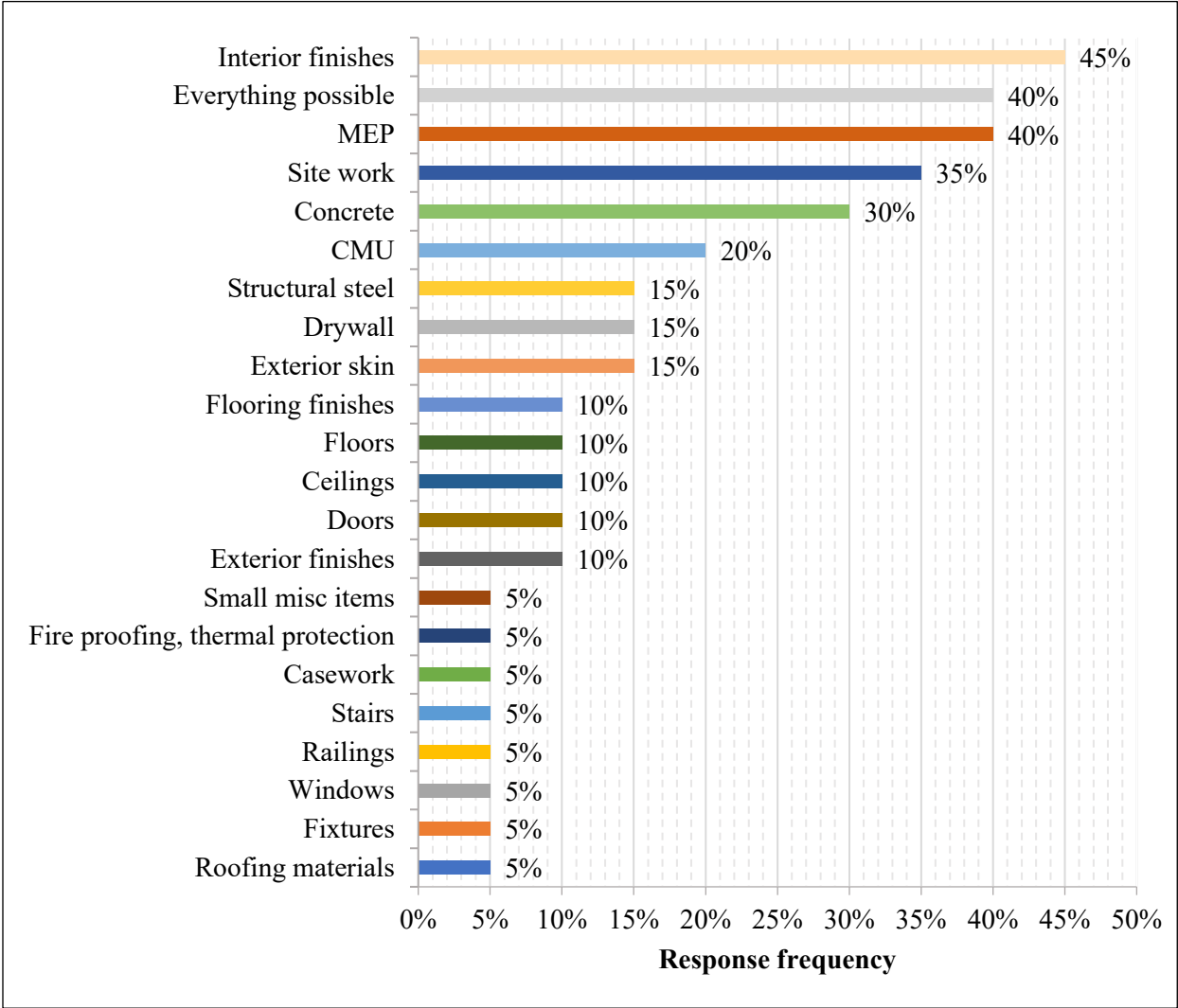
Figure 4-3 Additional Scopes of Work to Take Off Using BIM

It was observed that 7 participants indicated typically taking off a certain scope using the model and also indicated that same scope in the desired scopes to take off. This repetition confirmed that the scopes taken off depended greatly on the quality of the information populated in the model. Although information about a certain part of the job could typically be found in most models, the estimators either wanted that information in every single model or wanted additional information about these scopes of work.

Seven out of twenty participants indicated they wanted to take off everything possible from the model. It was commented that the additional scopes of work that were desired were those not available in the model.

Figure 4-4 brought together on one graph the results of most categories from the two previous graphs (figures 4-2 and 4-3) to visualize the relations between the answers.

In 8 cases (interior finishes, MEP, site work, doors, exterior skin, concrete, structural steel, windows), there was a clear correlation between what estimators wanted to take off from the model compared to what was usually possible to extract. In cases where estimators could not typically extract the necessary information, there was a high demand to do so. The opposite was also visible, yet the gap wasn't as great. For example, although concrete and structural steel were considered as being taken off often, there still remained a fairly high desire to be able to do so. For concrete, the relationship to who performed the work had an impact. From a concrete self-performing general contractor, expectations from the model were higher than for the person who was looking for an overall concrete quantity organized by type (footing, foundation wall, etc.).

One respondent indicated there were no additional scopes of work he wanted to take off. This suggests that for his intents and purposes, BIM QTO was providing him with the necessary information.
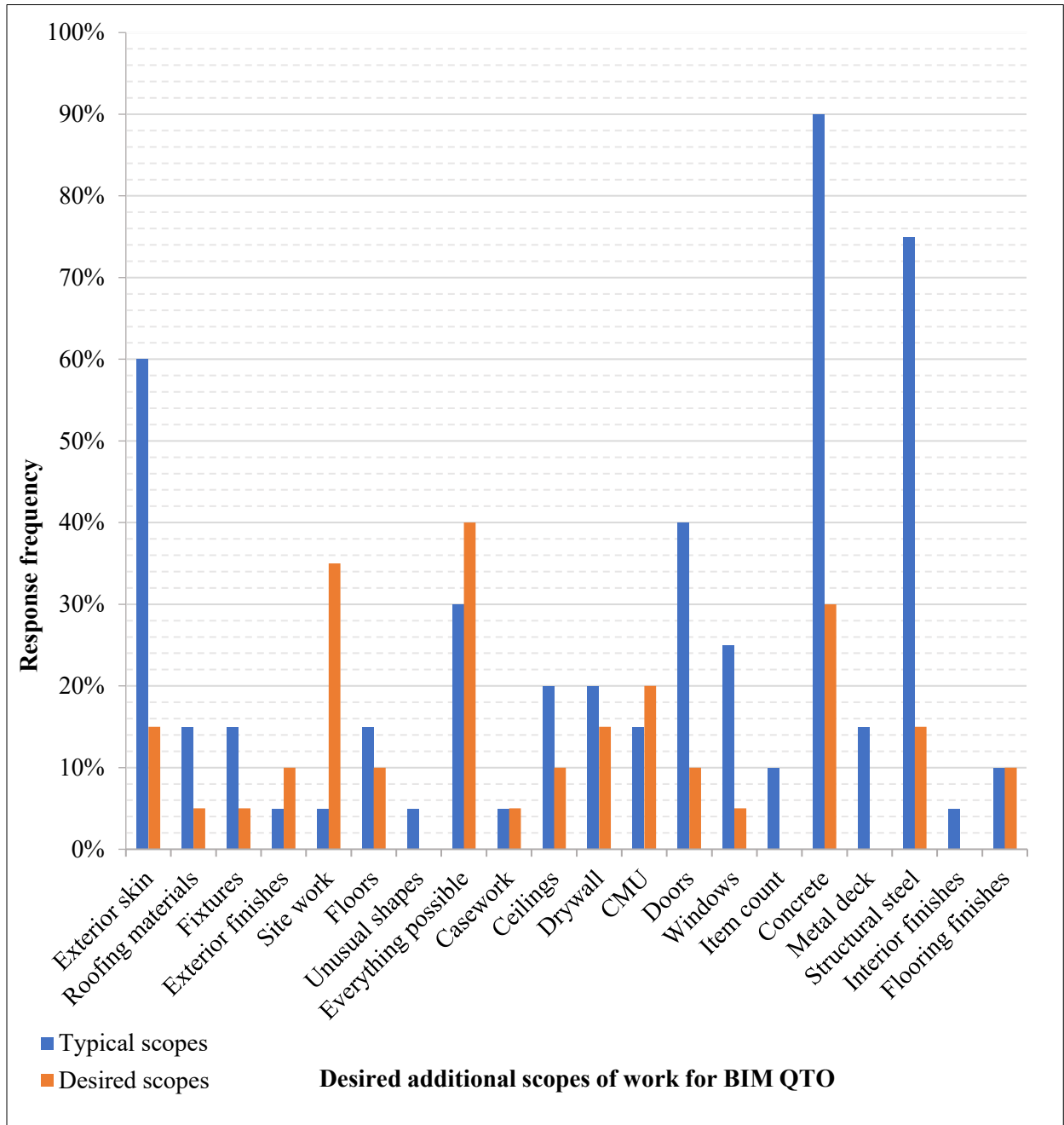
Figure 4-4 Comparison Between Typical and Desired Scopes of Work

4.3.4   Question 4.1 – At Which Design Phase Do You Typically Receive the Model?

The answers provided to this question were sorted into three categories and presented in Figure 4-5.
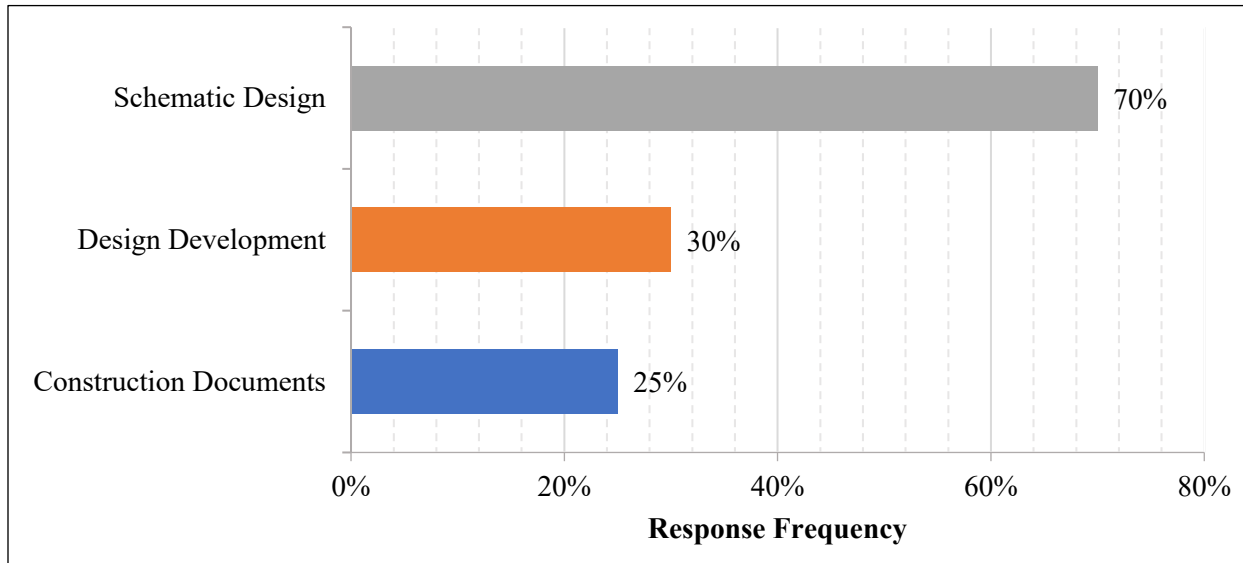
Figure 4-5 Typical Design Phase at Which the Model is Received

A few responses indicated a specific level of completion within a phase (such as 50% Design Development) which was grouped within the overall phase for simplicity. Four respondents indicated more than one phase. This choice was dependent on the contract type they had with the owner. For example, the typical design phase at which the model was received in a DBB contract was at the Construction Documents (CD) stage. However, for CMAR or DB, where the general contractor was involved early in the design process, answers ranged from SD to DD (except for one CD). This aspect showed that the level of completion at which the estimators received the model was at least in part dependent on the contract type. The time at which the owner brought in the general contractor in the design phase also played a role in the time at which the model was received.

It was worth noting that five participants indicated that there had been times where it was difficult to obtain a model at all, particularly in DBB contracts. According to the interviews, that tendency had dramatically improved in the previous year and models were more readily made available to estimators.

Although the Schematic Design (SD) models were most often received, there was a clear consensus among four respondents that they were indeed useful but not specifically for extracting data. Most of the time, it seemed that the model was used for visualization and project understanding purposes during the early stages. Ten other participants, however, indicated taking off certain quantities from the model even at the SD stage. This raised the question of what type of information was necessary for estimators to extract for each phase. The interviews also provided information on two different types of estimates: conceptual estimates and detailed estimates. The model was helpful in either of these two estimates based on its completion phase.

4.3.5   Question 4.2 - At Which Design Phase Would It Be Most Beneficial to Have the Model? Why?

On the topic of the most beneficial design phase to receive the model, the responses were organized in 5 different categories as seen on Figure 4-6.

Eight out of twenty respondents gave more than one answer as benefits of using the model differed according to the project at hand and needs of the estimator. However, one category was distinct from the others as 65% of respondents desired to receive the model as early as possible. Reasons underlying this response included the ability to be aware of the project background to understand the first ideas and evolution of the project, early involvement of the general contractor to provide a more thorough analysis and share their expertise in the early

project stages, better understanding of the overall estimate before changes were made and leveraging the time savings aspect by performing multiple estimate iterations from the successive models.
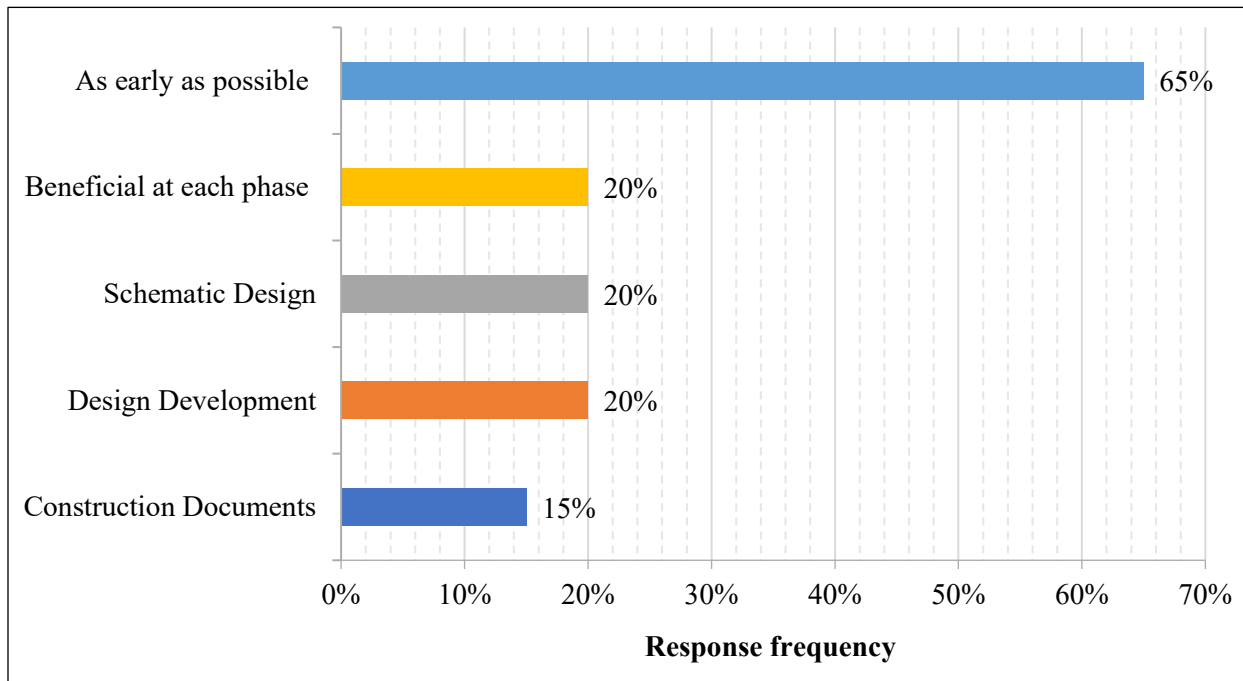
Figure 4-6 Most Beneficial Design Phase at Which to Receive the Model

In addition, it was said that the early model didn't provide many additional benefits as far as taking off quantities since traditional 2D take-offs could be done in the same time frame. However, the model contained valuable information often lacking in the 2D renderings and very schematic plans usually available at the SD phase. The 3D vision allowed to better comprehend the designers' intents even with a low level of detail in the BIM.

The other categories did not emphasize a particular design phase at which the model would be more beneficial. This result could be due to the fact that the definition of "the most beneficial phase" was dependent upon the estimators' needs and the specific project at hand. As

estimators' objectives varied from one project to another, different aspects of the model became more or less useful, which could explain why the answers were almost equally spread among the design phases. Moreover, the fact that 4 participants found the model to be beneficial at each phase confirmed the fact that a model was useful for different reasons as it evolved throughout the design stages.

Generally, based on the comments given in the interviews, it appeared that the most beneficial phases for detailed QTO were found in the DD and CD phases because of the higher level of detail and more complete information available in the models.

4.3.6 Question 5 - Where Would You Like to See BIM QTO Evolving in the Future?

The responses were organized in 9 categories as shown in Figure 4-7.

More than half of the interviewees provided more than one answer. Overall, the hopes of estimators with regard to BIM QTO covered 4 essential areas: software automation (including ease of use by estimators), model quality (information, standardization, timeliness), model as part of the contract documents and designer responsibilities.

In 60% of the interviews, the automation aspect was discussed. Reducing the number of steps to extract the quantities and organize the estimates was the leading desire of the estimators. Their hopes were to simplify and automate the process of taking off quantities and producing the bid for the owner. Participants often mentioned the solution as being a unique platform that would provide both QTO and estimating functionalities, where specific elements selected in the model would also be selected in the cost estimate. This two-way communication between the visual and cost aspects would enable an easier understanding of where the costs lie and reduce steps in the processes. In this category was also included the need to have a more streamlined

communication method to generate reports, which was another aspect of automating the BIM

QTO process.
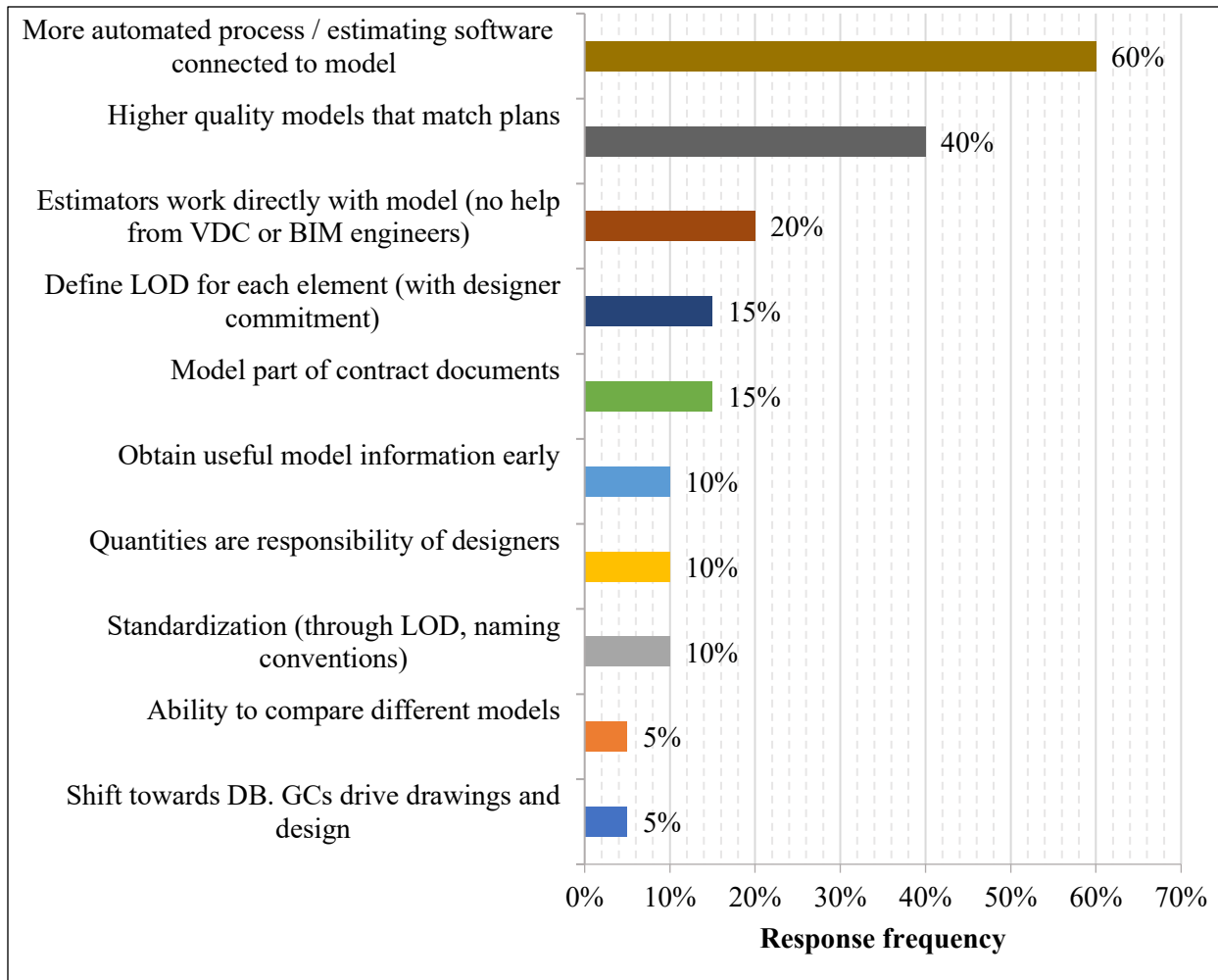
Figure 4-7 BIM QTO Evolution

The automation and process simplification aspects were addressed in the hope of

allowing estimators to extract quantities from the model individually without additional help

from BIM or Virtual Design Construction (VDC) managers. The typical workflow in BIM-based

QTO often involved both estimators and VDC / BIM managers. The VDC / BIM managers

vetted and prepared the model for take-off and the estimators cross-checked the numbers and

added the cost factor to the quantities. The respondents who discussed automation hoped to take advantage of an automated and simplified tool that would allow the estimators to perform their BIM-based QTO and estimates independently.

The second highest wish of estimators for the future of BIM QTO was to see models matching the 2D plans, or in other words, no discrepancies between 2D plans and details and the model which was identified as the main challenge (see paragraph 4.3.7). Aspects related to the model quality were: obtaining the necessary information early enough and standardizing the modeling methods through naming conventions and level of development (LOD) standards. This would be accomplished by creating pre-defined names and requiring certain scopes of work to be modeled to a certain LOD to allow a trustworthy take off of those scopes.

A participant observed that scopes of work at LOD 300 and above could almost systematically be taken off. As an example, structural steel and structural concrete were regularly drawn at LOD 300 or higher by the engineers, which were the most frequent scopes of work taken off (see Figure 4-2). Certain estimators figured that by requesting specific LODs for certain scopes of work, they would be in a position to extract the quantities with little need for model preparation or quantity verification.

To further the topic of model quality, it was reported that if the model were used to generate the 2D sets of drawings and remained the primary source of information throughout the project, the trust in the model's quantities and available information would increase. It was noted that in many cases the model was not regularly updated and that the details were drawn separately on the 2D sheets which brought differences between the plans and the model, thus making the model unreliable.

Three out of the 20 respondents wished to see the model become part of the contract documents. They saw it as a necessary step to help increase the quality of the detail and information contained in the models and minimize differences with the 2D sets of drawings.

A tenth of the participants found it useful to see the designers take ownership of the quantities embedded in their models in the hope of increasing the quality of the model information.

4.3.7 Question 6 – What Challenges Do You Face When Taking Off Quantities from BIM? (Rank the Challenges in Order of Importance)

The responses were organized in 7 categories as presented in Figure 4-8. From a broader perspective, it could be said the results could be assembled in 3 major categories with their subcomponents. These categories were quality and accuracy of the model, estimator commitment to BIM and software and workflow challenges.

The first major category was the quality and accuracy of the model that each respondent mentioned as being a major challenge (ranked first 85% of the time and 2nd 15% of the time). The 3 identified subcomponents were:

- Estimators receive the model too late or not at all

- Model information organization and naming convention – differing between designers and estimators

- Lack of information in the model

Not all respondents specifically mentioned the subcategories. However, it is possible that those who only mentioned model quality and accuracy also had in mind one or several of the 3 more precise descriptions within the model quality definition. It was clear that the greatest

challenge dealt with how the model was designed and how much reliable information could be extracted.
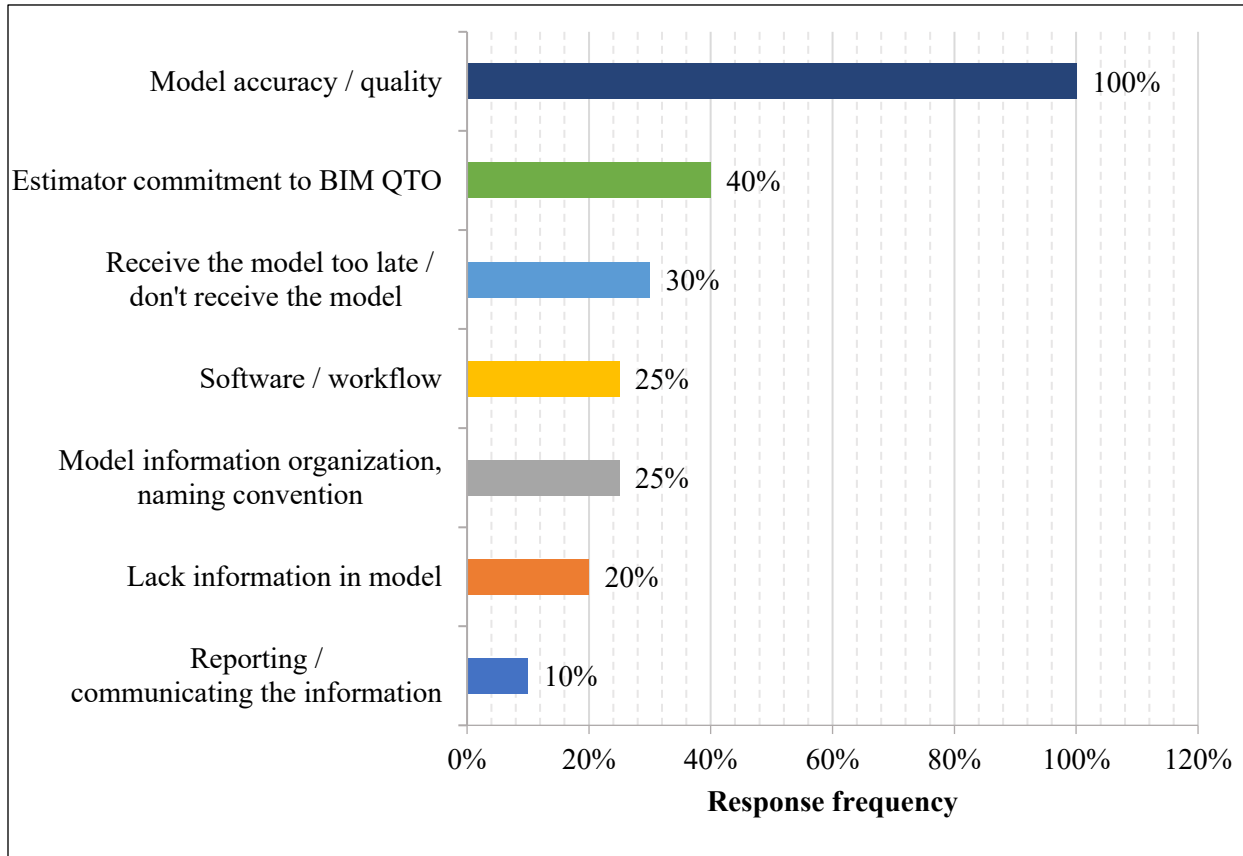
Figure 4-8 BIM QTO Challenges

It was worth noting that the word "trust" was used by 8 respondents with relation to the use of the model for QTO purposes. The fundamental issue was to know what to trust in the model and what not to trust.

The second major category was the estimator commitment to BIM QTO, which was not developed into subcategories. This concern was shared by 40% of the respondents and was ranked 2nd or 3rd in 75% of the responses. It addressed the difficulty of introducing the BIM QTO

technology to the estimating teams who were comfortable with their current QTO techniques and who trusted the numbers they were able to extract from the 2D sets of drawings. According to the discussions, it seemed that the age of the employees and years of experience using a certain technique played an important role in the reluctance or motivation to use a new method. One interviewee responded that the estimators' numbers were their job; they could not afford to risk making mistakes with a new method when they knew that their current system had yielded good results for the 30 previous years. Another stressed the reluctance of estimators to change their process. A third individual underlined people's need for time to understand, accept and figure out the new technology, in addition to the innate reluctance to change their processes and habits.

The third major category addressed the software and workflow challenges. A related subcategory shared by 2 respondents was the reporting and communication aspects of the results drawn from the models. How was the owner to review the model and related contents on his own, without the help of the general contractor?

Beyond the reporting aspect, the overarching concern was the complexity of the software tools available. The introduction of new workflows with new tools brought several challenges linked to the complexity of the model in comparison to the more common computer based 2D take offs. New software skills were necessary to search in the model to identify what was reliable or not and to organize the information for quick future access and quantity comparison. In addition, software expertise was necessary to understand how the software quantified certain materials which differed from the way the estimator calculated the quantities. For example, when taking off quantities of exterior glazing with 2D take-off, the area would include both glass and mullions. In a BIM, glass panels and mullions were two different objects. Therefore, if only panels were quantified, a percentage of the area would be missing in the estimate.

Another aspect related to software was the workflow and interconnection of various take off and estimating tools. As identified in question 5, where respondents desired to see BIM QTO evolving in the future, there was a very clear hope that the process would become more automated and streamlined. This desire was confirmed in the responses about BIM QTO challenges but with less emphasis. This could be due to the fact that the concern had already been addressed in the previous question or that it was to be seen more as a future expectation than as a serious challenge. Of those who considered software / automation as a challenge, the corresponding rankings were from 2nd to 4th place, three being 2nd place, one 3rd place and one 4th place.

Although not specifically chosen and ranked as a challenge to BIM QTO, the topic of the legislation of construction documents was brought up a few times in the interviews, although not specifically as a response to this question. It was mentioned that estimators were still required to do 2D take offs as only the 2D construction documents were considered valid from a legal standpoint. Therefore, relying solely on the model was a risk unless the estimators had a confirmation from the design team that the model was trustworthy for quantity and data extraction.

4.3.8   Question 7 – What Specific Strategies Do You Use to Overcome These Challenges?

The provided results could be divided into 3 groups: those who relied solely on internal methods, where the General Contractor solved the challenges relying on their own resources, without any help or partnership with the design team; the second group relied solely on the design team making changes or adapting their models; and the third group relied on both internal

and external strategies to overcome their BIM QTO challenges. The statistical breakdown is found in Figure 4-9.
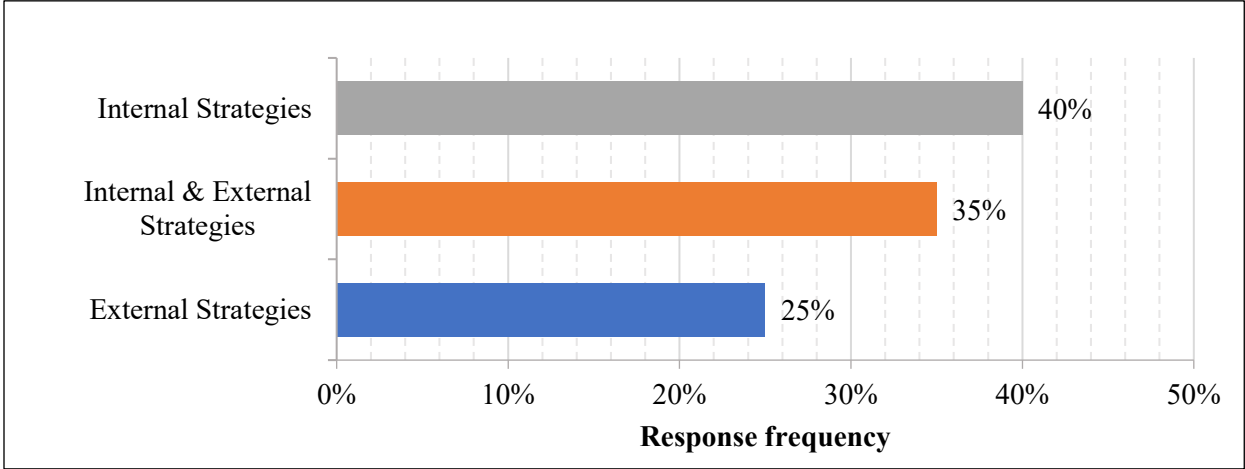
Figure 4-9 Overall Strategy Groups

The group that focused exclusively on internal strategies was the most common, with 40% of the responses. Roughly a third of the respondents relied on working with their teams as well as with the design teams to overcome the challenges listed in the previous section. This group's responses spanned the whole range of specific strategies listed in Figure 4-10.

These types of strategies included, among others, vetting the model, providing BIM QTO training along with some in-house modeling or model adaptation. The smallest group (25%) exclusively asked the design teams to adapt their workflow and modeling techniques to respond to their challenges. Such solutions included discussing the estimators' needs with the design teams in the early phases of the project or along the way, or discussing future needs with the client to ensure that the model contained the necessary information.

The reader should bear in mind that as the interviews were open-ended, it was possible that other solutions were being implemented and that only the most relevant strategies that came to mind at the time of the interview were shared. Moreover, the strategies provided in the answers were general in nature and did not always specifically cover each challenge the respondent had mentioned in the previous question. Had the participants been able to choose from a list of possible solutions, it could have potentially reminded them of certain strategies they were using that they did not specifically address at the time of the interview.

Beyond the 3 general groups, the strategies were organized into 13 categories as shown in Figure 4-10.

The top 6 categories covered aspects such as communication, BIM proficiency and training. The lower half covered a broader variety of topics that were limited to a maximum of 3 respondents, with 4 strategies given only once.

From the provided data, it appeared clearly that communication was the most widespread strategy identified, whether with internal teams or with design teams. The majority of the communication aspect was directed towards the design teams in order for them to better understand what the estimators wanted from the model and what types of changes could be made to simplify the QTO process. Out of the 12 responses directed towards design teams, two of them specifically mentioned the use of a BIM execution plan. Others spoke of kick off meetings and setting standards for the project which could be considered a form of using a BIM execution plan.

Figure 4-10 Strategies to Overcome BIM-Based QTO Challenges
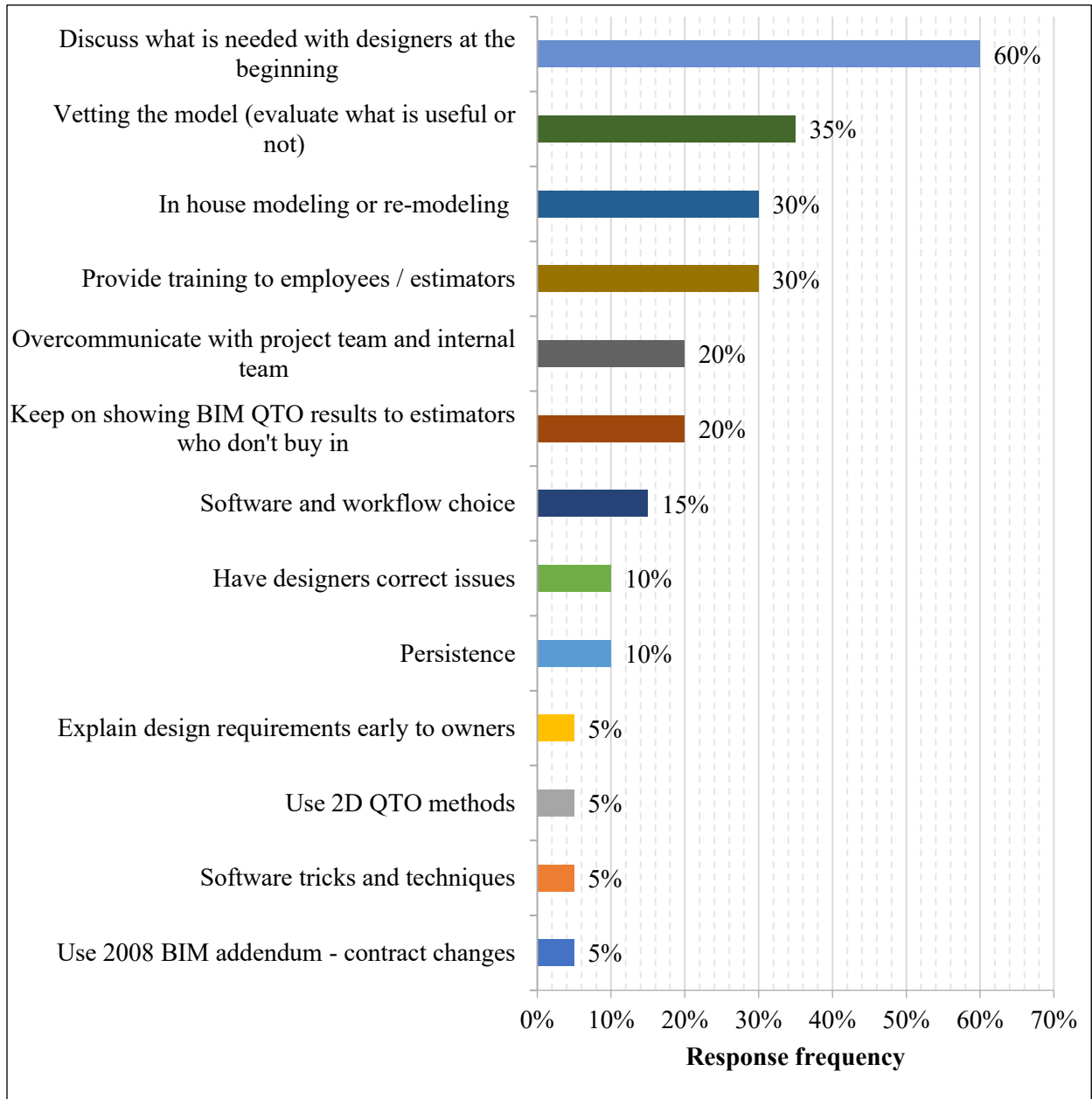
Six responses indicated or implied that early communication with the design team yielded positive results. They stressed the importance of having the right contract type to help in the communication effort. DB was referred to 3 times as being a better delivery method to allow efficient collaboration between the design team and estimators. The key indication that was

shared by all 6 respondents was the need for early involvement. If the general contractor was brought in too late, the design team was reluctant to go back in the model to change the naming conventions or make other changes as requested.

Further communication aspects were directed towards team members to solve the challenge of estimators' resistance to BIM QTO. Repeatedly communicating about the topic and regularly showing BIM QTO results in comparison to traditional take-off results were said to change the mentality. Three individuals indicated that the VDC or BIM managers would show their QTO results to the estimators even without being asked, in order to demonstrate that the results were similar and were retrieved in far less time as through manual take off. This type of attitude showed the commitment and confidence certain respondents had in the technology.

To overcome BIM QTO challenges, it was necessary for estimators to be proficient using models and the related software. Unique skills were required to be able to vet the models that the estimators received from the design teams. Seven individuals addressed the aspect of vetting the model, that is, evaluating which parts of the model could be trusted and which could not. Acquiring those skills was a learning process. Most teams used the VDC or BIM specialists to help identify which information was trustworthy. In some cases, estimators and specialists would get together to evaluate how the model would be used most efficiently. Based on that information, the BIM QTO teams would then do the preparation work to extract the quantities. This preparation could either be re-modeling the project, or working with the technical aspects of the model, such as splitting it, or isolating specific elements to organize the take-off process. In any case, the process required additional work from the General Contractor to allow the model to be profitable.

Finally, among the top 6 categories was the aspect of training. This strategy was referred to 6 times and affected only the internal teams (estimators or BIM / VDC managers). The goal behind this solution was to provide the BIM users with the necessary skills to take advantage the available tools efficiently. More on the topic was provided in the responses to question 8 which are detailed in the next section.

It was interesting to note that two individuals related the importance the company leadership played in providing the necessary tools to overcome the challenges. In those cases, the leaders encouraged BIM QTO to be implemented and were active in providing the necessary training resources to take full advantage of the technology.

4.3.9   Question 8.1 - How Much BIM QTO Training Have You Received?

The answers to how much BIM-based QTO training the respondents received were outlined in Figure 4-11.

It was difficult for each participant to objectively state the number of hours of training provided, therefore, the answers focused essentially on the context of where and how the learning took place. Eleven out of the 20 interviewees gave a figure which was contained between 3 and 100 hours of training. However, some counted the hours spent researching and learning alone, whereas others focused only on official software training provided by the company.
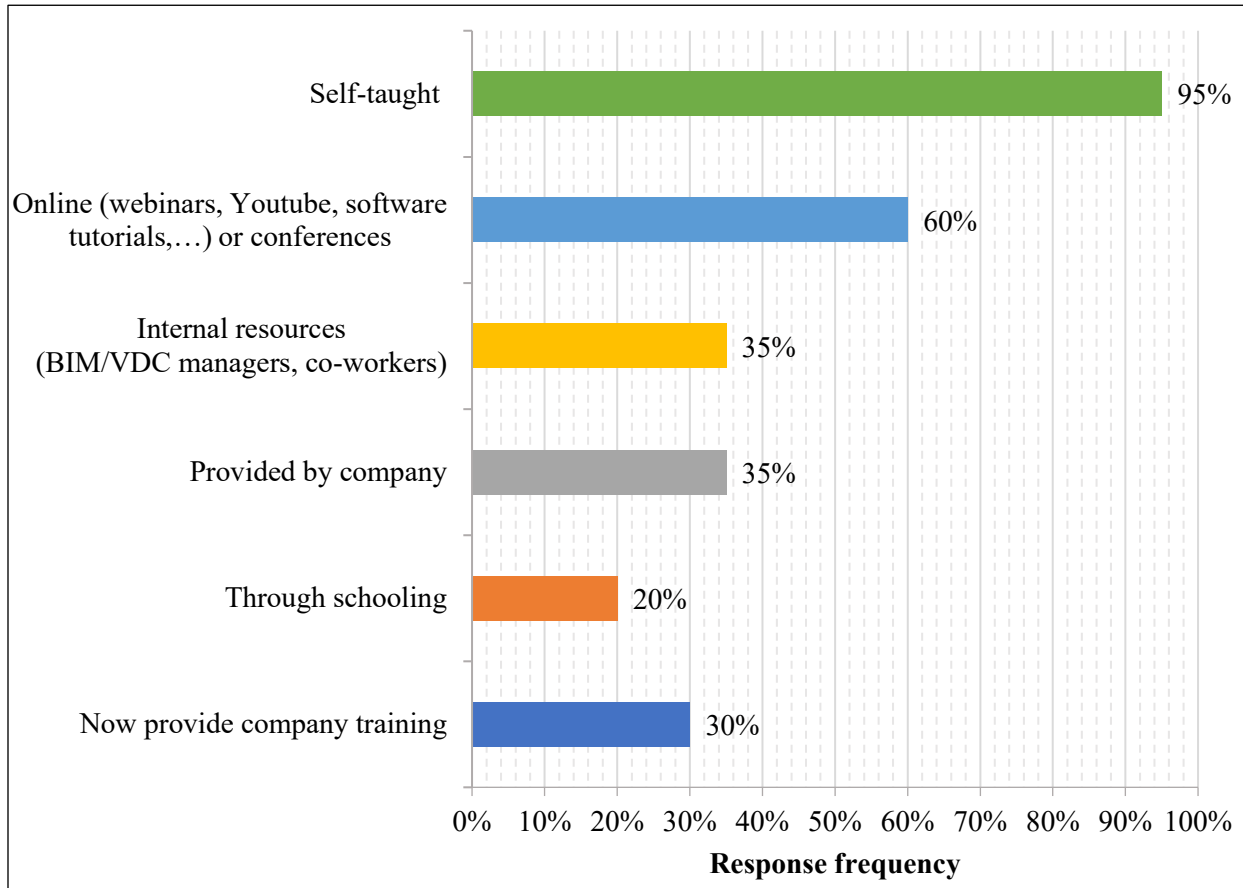
Figure 4-11 BIM QTO Training Received

The results yielded 5 types of responses which detailed how the estimators acquired their BIM QTO skills. It is worth noting that a limited number of resources were available at the time they acquired their skills which would explain why the responses were summarized in 5 categories. One additional category was created to encompass those who indicated that they provided training to other team members. Most respondents provided answers to more than one category.

The highest-ranking category was "self-taught" and was named by each participant but one. Two out of the 19 that were counted in this category had not explicitly said those words, but they were clearly implied in the given answer. Respondents explained that since the technology

was new and not many resources were available, most of the learning took place through trial and error while trying to accomplish certain tasks. Furthermore, this aspect showed the respondents' desire and motivation to learn to perform BIM-based QTO. Those who did not have such motivation were probably not able to learn and probably discarded the idea as it required much self-disciplined work on their part. The individual who did not express learning the tricks and techniques on his own due to lack of time and pressing deadlines was the one who resorted to using the traditional 2D take-off techniques to overcome BIM QTO challenges. It seemed that there was a direct correlation between the estimator's motivation and desire to use BIM for estimation purposes and the dedication to learning the techniques with no or little additional external help.

The second highest ranking category (60%) included indirect training resources through online tutorials, webinars or specialized conferences on the topic of BIM-based estimating and QTO. This category was related to self-learning but described the specific way that education was provided. Proficiency with BIM software came from actively searching for new tutorials and webinars and then spending time implementing the new skills through practice, and trial and error.

A little over a third of the interviewees described receiving training through the company. This training was provided in different ways: some firms hired software companies to train the estimators in specific aspects of BIM software (not always 100% BIM QTO related), some had in-house estimators or BIM / VDC managers provide formal training and, in one case, the company challenged the estimator to learn how to perform BIM-based QTO, allowing him to allocate the necessary time to accomplish that task. Moreover, the same proportion of participants explained that they also sought help through the internal resources (co-workers or

BIM / VDC managers) of the company. Some organizations placed BIM / VDC managers and estimators close together in the office to encourage such collaboration. It was not unusual to hear respondents explain that they often sought help on specific aspects from their colleagues, allowing them to slowly broaden their skillset over time.

A fifth of the participants learned certain BIM QTO skills during their university degree training.

4.3.10 Question 8.2 - On Average, How Much Time Do You Spend Each Month for QTO Related Professional Development?

The answers to this question were summarized in Figure 4-12. Four categories emerged from the shared information. One respondent did not make it into one of those categories as the only provided indication was that the he developed his skills continually. Several others gave similar responses where they developed and polished their skills continually while providing a specific monthly hour estimate as indicated in Figure 4-12.

60% of the answers ranged between one to four hours of personal development a month. In most cases, such development took place irregularly and in sporadic bursts as some respondents attended conferences or took time to learn about a new software coming out. These figures were usually days or hours per year brought down to a monthly basis. The majority of the respondents indicated an average of 1 to 4 hours a month. Only two individuals indicated practicing more, with 6 to 8 hours and 10 to 15 hours a month, respectively.
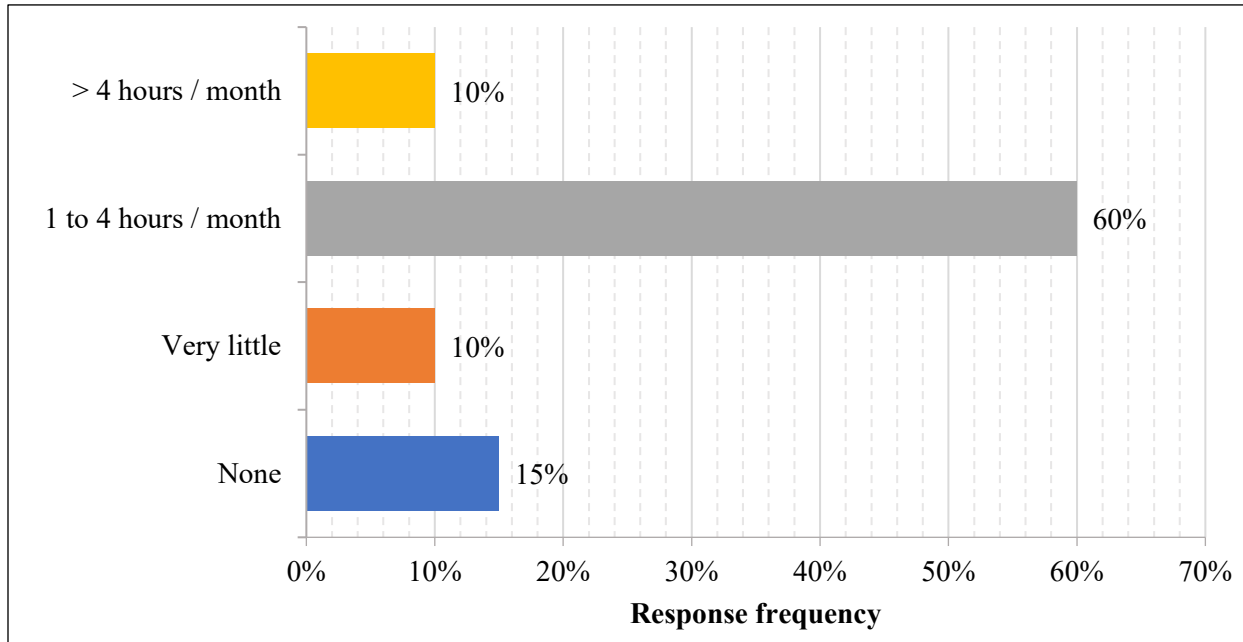
Figure 4-12 Time Spent for BIM QTO Professional Development

Two participants spoke of "very little" which was interpreted as a range between 0 and 1 hour a month in this study. The three respondents who explained that they didn't continue developing their BIM QTO skills indicated that it was because it either wasn't their job responsibility, were too busy with current work to keep up with ongoing training or were waiting for the models' quality to improve before spending additional time on BIM-based QTO.

4.3.11 Question 9 – Which Software Do You Use for BIM QTO?

The responses to question 9 about BIM QTO software were summarized in Figures 4-13 and 4-14. Figure 4-13 outlined which software was referred to by each participant. Sixteen individuals mentioned using more than one software package. Figure 4-14 indicated the frequency of use of the most commonly employed software packages.
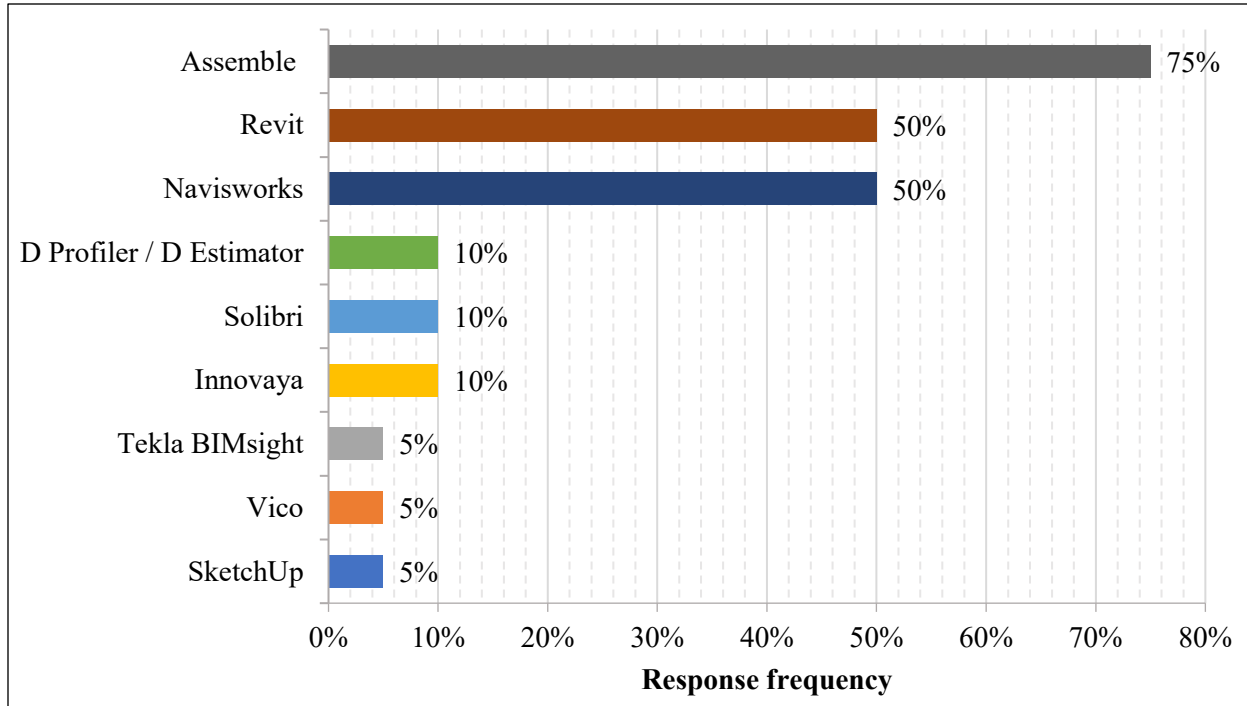
Figure 4-13 Software Packages Used for BIM-Based QTO

Overall, 9 quantity take off software packages were mentioned, out of which three clearly differentiated themselves from the rest. The top 3 were Assemble, Autodesk Navisworks and Autodesk Revit, with Assemble being a step ahead in popularity. The six others were mentioned once or twice.

Assemble's popularity seemed to be essentially due to its ease of use and the short training time required compared to other software packages. It was noted that Assemble was user-friendly whereas Navisworks required more training time and expertise to be able to extract quantities efficiently. Navisworks, however, was identified as allowing more flexibility in selecting and isolating elements in the model. One individual differentiated his own software use and that of the other estimators, indicating that he used a mix of Assemble and Navisworks

whereas the other estimators relied solely on Assemble. This aspect seemed to confirm the necessity of user-friendly software for BIM QTO acceptance by team members.

It was evident that the software choice was in constant evolution. Several respondents had used different software packages in the past and explained regularly testing new ones. The given results were indicative of the software being used at the time the interviews were conducted. It was common for participants to refer to software packages they had worked with in the past but had left behind. The quest for the ideal tools and workflow was felt throughout the discussions.

Two individuals noted that the software choice also depended on the level of detail of the needed estimate. For conceptual estimates, Sketchup and D-Profiler seemed more adequate. For more detailed estimates, the more conventional and powerful tools were used such as Navisworks, Revit or Assemble. Another aspect that came into play was the format of the model file. In some instances where the model had not been created in Revit, specific software packages able to open other file types became necessary.

As identified in figure 4-14, Assemble kept the lead in terms of how much it was used by the different respondents. Although Navisworks and Revit were named by the same number of individuals (10 each), their average use differed widely. Navisworks was 60% more employed than Revit and represented 65% of the use of Assemble.
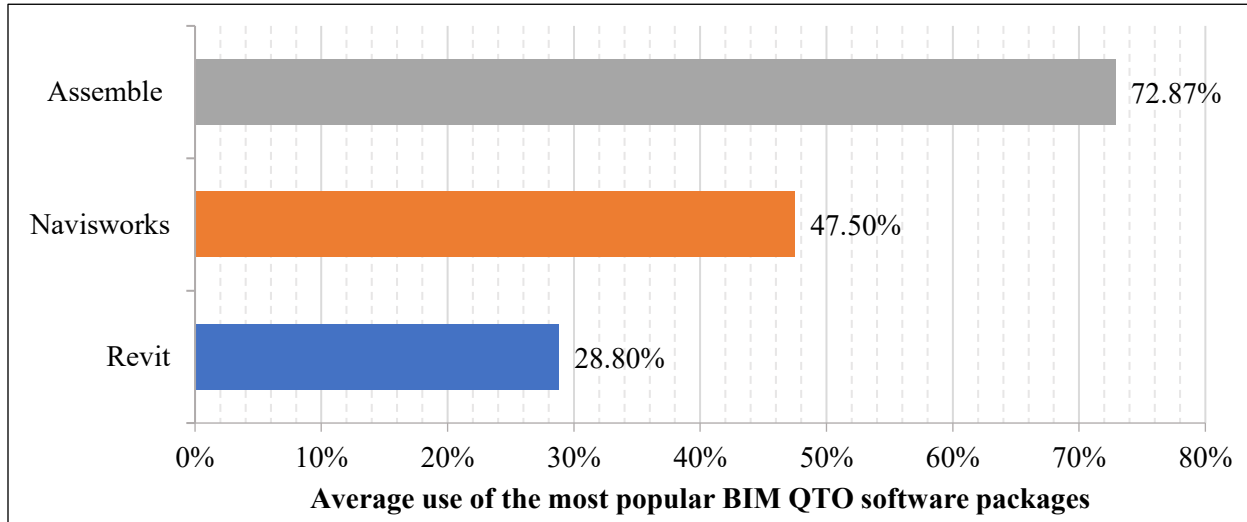
Figure 4-14 Frequency of Use of Top Software Packages

4.3.12 Question 10 - Any Other Thoughts About BIM-Based QTO?

As this was a very open question, responses varied greatly. All but four provided additional information and it was possible to find several trends in the comments that were shared. Five respondents stressed the importance of collaboration between project stakeholders to ensure the success of BIM QTO. Comments ranged from having the designer and GC collaborate early on, to the need for agreement by all the parties on how the model would be used.

Another four individuals expressed confidently the opinion that BIM-based QTO would progress in the years to come and a fraction shared that it was still in its early stages. One indicated that it was the way of the future.

Two participants mentioned the progress they had seen in the quality of the design and of software over the past year or two. It has been said that some architecture firms had caught the

vision and were able to provide the quality the estimators required. However, these were seen as exceptions rather than the norm.

Two individuals observed that the available time provided to designers to design, draw and model projects was too short. As BIM required additional information not always indicated in the 2D documents, the necessary time to produce a model was extended and usually not considered by the owner. Therefore, they suggested that the designers be granted additional time to produce the documents to the required level of detail.

An interesting comment was shared in this section and was also recorded by another participant in response to question 1 on the benefits of BIM-based QTO. Both interviewees noted that the overall costs and number of hours of the estimating department had not diminished with BIM use. This observation was surprising as most participants stressed the increased speed of the process. It was noted that the speed factor contributed to providing more estimate iterations of a project in a given time frame compared to what had been done traditionally. Thus, the quality of the service provided to the owner increased as estimators spent more time on evaluating options and adjusting budgets than on taking off quantities.

4.3.13 Follow Up Question: Rating of Today's BIM-Based QTO Adequacy in Aspects Previously Identified as Challenges

In response to this question, each of the 20 respondents was asked to provide numerical values as asked on a scale from 1 to 10, 10 meaning that BIM QTO was perfectly suited to the task and 1 meaning that it was not at all useful. The rated aspects were: model quality, employee training and skill, implementation costs, software availability and adequacy, employee commitment to BIM estimating and legal and model ownership aspects. All 6 of these challenges

had been identified in the literature as the main difficulties the industry faced with regard to BIM-based QTO and were listed in the question. An additional "other" section was provided to allow respondents to add another category if necessary.

Seven individuals added a few comments to explain their ratings and one of them provided ranges instead of specific numbers as the responses depended on several other factors. In order to simplify the results, each range was averaged to a single number when inserted into the results table.

The averages of the results are found in Figure 4-15. The most challenging aspect according to the respondents was the model quality. The least difficult were the software availability and adequacy aspect along with the implementation costs. The remaining three results with similar scores were: employee training and skill, employee commitment to BIM estimating, and the legal and model ownership aspects. One individual added the "faith/trust in model accuracy" aspect in the "other" section and rated it 1 out of 10.

These trends seemed to confirm the challenge rankings identified in question 6 (what challenges do you face when taking off quantities from BIM?) which essentially covered the model quality, employee commitment and software aspects. An important point about the legal aspect was unveiled in this follow up question. Although it was not specifically mentioned in the open-ended challenge question, it was ranked as the 2nd most impactful challenge in this question. This could be interpreted as respondents seeing a potential relationship between the legal aspects and the model quality. For those who spoke about the topic in other areas of the interview, the jurisdiction aspect was shared as an underlying condition to promote the needed change in model quality.
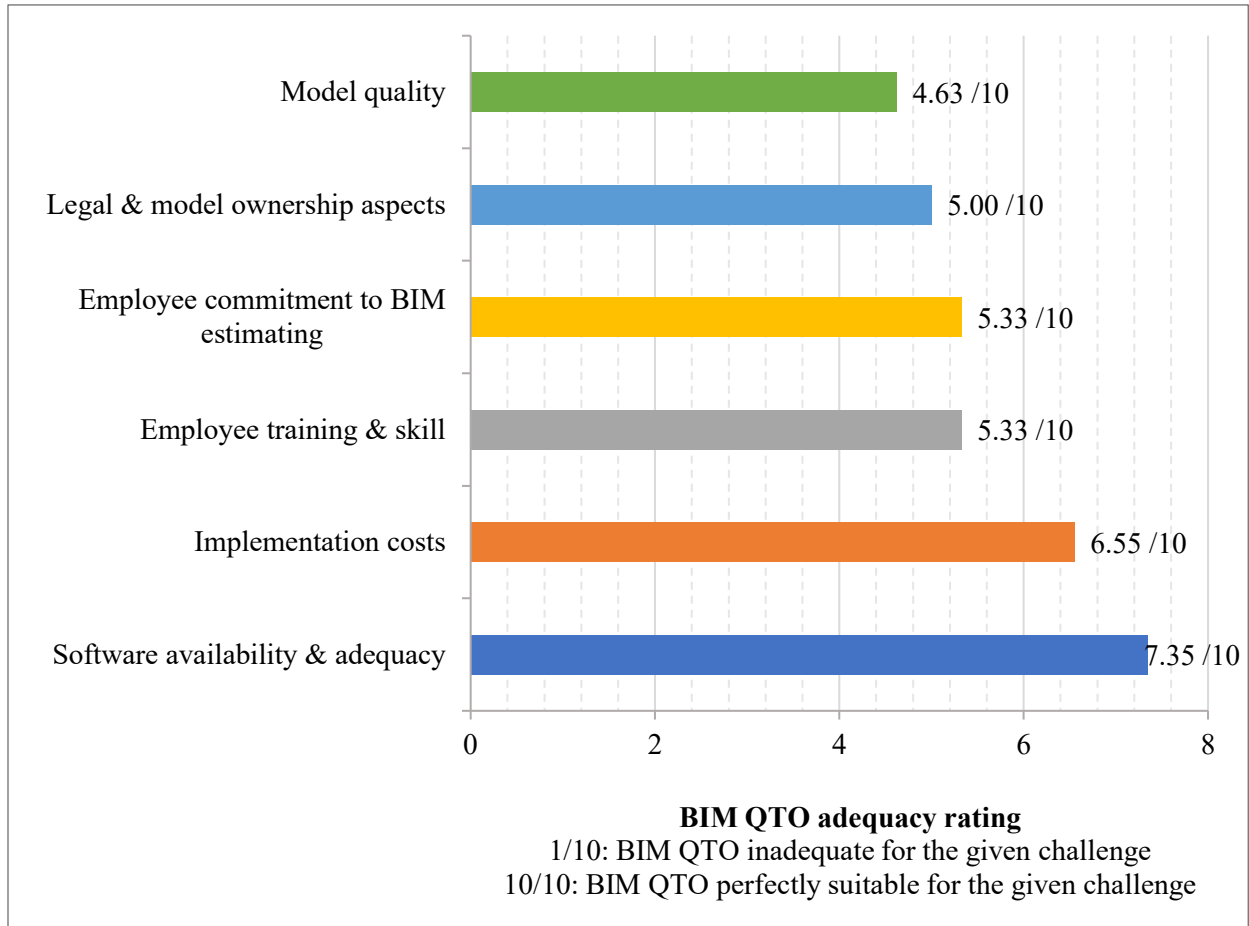
Figure 4-15 Adequacy Rating of Identified Challenges for BIM QTO

Of the seven respondents who shared the reasoning behind their results, the following

insights emerged:

- There was a difference between the estimator's and designer's purpose for the model use. Therefore, it required the estimator to put in a lot of work to obtain a model that would allow to take off quantities.

- It was difficult to find people with the skills to navigate and analyze 3D models. Moreover, there was a clear distinction between BIM and non-BIM people. According to one respondent, all GC employees should know how to use BIM for their tasks.

- Receiving support from the leadership of the estimating department took approximately two years.

- The training aspect should also be directed towards owners and authorities to help them understand the BIM process and benefits it would bring to all parties.

4.3.14 Demographics Survey

The demographics survey asked respondents information about project types and sizes, contract types, individual and company experience in BIM QTO, number of BIM estimators, company yearly revenue and participant's job title.

Six types of project delivery methods were shared by interviewees and were summarized in Figure 4-16. Respondents were asked the following question: of the projects taken off using BIM, what were the contract types? They were asked to choose from a list of project delivery methods and add any other they might have (see appendix A). Most participants indicated having experience with multiple contract types. One respondent added the "competitive sealed proposal" delivery method. All others fit in the four other categories. The Construction Manager / General Contractor (CM/GC) responses were grouped into the CM at Risk category. One respondent specified Design Assist / GMP. This was organized under the Design Assist and CM at Risk groups

Overall, the two most frequent delivery methods used for BIM QTO were CM at Risk and DB in 85% and 70% of the cases, respectively. One participant commented that he worked on only a few DB contracts and that they provided the best experience. References to the quality of the DB project delivery method were made by seven participants in the interview portion of the study.
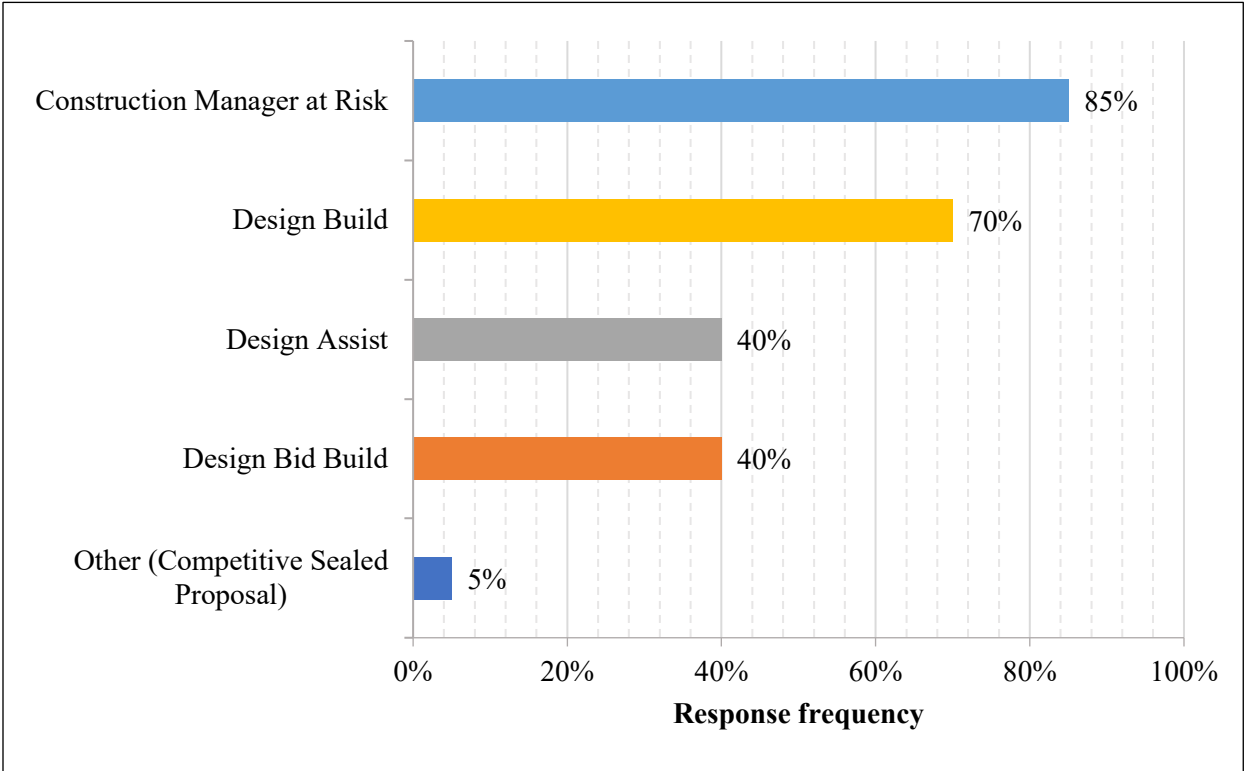
Figure 4-16 Project Delivery Methods

DBB and Design Assist followed with 40% each. Finally, only one respondent provided another delivery method. Competitive Sealed Proposal is similar to a DBB contract but differs in how and when the bids are disclosed.

The answers provided in the demographics survey regarding the time companies and estimators were involved in BIM-based QTO confirmed that the technology was in its early stages. Both companies and participants were using BIM QTO on average about 6 years. There didn't seem to be any specific correlation between the size of the company and the time it had been using BIM QTO. The minimum experience for both company and participants was close to 2 years. A difference was noted on the maximum experience of companies and estimators. The company that used it the longest had 12 years' experience and the most familiar respondent had

been taking off simple volumes for 20 years. The next highest experienced participant was practicing BIM QTO for 10 years.

The survey provided insightful information on what role each participant played in the company. 50% of them had a BIM, VDC or technology related job title (one of which had a joint title as VDC and preconstruction manager). 35% had estimator titles (one of which had a joint title as preconstruction director and chief estimator). 10% were preconstruction managers and the resulting 5% was a database manager who defined his title as being more of a data manager, performing integrations between the estimating software and accounting program. As the interviews progressed, another question about the respondents' background was asked. The goal was to understand what relationship they had with BIM QTO when their title was not technology related. The results showed that of the 50% who did not have a technology title, 60% had a previous BIM/VDC experience or were technology driven, and 40% came from a traditional estimating background.

Figures for the company yearly revenue differed widely. The lowest revenue was $300,000 and the highest was 7 billion dollars. The average was a little over 2 million dollars. No direct correlation was found between the company yearly revenue and experience or number of BIM estimators. Five companies had 25 and above BIM estimators (the highest was 100) and four respondents indicated that they did not know how many were in their company.

The types of projects companies worked on using BIM QTO covered a wide range of buildings such as office spaces, airports, education buildings for every age group, hospitals, medical centers, entertainment facilities, shopping centers, prisons, hospitality buildings and residential among others. Project sizes ranged approximately from 10,000 to 1.7 million square feet, the average being between 135,000 and 765,000 square feet. These findings indicated that

BIM QTO was not limited to specific project types or sizes and covered many different

buildings.

5 CONCLUSIONS

5.1 Conclusions

The problem of the study was that commercial general contractors were reluctant to use BIM for QTO purposes, notwithstanding the time savings and increased accuracy potential. Based on the findings, the following conclusions provide insights on what GCs could implement to alleviate their concerns and make better use of the technology. The following eight areas point to potential solutions.

5.1.1 BIM QTO Speed

The ability to take off quantities faster with BIM-based QTO was almost unanimously stated in this research. 50% of participants added that this benefit depended on the quality of the model. Yet, all respondents agreed that the greatest or second to greatest BIM QTO challenge was the quality and accuracy of the model they received from design teams, whether the model was absent, incomplete, or the properties and objects weren't properly labeled.

Based on these findings, it could be assumed that the most valuable strategy to both leverage the speed benefit and overcome the main challenge of model quality would be to address the issue with those who create the models, the designers. However, the contracts didn't always provide the adequate framework to enable estimators to collaborate efficiently with the design teams. One respondent mentioned the necessity of meeting with the owner early in the

process to guide and show him how to set up the contractual aspects with the designers. Such a discussion would be useful to establish what type of deliverables and model level of detail would be required to enable a more efficient project management. Thus, the owner would be in a position to select the appropriate contract, state the general contractor's needs to the design teams to enable an early collaborative approach to the project.

The strategies to overcome challenges exposed in question 7 showed that 40% of the respondents relied solely on internal measures to overcome difficulties (training, model vetting, etc.). Although these aspects were essential to become more efficient in model navigation and quantity extraction, the data pointed to the greater necessity of communicating and setting standards between the designers and the general contractor at the beginning of the project. This was referred to several times as the BIM execution plan or the kick off meeting. Such discussions didn't always produce the desired outcome since the relationship between general contractors and design teams often depended on the contractual link between them. It has been said that DB contracts were the most efficient (see paragraph 5.1.2).

It was reported that the model preparation work was time consuming. The first BIM-based quantity take-off seemed to take more time than 2D take-off. However, for multiple iterations, once the parameters were set up according to the estimators needs, the quantities of the updated model were extracted almost automatically. It was indicated that the time savings were made on the long run and not on the first QTO. This showed that collaborative contracts with early GC involvement benefited most from this technique. A respondent shared an example of how he leveraged the speed component for efficient value engineering. During the later stages of design, the general contractor gathered the owner, the designers and the main subcontractors over a period of 3 days. Options were brought forth by the different participants and integrated in

the model. At the end of the day, the estimator would extract the quantities and create the updated budget to show the team the next morning. This process lasted 3 days and resulted in several lower budget options being proposed and accepted by the owner. According to the respondent, the process saved roughly 6 weeks of traditional value engineering coordination, with information going back and forth between team members traditionally through e-mail and other means.

To summarize this point, the author would recommend working early with both owners and designers to communicate the estimators' needs. This would benefit the owner in the end with faster estimate iterations, improved design and budget mastery before the construction begins. The owners choose the delivery method and decide when to involve the general contractor. They also dictate what type of deliverables the designer should produce. The designer has the ability to create the models with the necessary data, with the appropriate naming conventions as long as that information is communicated early. Data provided by respondents showed that design teams' model quality had improved because of estimators' early communication of what the model would be used for and how the design team could help in automating that process.

5.1.2 Project Delivery Method

From the research standpoint, information on the project delivery method was only asked for in the demographics survey to provide general background information. However, several important references to the contract choice were addressed by the participants during the interview phase which showed its impact on the BIM QTO process.

The project delivery method provided the framework in which stakeholders would participate in the project. There was a recurring indication that early general contractor involvement was a necessary component to succeed with BIM-based QTO. Design Assist, CM at Risk and Design Build each allowed early involvement of the estimator and yet, their efficiency varied.

Seven individuals made positive references to DB contracts for BIM QTO purposes. It was usually much easier to receive models in the early design phases with DB contracts compared to other delivery methods. Since the architect and general contractor worked together as a team, estimators had more say on what deliverables were needed when. One respondent's wish when answering question 5 was to work more with DB contracts.

Additionally, one participant emphasized that BIM execution plans worked more efficiently in a DB framework. Working with a contract that bound the architect and the general contractor forced collaboration. Another individual stated that with non-negotiated contracts, the estimators were "at the mercy of the architect of what is in the model and when they want to give it." A third participant emphasized that he would create assemblies with the architect early. At the end of an interview, one of the interviewees summed up what in his opinion were the two essential aspects to ensure the success of BIM-based QTO: first, choosing the right contract, either IPD or DB. Second, ensuring all stakeholders understood what the estimator was doing with the model and why. In other words, it was vital to communicate clearly within the appropriate project delivery method for BIM QTO to be successful.

5.1.3 Design Phase and Estimate Detail Level

Based on the discussions, the two types of estimates general contractors produced were the conceptual estimate and detailed bid. Additionally, the three specific design phases that were indicated were Schematic Design (including procurement and intent documents), Design Development and Construction Documents.

When asked which phase would be most beneficial for BIM QTO, 65% wished to have the model as early as possible. The remaining answers were scattered between each of the three phases or indicated that each phase was beneficial. Some respondents indicated that there was much more information to be drawn from the DD and CD phases because the models were more complete. Yet, most asked for the model as early as possible.

This variety of responses indicated that the model served several purposes, not simply that of extracting quantities. Early models allowed the estimators to understand the designers' intents, see the project evolution and visualize in 3D. Some found quantity extraction useful at that stage while others stated that such information would be taken off more efficiently from 2D plans. An important point that was mentioned was that SD models were useful for conceptual estimates. Four participants mentioned creating simple models through the D-Profiler software to obtain early BIM-based estimates. The DD and CD models were at times considered most beneficial because more complete and therefore more useful for detailed estimates.

It was mentioned how subcontractors, specifically for the MEP trades, modeled their scope of work entirely to the level of detail of shop drawings. This process was beneficial to them as they were able to make efficient use of the model by extracting valuable and accurate quantities for the cost estimate as well as use those numbers to order the materials. Furthermore,

these drawings were used to perform the work. It should be noted that the end goal of the work to be performed should dictate to what level of detail the model should be designed.

The essential conclusion to be drawn from these indications was that the use of the model differed depending on the level of detail required in the estimate. Just as it would not be reasonable to have detailed quantities available in SD documents, the same should be expected of models. Additionally, an efficient use of the model depended on the time at which the estimators received it. The date at which the model was received by the general contractor was dependent on the owner's decision and the contract type.

In order to leverage the benefits of the model, its use should be defined in the BIM execution plan as the result of a discussion between the owner, designers and estimators. Questions to consider would be: How many estimates are necessary for the owner? What types of estimates are required (conceptual, detailed or other)? At what point in time will those estimates need to be delivered? What information would be most efficiently taken off from the model for each different estimate? What level of development is useful for each estimate?

Without early concerted and coordinated effort between project participants, the data contained in the model at the different stages of development will most likely reflect the needs of those creating it, which differ from the many different applications necessary for the overall team.

5.1.4 Taking Advantage of What Each Model Has to Offer

Understanding what to expect from a model was a recurrent theme. It was found as an answer to questions about training, most beneficial design phase, BIM QTO benefits and others. An important concept that was discussed was that although no general modeling standard could

be found, each model was useful to estimators, whether it be solely for visualization purposes or if several scopes of work could adequately be taken off.

One participant summarized it this way: "it's never all or nothing. Some people see one thing wrong in the model and consider the whole thing untrustable." Another stated that if estimators were faced with a model that did not provide the quantities as needed and could not perform the take off with a simple click of the button, they would probably never implement BIM QTO.

In contrast, efficient BIM users understood that they should rely on those aspects in the model that were most useful. For some models, it was one or several specific scopes of work. For others, only the visualization aspect was helpful. Some respondents used the model to double-check their 2D QTO numbers. In its current stage, BIM QTO should be used as an additional tool to traditional take offs, not as a substitute. With this understanding, the estimator should use the model in the way that would be most appropriate for each specific project. The trends expressed in the data indicated that over time, through early and meaningful collaboration between general contractors, owners and design teams, the model would become more valuable as information is named, organized and detailed according to BIM execution plans.

5.1.5   Legal Aspects, Jurisdictions

References to the legal and ownership aspects of models were relatively few compared to all the other data that was discussed. This aspect was not clearly expressed in the challenges portion of the discussion. It was mentioned by three respondents in the BIM evolution question (question 5). According to the study of previous literature, the legal and model ownership issue was ranked as one of the six main challenges to BIM estimating implementation.

In the follow up question, the legal challenge was rated 2ⁿᵈ in order of importance, behind the model quality issue, and judged more of a challenge than employee commitment or training. The difference between the relative low interest in the legal aspect, mentioned by only a few during the interviews and the ratings in the follow up question raised several questions as to the impact legal requirements would have on BIM QTO.

It was indicated that jurisdictions relied solely on 2D documents. With regard to BIM QTO, this brought the following challenge: the designers were legally liable for the information contained in the 2D documents only. Any quantity error extracted from the model would be the estimator's responsibility, not the designer's. The risk of BIM QTO rested on the estimator and not on the designer. For example, when extracting drywall quantities from 2D documents, there is usually little room for interpretation. However, extracting that same information from a model where parameters aren't set in an organized fashion could lead to serious quantity differences. The designer would not be liable for those differences because he had no responsibility for the manner in which the information was integrated in the model as long as the 2D drawings showed the needed measurements.

Model quality being the main challenge, some discussion covered the topic of the relationship between the model and the 2D documents. It was said that models were more reliable when the 2D plans were directly extracted from them. Problems arose when a model was created separately from the 2D plans, without a constant link between the two.

Overall, three respondents voiced the opinion that making the model an integral part of the contract documents was a necessary step to improve model quality. This type of action was similar to those who recommended speaking with the owner early and setting the right type of contract to better guide the designers in the necessary deliverables for efficient BIM QTO. It can

be assumed they hoped that by making the model a mandatory deliverable, less effort would be required of the general contractor to initiate early collaboration.

Integrating the model in the legal documents would be a helpful step to encourage designers to keep an updated version of the model which would correspond to the 2D documents. For example, seven participants agreed that the DB delivery method maximized the use of the model, since the contract framework brought estimators and designers together early in the design process and allowed estimators to indicate what they needed from the model. But having the model as a part of the legal documents would probably not be a substitute for the other important coordination aspects that were necessary for efficient communication with the owner and general contractor. It should be considered as one of the several useful components that would make BIM QTO more efficient.

Designing and organizing a model to efficiently extract quantities also necessitated specific coordination through a BIM execution plan to answer all the specific questions of the level of development of specific scopes of work, when the model will be updated, at what frequency, etc. This provided the framework to discuss and plan the ways in which the model would be used. Jurisdictions alone would probably not provide all the answers to individual project needs.

5.1.6 Software and Workflow

Responses regarding the available software presented interesting data. Two indicators pointed out that software and workflow seemed to be a minor challenge in comparison to other BIM QTO hindrances. The first indicator was that 25% of respondents mentioned software and workflow as one of the challenges of using BIM QTO. The second indicator was found in the

follow up question. The "software availability and adequacy" issue was ranked as being the least challenging among the 5 other suggested difficulties. These responses gave the impression that the software and workflow challenges were minor in relation to other difficulties needing attention.

Yet, 60% of the respondents in their answers to question 5 about where estimators wanted to see BIM QTO evolving in the future, referred to improvements in the software automation aspects. These findings could be interpreted in two ways. First, the available software automation aspects did not provide the estimators with the necessary tools to work efficiently. The second interpretation which the author believed to be the most likely, would be that these aspects were addressed more as a wish and not as a necessity, as other difficulties were more relevant. Moreover, it was specified several times that the quality of the available software had improved dramatically over several previous years. It was probable that estimators felt optimistic about the chances of witnessing workflow improvements in the upcoming years as past trends showed sustained progress. Therefore, their hopes naturally tended to see something improve that they believed could be overcome in a short period of time.

5.1.7   BIM QTO Training and Leadership Support

The participants of this study should be considered as BIM QTO pioneers in the sense that 95% of them were self-taught. Their training came essentially through their own use of the available tools and online resources as they became available. Several of them referred to help from internal BIM-users, receiving company sponsored training or some instruction in their post-secondary education.

It was interesting to note that 30% indicated that they provided the company training at the time of the interview. That response was shared without being asked specifically, which indicated that the number might have been higher. One individual was specifically hired by his firm to develop and train employees in BIM-based QTO.

Most estimators indicated that no formal BIM QTO training was available in previous years and that they learned through trial and error. Most training essentially covered how to use specific BIM software, but not the overall BIM QTO processes, tricks and techniques. However, it appeared that at the time of the study, the tendency was changing as the first generation of BIM-estimating trainers were providing official BIM QTO training to the teams. Some taught specific classes that were being implemented to help estimators use models and learn about the tricks and pitfalls of BIM QTO, not only demonstrating the software's QTO capabilities.

Although the topic was not directly addressed in the interview questions, the impact of leadership was discussed. In the instances where leadership was involved (whether reluctant or in favor of BIM QTO), it was observed that the level of implementation was a direct result. A case was reported where younger estimators who could more readily use BIM estimating weren't doing so to please their supervisors who were older and not familiar with the technology. A similar situation was also shared where young technology-driven estimators were not able to embrace BIM QTO because of the current leadership that had over 30 years of experience and was not willing to take the risk of changing their current methods. Another respondent indicated that it took roughly 2 years to receive support from the leadership for BIM QTO. One individual felt the difference between his current and previous employer. In his previous position, he had no support from the leadership and felt the push back from the estimating team. The position he

held at the time of the interview had been specifically designed for him to develop BIM QTO. He provided training and support to the estimating team in all BIM QTO aspects.

As an answer to the question about why a particular company had far more BIM estimators than the average comparison companies, one respondent indicated that the company leadership was driving BIM QTO implementation and development. The leadership of that company pushed the use of BIM and VDC "all across the board." It was worth noting that the author interviewed two employees from that company, the first being a VDC engineer and the second being of a traditional estimating background, but using BIM QTO nonetheless, although to a lesser degree than that of the VDC engineer.

5.1.8   BIM Estimator Profile and Attitude

At the time of the study, it was apparent that the roles of the BIM/VDC managers differed from traditional estimators. Several workflows were identified. In some cases, both estimators and BIM/VDC managers would extract the quantities on their own; the BIM users would then show their results to compare with the estimators'. This process was seen where the estimators' confidence in BIM QTO was very low and BIM managers wanted to demonstrate the benefits of BIM-based QTO. In other cases, both parties would come together at the beginning of the project to identify what could be extracted efficiently through the model and what should be taken off from the 2D documents. A third workflow suggested having the BIM specialists prepare the model and hand it over to the estimators to perform the quantity extraction aspect. These examples demonstrated how several skill sets were needed to manipulate models and work with them.

During the interviews and through the written answers that were sometimes provided in the follow up question, the author sensed the respondents' motivation towards BIM-based QTO. There were also clear distinctions in the follow up question ratings which showed that there were large discrepancies in the perception of BIM QTO adequacy towards the listed challenges. Moreover, the answers provided to question 7 on the topic of specific strategies to overcome challenges gave some indication of the respondents' motivation to make progress with regard to BIM QTO.

To analyze and quantify the attitude differences, the results of the follow up question were separated according to the respondents' position and relationship to technology. From the demographics survey, 3 types of profiles emerged: those with a traditional estimating background (4 respondents), those that were currently associated with a BIM or VDC title (10 respondents) and those who either previously had a BIM or VDC title or were technology driven (6). The ratings to the 6 main challenges were compared along with an additional category which calculated the average of the ratings per person.

The results are summarized in Figure 5-1. Although the sample was very low to be able to draw statistical conclusions (20 individuals), it nonetheless provided interesting trends. The group that was technology driven, or which had previously worked regularly with BIM, scored highest on average (over 1.1 points in comparison to the traditional estimators). In addition, this group was very positive on the software availability and adequacy, and implementation costs (8.00 and 7.00 out of ten respectively).
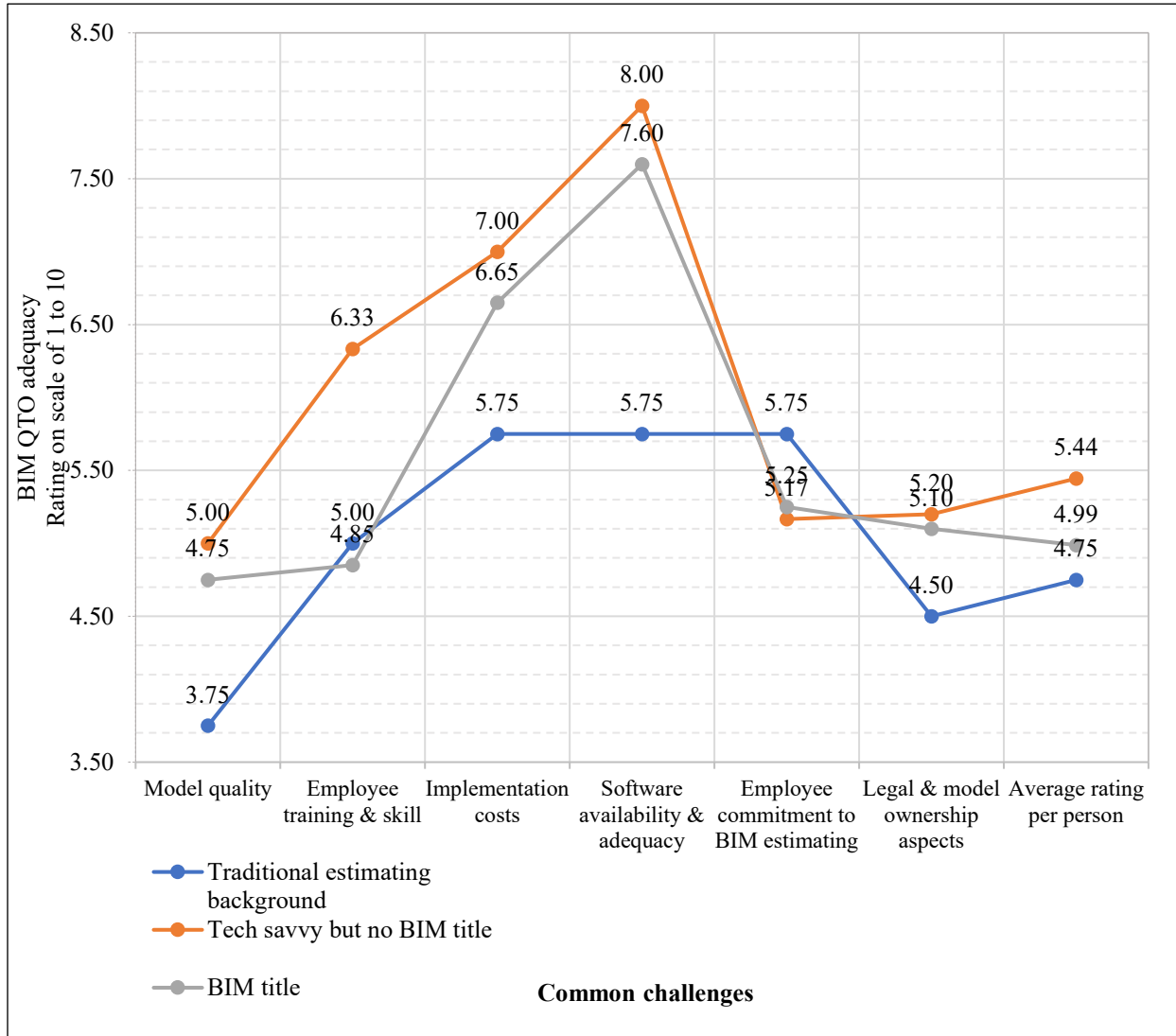
Figure 5-1 Adequacy Rating of Identified Challenges for BIM QTO According to Profile

In contrast, the participants that had a traditional estimating background had the lowest overall rating average per person and gave substantially lower grades in the model quality, implementation costs and software availability and adequacy categories. The highest score for any given category did not exceed 5.75 out of ten. The lowest went as far as 3.75 for the model quality aspect.

Those currently working with a BIM or VDC title usually scored in between both groups but were a little under the technology driven group, except for both employee-related challenges. It is important to bear in mind that all those who were interviewed used BIM regularly for their quantity take-offs, even if only for visualization purposes or to cross check numbers. The survey participants with a traditional estimating background were still more BIM-oriented than average industry estimators.

The participants' number of years of experience in BIM QTO followed a similar pattern. Those who had a BIM title or were technology driven had an average of 6.63 and 6 years respectively. Those with a traditional estimating background averaged 2.75 years of experience in BIM QTO.

Several comments pointed towards a motivation difference between those that were comfortable with BIM-based work and those that were not as comfortable. One respondent stated that if people didn't understand how to navigate or analyze 3D models, they tended to avoid them altogether. Another stated that some employees that were trained in BIM QTO retained the skills and some did not. This could be linked to how much time those employees spent working with the model following the training. A third believed that it should be the employee's personal choice to become BIM proficient, and not only company-driven.

The responses to the BIM QTO professional development question were analyzed to find if a similar correlation existed between the time spent to try to improve the process and the estimators' attitude and commitment to the technology. No correlation was found to support the hypothesis that those least committed to BIM QTO spent less time honing their BIM QTO skills. In fact, the traditional estimators spent more time than those with a BIM/VDC title. Moreover,

those that were technology driven spent on average twice the time the traditional background estimators devoted to those tasks.

Based on the follow up question responses and several comments throughout the interviews, it seemed that those whose current title or current interests related to the BIM QTO tools were those that were personally self-driven and passionate about the tool. Several of them had become the company BIM QTO trainer. Some yearned for leaner and more automated systems to become more efficient. It was evident that they tried to make the most of the available software packages and often looked for new and better techniques to increase their efficiency notwithstanding the challenges they faced. They were at times pushing this new technique despite reluctance from estimators, supervisors and executives. The personal drive and passion seemed to be the main factor that led them to keep improving the available tools and processes. Individuals with these types of profiles will certainly be the ones that will bring BIM QTO to the next level in the upcoming years.

5.2 Recommendations for Future Research

The research raised additional questions and topics related to BIM quantity take offs that would require further study. The topics are listed below:

- What are the architects' and engineers' views on the topic of BIM QTO and what difficulties might they face in changing their BIM design methods?

- How useful is BIM QTO for the trades? Can it provide the needed level of detail for their purposes while increasing efficiency and profit?

- What can be learned from MEP trades that use detailed models to quantify and order materials? What type of systems and training do they provide to their employees? What could general contractors learn from their methods?

- A thorough examination of the influence of leadership in the BIM implementation process would shed some light on how to implement a new technology and manage internal change.

- A more thorough investigation of the impact jurisdictions would have on BIM QTO if models were required to be part of the contract documents would be interesting.

- How would challenges to BIM-based QTO and strategies differ between a conceptual and detailed estimate?

- A deeper analysis of the correlation between estimator attitude to BIM QTO and the success of the technology.

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APPENDICES

APPENDIX A.　　　DEMOGRAPHICS SURVEY

1. What project types (ie: office, hospital, warehouse, ...) and sizes (approximate square footage) have you taken off using the quantities from BIM?

2. Of the projects taken off using BIM, what was/were the contract type(s) (Design Bid Build, Design Build, CMGC, CM at Risk, Design Assist, other: please specify)?

3. For how long has the company been involved in BIM-based quantity take-off?

4. How many years of experience do you have using BIM in quantity take-offs?

5. Approximately how many estimators use BIM
   a. in your office?
   b. in the company?

6. What is the approximate company yearly revenue?

7. What is your job title?

APPENDIX B.   INTERVIEW QUESTIONS

Interview questions: (these questions do not need to be answered in writing. We will cover them during our online discussion).

1. What are the benefits of BIM-based quantity take-offs (QTO)?
2. Which scopes of work do you typically take-off from the BIM?
3. Are there additional scopes of work that you would like to take-off from BIM?
    a. What are they?
4. Model design phase:
    a. At which design phase do you typically receive the model from the designer?
    b. At which design phase would it be most beneficial to have the model? Why?
5. Where would you like see BIM QTO evolving in the future?
6. What challenges do you face when taking off quantities from BIM?
    a. Are the items you just provided, ranked in order of importance?
    b. If not, how would you rank them?
7. What specific strategies do you use to overcome these challenges?
8. BIM QTO training:
    a. How much BIM QTO training have you received?
    b. On average, how much time do you spend each month for QTO related professional development?
9. Which software do you use for BIM QTO?
    a. If you use multiple software packages, please assign the percentage of use of each type.
10. Any other thoughts about BIM-based QTO?

APPENDIX C.   FOLLOW UP QUESTION

How would you rate today's BIM based QTO adequacy in the following aspects (on a scale from 1 to 10, 1 being inadequate and 10 meaning the aspect is perfectly suitable for your needs)?

1. Model quality

2. Employee training and skill

3. Implementation costs

4. Software availability and adequacy

5. Employee commitment to BIM estimating

6. Legal and model ownership aspects

7. Other: please specify