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How Can Building Information Modelling (BIM) Support The New Rules Of Measurement (NRM1)

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How Can Building Information Modelling (BIM) Support The New Rules Of Measurement (NRM1)

Report for Royal Institution of Chartered Surveyors

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Abbreviations

BCIS	Building Cost Information Service
BIM	Building Information Modelling
BoQ	Bills of Quantities
CAD	Computer-Aided Design
CAWS	Common Arrangements of Works Sections
D	Dimensional
GIFA	Gross Internal Floor Area
IT	Information Technology
M&E	Mechanical and Electrical
NRM	New Rules of Measurement
OGC	Office of Government Commerce
PBE	Preliminary Building Element
QS	Quantity Surveying
QTO	Quantity Take Off
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
SFCA	Standard Form of Cost Analysis
SMC	Solibri Model Checker
SMM	Standard Method of Measurement
UK	United Kingdom
US	United States

Executive Summary

The emergence of BIM has remarkably changed the way the construction industry operates. BIM through its extensive digital capability of virtually representing physical and functional characteristics of a built facility creates a shared source of information among the construction project team thereby forming a reliable platform for the decision making process to take place throughout the whole life cycle of the facility. It has shifted the industry from traditional paper based information management processes which typically tend to be cost ineffective, tiresome, error-ridden and time consuming, to automated processes facilitated by sophisticated technology that bring a number of advantages in terms of time, cost, and quality.

BIM's capability of automating measurements through extracting quantities directly from digital building models is its key benefit towards quantity surveyors as it clearly accelerates the traditional estimating process. BIM based estimating can be executed in three ways, namely, by exporting the measurements to spreadsheets, by directly linking modelling tools with estimating plug-ins, and using specialised BIM estimating tools. However, quantity surveyors in the UK construction industry are yet to integrate the comprehensive use of BIM into their practices. The key reason for the limited usage of BIM in quantity surveying practice is the unavailability of BIM based cost estimating or take-off software tools that fully adopt the UK practices and standards of measurement.

Attempting to bridge the gap of a BIM based estimating or take-off tool that adheres to the UK standards and practices of measurement, this research investigates the required information from a BIM model to support the estimating process according to the RICS standard of NRM1 order of cost estimating and elemental cost planning. Additionally reviews the technical requirement for BIM based software tools to support NRM1. A comprehensive literature review, a series of in-depth interviews with BIM experts, and a workshop with a group of quantity surveyors, on BIM in general; application of BIM in quantity surveying functions, estimating and cost planning in particular; standards for cost estimating and cost planning laid the foundation of this research. The information requirement outlined in this report provides overall guidance for the quantity surveyors on the types of measurements a BIM model can generate, and the ways of utilising the quantity information in a BIM model in cost estimating and planning. The review of technical requirements enables the quantity surveyors to select the most appropriate BIM based cost estimating tool for a specific scenario from a number of those available. The research reviews the four most well known tools in the UK market, namely, Solibri model checker, Autodesk QTO, CostX and Causeway BIMmeasure based on a set of criteria which is relevant to the NRM1 cost estimating and cost planning exercise.

The study reveals it is essential for the project team to agree on a set of requirements which is defined from the viewpoint of cost estimating and planning to enable the quantity surveyor to use BIM more effectively. Having formed the basis of such information requirements it suggests that the efficiency and accuracy of cost estimating and planning processes can be significantly improved by supporting BIM models with NRM 1 requirements.

1.0 Introduction

1.1 Background

In light of recent technological advancements in the construction industry especially in relation to Information Technology (IT), there has been a marked shift from traditional paper based formats of processing information to sophisticated software that can facilitate or even automate processes that are usually non-value adding, tedious, error-ridden and time consuming.

Building Information Modelling (BIM) is a paradigm shift that has recently started to make waves in the United Kingdom (UK). BIM is a digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition (CPIC, 2011).

BIM is currently on an upward trend in the UK construction industry and gradually gathering momentum in its uptake among industry stakeholders (Boniface et al., 2010; Nisbet and Dinesen, 2010). Over recent years, BIM has emerged as the centrepiece of discussions and debates in construction conferences, workshops, etc. around the UK and there has been an increased amount of literature, information, research and academic writings about BIM. Numerous eminent publications such as Eastman et al. (2011), Smith and Tardiff (2009), Hardin (2009), Kymmell (2008) and Jernigan (2007) have explained the general theories of BIM, the benefits and opportunities, technical tools and software and implementation strategies. Unlike Computer-Aided Design (CAD), which only requires designers to work differently, BIM is going to significantly change the working ways of all the disciplines involved in the construction industry and quantity surveyors are no exception. For quantity surveyors, BIM presents huge challenges and opportunities, particularly in the area of cost estimating and quantity take-off. BIM offers the capability to automatically generate quantity take-offs and measurement directly from a 3D digital model of a building, a process that traditionally is very time consuming. Thus, BIM can potentially revolutionise the way construction cost estimates/cost plans are produced. In the UK, estimating of construction work is governed by the RICS latest issue – New Rules of Measurement (NRM) Order 1 for cost estimating and cost planning. Nevertheless, there is no evidence to prove the feasibility of existing BIM based cost estimating tools that offer direct support to the NRM1 rules. The cost estimating processes with BIM to follow the prescribed standard of measurement rules can be complicated and tedious (Olatunji and Sher, 2010). This can be due to the lack of standards to support systematic data exchange between software applications and BIM models (BCIS, 2011; Sabol, 2008). Such limitations with BIM are seen as problematic issues that might affect not only quantity surveyors, but also other construction disciplines in the design and construction process.

1.2 Aim and Objectives

1.2.1 Aim

The project aims to develop the information requirements for Building Information Model to support the New Rules of Measurement (NRM) order of cost estimating and elemental cost planning.

It will also produce a technical requirement for BIM software tools to support NRM.

1.2.2 Objectives

The project's key objectives are:

- To review BIM in general and its application to cost estimating and quantity take-off
- To examine the NRM1 for both cost estimating and elemental cost plans
- To develop information requirements for BIM model to support NRM order of cost estimating
- To review technical requirement for BIM based software tools to support NRM order of cost estimating

1.3 Justification

Although BIM adoption is on an upward trend within the construction industry, the UK is showing a slow uptake of BIM with only 23% of UK contractors having adopted it and only 7% implementing the BIM process on 30% or more of their projects (McGraw-Hill Construction, 2010). Nordic countries appear to be leading the way as in 2007, Finland and Denmark required BIM to be used in all public sector projects (Kennett, 2010). Norway was not far behind with the Statsbygg agency requiring IFC/BIM use from 2010 onwards (Nisbet and Dinesen, 2010). Whilst in the United States (US), two of the largest public asset owners, the US Coast Guard and the General Services Administration, have set BIM as the requirement for certain functions (Kennett, 2010). Even in the Asia-Pacific region, Singapore's Building and Construction Authority is looking to push BIM to the forefront of the local construction industry by declaring the establishment of mandatory BIM submissions by 2015 for local projects while committing substantial subsidies for the cause (Loo, 2011). Nisbet and Dinesen (2010) pointed out that BIM is already in widespread use and as the global trend continues, industry practitioners ought to be wary of being left behind. The UK government has recently acknowledged this trend and is joining the radical movement of adopting BIM by also making it a prerequisite for all those involved in public sector projects to be BIM ready by 2016 (Morrell, 2011).

Further, recent BIM survey results reveal that many professions such as engineers and contractors are lagging behind the architects in adopting BIM (McGraw-Hill Construction, 2010; NBS, 2012). Notably, quantity surveyors are found to be slow to embrace the use of BIM. According to the RICS BIM survey (Matthews, 2011), many quantity surveyors are still not aware of what BIM is and only small numbers (10%) claimed to have used BIM.

There is also a little evidence to show that BIM is systematically introduced by the quantity surveying (QS) profession in UK. According to the initial background studies, the majority of literature available on BIM focus on the architects' and designers' interest at the utmost and only a very few connect BIM and the practice of quantity surveying. In addition, there are also limited case studies found within the UK to portray the integration of BIM into QS practice. This signifies an alarming need to gain quantity surveyors attention into this new evolutional technology and help them to keep up with the pace of other industry professionals to maintain their competitiveness within the industry. Hence, research about the integration of BIM into QS practice in the UK is a timely need.

Undeniably, BIM presents huge potential in easing quantity surveyors' time-intensive functions by enabling automation of quantities extraction directly from 3D digital parametric building models (Matthews, 2011b). However, there are challenges which inhibit quantity surveyors from fully utilising the benefits of BIM and they need to be overcome for a successful BIM implementation, (Olatunji, Sher, & Gu, 2010). The limited usage of BIM in QS is largely due to the fact that majority of the BIM based cost estimating or take-off tools have been developed outside the UK adopting different practices and standards of measurement. The BIM based cost estimating or take-off tools found in the current market such as Tocoman, Innovaya and Autodesk QTO have been developed outside the UK and designed to suit the practices, measurement rules and requirements in other countries.

In 2011, the RICS Quantity Surveying and Construction Professional Group issued the New Rules of Measurement (NRM), which are a standard set of measurement rules for cost estimating, works procurement and post-construction procurement to be used in the UK (RICS, 2011). At the moment, there are few BIM based cost estimating tools that provide direct support for the NRM. This is because the process is not straightforward and it requires in depth understanding of the information requirements to comply with NRM at different stages of the design and construction process and the ability of BIM technologies to integrate the required information. Therefore, it is significant to establish the information requirement to support the cost estimating/planning processes according to NRM through BIM.

1.4. Benefits

The project's key benefits are:

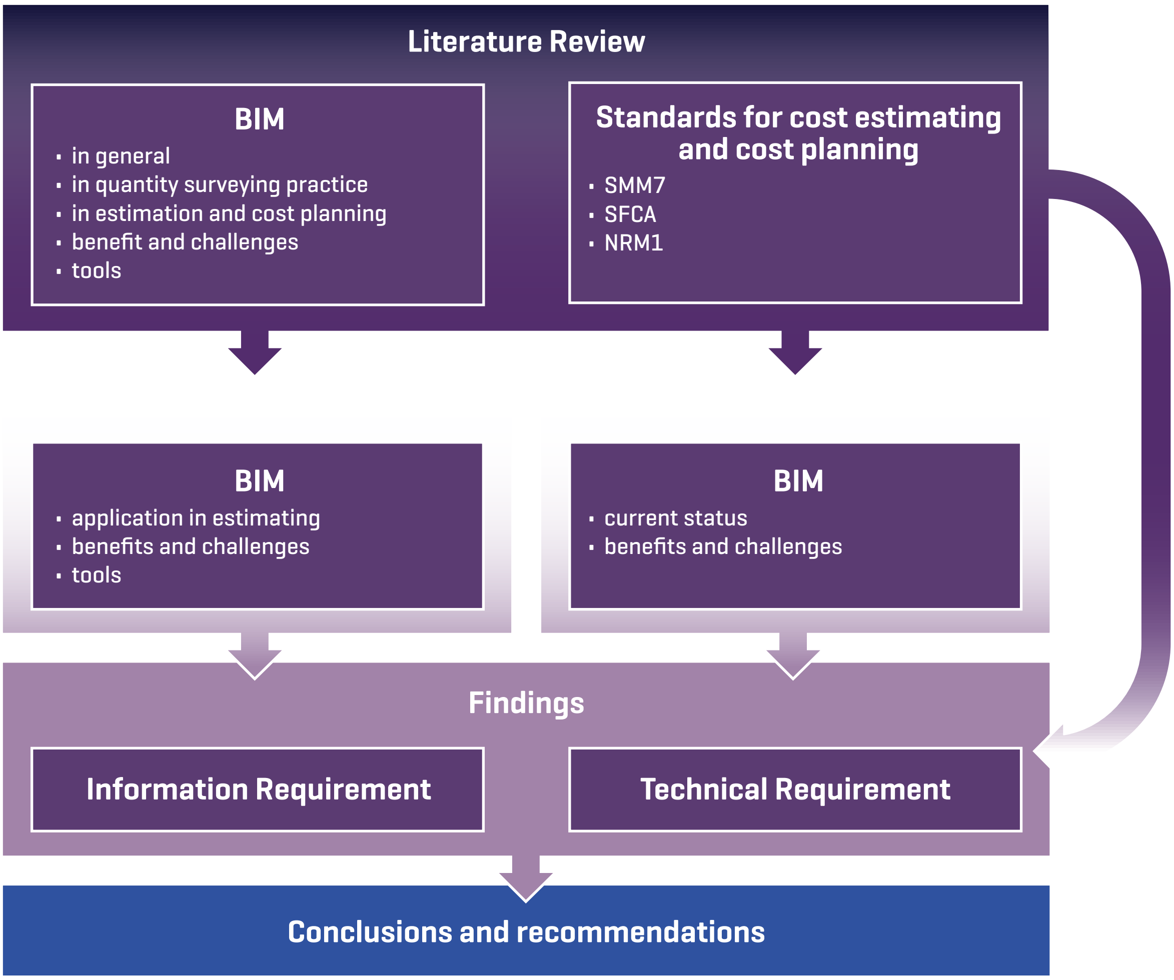
- Increase awareness of BIM technology among QS professionals
- Provide practical guidance to select BIM technology
- Provide practical guidance for design team for the BIM information requirement from QS perspective
- Provide technical requirement for BIM software developer to support NRM1 in their products

2.0 Research Process

Having recognised the significance of developing an information requirement to support the cost estimating/ planning processes according to NRM through BIM, the study deployed three main research methods to achieve its aim and objectives within a qualitative research design - Literature review, expert interviews and workshops.

A comprehensive literature review was conducted throughout the research to build-up the study and then to strengthen the findings. This helped to establish the background of the research, identify the key concepts of the research, and develop interview guidelines and workshop protocols. NRM 1 was extensively referred to during the research process. In addition, several in-depth interviews were conducted with BIM experts in the construction industry followed by a workshop with the quantity surveying staff of a leading construction company. In-depth interviews and the workshop were extremely effective in helping to understand the prevailing situation of BIM and BIM based estimating/ cost planning procedures in the UK construction industry along with the associated benefits and challenges. These methods provided the necessary interaction and flexibility for the experts and the QS professionals to demonstrate their knowledge and express their opinions on the subject. The data gathered through the interviews and the workshop was analysed, employing qualitative data analysis techniques and subsequently combined with literature and the components of NRM1 to develop the information requirement and arrive at the study's conclusions. Figure 1 summarises the research process whilst indicating the key research themes which were focused in each research method.

Figure 1: Research process



3.0 BIM and its application in cost estimating and cost planning

3.1 BIM in general

Figure 2: Terms and Phrases for the Definition of BIM

Source: Rawlinson 2012

3.1.1 Definition

It is important to define the term BIM in researching about BIM adoption in QS practice. BIM is constantly evolving and is an extremely broad subject to be investigated. With a number of theories available, BIM can easily be confused and misunderstood. Aranda-Mena et al. (2008) commented that BIM is an ambiguous acronym which can be interpreted in various ways by different professions at different levels as in Figure 2. Hence, it is important to carefully look into the terminology to establish a clear understanding of the basis of this research.

The term 'BIM' has been widely acknowledged following the publication 'Comparing Pommes and Naranjas' by Jerry Laiserin in 2002. The article has been extensively cited in subsequent BIM related publications such as Smith and Tardiff (2009) and Aranda-Mena et al. (2008). Hardin (2009, p. 3) quotes Charles Eastman (1999) and defines BIM as:

"The digital representation of the building process to facilitate exchange and interoperability of information in digital format."

When examining BIM within different construction markets, the Smart Market Report (MacGraw Hill, 2010, p. 46) and UK's BIM Working Group's Strategy (2011, p. 100) have both adopted similar viewpoints as Eastman that BIM is:

"The digital representation of physical and functional characteristics of a facility... [and] shared resource for information... during its lifecycle... [which involved] creation and use of digital models and related collaborative processes between companies to leverage the value of the models."

These definitions all appear to have agreed BIM as a digital representation. From a theoretical point of view, it is a concept about creating a virtual model of a building to capture problems, simulate and examine the possible implications before its physical execution (Smith, 2007). Providing a more comprehensive description, Eastman et al. (2011, p. 16) and Boniface et al. (2010) explain BIM as the `modelling technologies and processes to produce, communicate, and analyse building models'. Referring to the aforementioned theories, Succar (2009) argues that BIM has to be positioned with 'a set of interacting policies, processes and technologies' to produce the management framework for digital formatted information over the project lifecycle.

The concept stimulates a new three-layer approach by Crotty (2012, pp. 81-82) to clarify and expose the idea of BIM; involving 'the BIM reference model', 'agreed standard file format for data exchange', and 'information exchange protocols'. Crotty's approach underlines the key information management principles to enhance communication and collaboration in the use of BIM. Tzortzopoulos (2011) agrees that by enabling information sharing, BIM can be a 'mechanism to facilitate communication' and 'method to codify knowledge'.

From the high-level multi-disciplinary perspective, ACE (2008, p. 4) and Smith (2007, p. 12) stated that BIM is a 'collaborative project oriented method' for the production of building models to involve all project stakeholders and enable them to 'insert, extract, update or modify' the data within the modelling process at different stages of project lifecycle, in order to support and reflect the roles of that particular stakeholder.

3.1.1.1 Building Information Modelling vs. Building Information Model

Although the acronym BIM is frequently used to represent 'Building Information Modelling' and 'Building Information Model' interchangeably, the meaning for the two terms should not be mistaken. Smith and Tardiff (2009) discovered that many confusions are related to the word 'model'. More often, BIM stands for 'Building Information Modelling' which is a verb to represent process or action that generates the product named 'Building Information Model', which is a noun (Wong et al., 2009). BIM model is known as the core of Building Information Modelling. In this case, BIM actually means much more than just the model itself, it is an emerging technology that truly transforms the whole building industry. This is why sometimes BIM is also being referred as Building Information Management - BIM(M) in order to reflect the bigger picture of BIM: the 'managed approach' for both the process and model to govern the 'collection and exploitation' of all project and asset information (BIM Industry Working Group, 2011).

According to Smith (2007, p.12) and Azhar et al. (2008) a building information model is "a data-rich, object orientated, intelligent and parametric representation of a facility that carries all information related to the building, including the physical and functional characteristics and project life cycle information". Kymmell (2008) further explains it as "the project simulation containing 3D models of building components which linked all required information with the project's planning, construction or operation and decommissioning". Therefore, a BIM model does not merely represent the 3D geometry of the building (Smith and Tardiff, 2009).

The BIM model also provides the multi-dimensional functions with its capability to store 4D (time) and 5D (cost) information, even up to 'nD' (any other design information). All elements of a building or project can be represented in the virtual model to the finest detail. The data encompassed within the BIM model includes the 'properties information such as function, shape, dimension, material, and processes', besides details about the building and its components (van Nederveen et al., 2009).

A BIM model compiles the reliable data either complete or incomplete in a single or multiple data format that can be interpreted using software applications (Smith and Tardiff, 2009). It is the digital database which contains a set of integrated and interrelated files including all the 'CAD drawings, geospatial data and other graphical and non-graphical data' within itself, to be used as the shared authoritative supply of information so that it can capture, manage and present the data of a building electronically from the perspective of any AEC discipline (Bacharach, 2009; Smith, 2007). As a result, in any construction project, the designed BIM model could generate fabrication drawings for any trade, produce accurate cost estimates and project schedules, and facilitate identification of element clashes at any time needed depending on the amount of information incorporated within the model itself (McAdam, 2010).

Nonetheless, it is still important for BIM users to take note that the goal of BIM is not just about the capability of accessing project information, but using it intelligently to achieve benefits and improve project understanding (Jernigan, 2007; Kymmell, 2008).

3.1.1.2 BIM Misconceptions

Jernigan (2007) revealed many misunderstandings about BIM that arise due to the complexity of the subject and market driven self interest. Hence, clarifications are compiled below to deal with major confusions about BIM:

- **BIM is not software or CAD/Revit, or even a 3D modelling tool (InPro, 2010).**
  There is a common false impression discovered by Hardin (2009) in the construction industry that many has claimed themselves to be 'using BIM' by purchasing the license of a BIM software and using them. However, it is impossible for a single software product to offer the entry into full BIM practices because the construction industry is too complex (Jernigan, 2007).
- **BIM is comprised of only a single building model or single database.**
  Crotty (2012) and Jernigan (2007) have found a recent view about BIM which is frequently introduced to industry practices – BIM model is in a form of a single model that can be accessible at the same time from a single database by all project team members. However, in reality, BIM project model should be developed from separate discipline-specific models, interconnected among each other. The single building model concept is clarified to be the single industry exchange standard which is the basis for information exchange for all project participants throughout the building life cycle (Smith & Tardiff, 2009).

- **BIM may be an excellent solution to the industry but it is not perfect.**
  BIM is not a panacea. Even though BIM offers massive flexibility and potential as the fully functional storage for project information, BIM is not the perfect solution to resolve all difficulties. BIM does not promise the perfect outcome as it still relies on human effort to input all the information into BIM (Jernigan, 2007). Human beings are not perfect, thus, the work produced in BIM are still subject to errors that can possibly cause problems during construction and in future. It is difficult to ensure total elimination of mistakes and risks in construction projects with the use of BIM. BIM only helps to reduce errors by minimising mundane tasks and repetitive data input (Jernigan, 2007). In this case, it is clear that BIM still requires a lot of hard work and human knowledge and skills remain fundamental towards the success of BIM.
- **Creation and use of models that do not support object or parametric intelligence are not BIM.**
  Eastman et al. (2011) has identified a few key model situations that do not represent BIM capability such as, 3D models without object attributes and support of behaviour, models composed of multiple 2D CAD combinations and models allowing dimension changes in one view but not automatically reflected in other views. These models contained no BIM intelligence; they can be problematic in supporting data integration and improving project understanding, causing inconsistencies and errors which affect the feasibility of the models.

In conclusion, it appears that there is no single unifying explanation that is able to define what BIM really is while theoretical concepts are continuously emerging and diversifying as BIM evolves over time. Smith and Tardiff (2009) suggested the way out of dilemma and confusion about BIM is to broaden knowledge on the processes used to create the data – 'modelling', instead of just knowing the 'model'.

3.1.2 The 'I' in BIM – Information Management/Delivery

The construction industry is information-intensive in its nature due to the complexity of buildings created and the complicated form of human organisation (Crotty, 2012). Conventionally, data transfer among project team members can be very time-consuming (Hardin, 2009). IT technologies have been evolving for years in various sectors to speed up human processes and offer better information system to achieve targets (Yan & Damian, 2008). The same evolution takes place in the construction industry when BIM is produced.

The 'I' in BIM is the information, which is where the opportunities and value comes from (Jernigan, 2007). Very often, the importance of 'I' in BIM is overlooked when most concentrations are placed on its geometry (Smith & Tardiff, 2009). In terms of information management, BIM is beneficial in the sense that the data captured in the model can be reused; review and revision of the information is allowed; information validation and checks can be performed (Azhar et al., 2008; Nisbet & Dinesen, 2010); this ultimately refers to 'interoperability'. It is explained as, "the ability to exchange data between applications, which smoothes workflows and sometimes facilitates their automation" (Eastman et al., 2011, p. 99).

In other words, it is the foundational technology to be incorporated in BIM tools to enable functioning as part of the integrated system (Smith & Tardiff, 2009). In this case, BIM is executed in the form of a composite model, which is collectively merged or imported from different models by BIM users, instead of expecting all users to work on the same model at the same time (Hardin, 2009). Interoperability enhances the compatibility of software and eliminates the needs for construction professionals to perform repetitive data input across multiple tools leading to inefficiencies and errors. By enabling the reliable accurate information to be generated and exchanged from a complete digital model using different BIM tools through single information exchange mechanism, it enables effective and transparent decision making processes to be executed in the project lifecycle (BIM Industry Working Group, 2011).

To support the information delivery and management in BIM, Crotty (2012) sets out the need to have agreed exchange file formats to be used in all key applications for identification of the type of information to be exchanged between applications; and an agreed protocol to govern who is responsible for the information and what level of details the information should contain at each exchange point of a project. Bacharach (2009) also suggests that project stakeholders agree on 'common interfaces, schemas and best practices' to promote interoperability and better collaboration in BIM.

Serving as a shared information repository for all project disciplines, interoperability standards are important requirements towards successful BIM implementation. Companies which realise the value of BIM in collaboration and integration are now seeing the need to create information sharing standards at the time of contract negotiation (Hardin, 2009). Standards enable sharing of complex information and ensure consistency in a project; they ease the preservation of revision and records of issues, comparisons of version and assessment of model completeness (Nisbet & Dinesen, 2010). They also cultivate innovation by providing a common environment for technical and business purposes (Smith & Tardiff, 2009).

If the data in BIM is to be interoperable, the data exchange format such as IFC and the agreements on consistency requirement such as Uniclass classification systems should be observed and enabled. The interoperability issue however, has raised a problem in the BIM working environment. Nisbet and Dinesen (2010) discovered that many individual applications are now increasingly providing the opportunity for highly structured and transferable information, but not yet absolute compatibility. Therefore, it is important for professionals to learn how to mix-and-match the use of different software and utilize different guidelines to achieve the best outcome from BIM in their expertise.

3.1.3 BIM Market Status in the UK Construction Industry

Building Information Modelling (BIM) has been widely adopted and is transforming the global construction community at large, with Scandinavian countries and the United States taking the lead (Kennett, 2010; Nisbet & Dinesen, 2010). In 2010, UK also pursued the same footsteps towards implementing BIM after the establishment of government's initiatives to adopt collaborative BIM working in all public projects by 2016 (BCIS, 2011; Morrell, 2011; Winston, 2010).

See (2007) revealed that the concept of building modelling, which is central to the BIM authoring software nowadays, originated since the 1970s when early building modelling systems were developed from UK government funded research. These systems later on advanced into CAD systems and the introduction of product information modelling before changing its name to BIM.

BIM is not a revolution, but an evolutionary development with discontinuous change (Boniface et al., 2010; Crotty, 2012). Over these few years, the UK AEC industry has been making great effort in transitioning from the 2D paper-based working environment to BIM virtual atmosphere. InPro (2010) revealed the serious drawbacks in paper-based working: a high amount of non-productive and wasteful work due to repetitive and error prone manual processes; regular modifications and rectifications; disorganised documentation and poor information management; lack of data and process integrity. Comparing BIM with the traditional working practices, model-based working introduces better flexibility and integration; including many other benefits.

BIM technologies and processes tightly coupled with lean 'thinking' and green initiatives are acknowledged as the preliminaries for achieving successful industry evolution and paradigm shifts (Davis, 2007) as in Table 1, besides leading to more radical improvements required by the UK government (BIM Industry Working Group, 2011).

Table 1: The Evolution of AEC Industry

From	To
Paper-centric	Digitally enabled
Project-centric	Lifecycle sustainability
Stovepipes	Collaboration
Tracking time	Quantifying value
Supposition	Simulation
Outputs	Outcomes
Conversation	Communication
Info-centric	Knowledge management

Source: Davis, 2007

3.1.3.1 BIM Adoption Level

According to Nisbet and Dinesen (2010), the uptake of BIM is gathering speed and gaining momentum in the UK construction industry. Research by NBS (2012) has shown a rise of BIM awareness in the last two years (Figure 3). As shown in Figure 3, the number of BIM uses is also growing. NBS findings also report many who are aware of BIM are expecting the use of BIM in projects to grow significantly and reasonably quickly (Crotty, 2012).

Nonetheless, studies have discovered that majority in the UK construction industry are still struggling in Level 1 of BIM adoption as illustrated in Figure 4 while only a few large firms have moved forward to Level 2 (Boniface et al., 2010).

Evidently, United States (US) is ahead of all those in Europe and henceforth known to be leading the BIM users internationally. In comparison with the BIM adoption level in US, McGraw Hill's (2009; 2010) survey captured a relatively low BIM usage in UK. It would probably be difficult for the UK to catch up with the US's BIM position within a short period of time, however, with many BIM awareness campaigns and marketing press available, the UK industry is likely to see a gradual rise in BIM usage in the near future.

3.1.3.2 Drivers for the Use of BIM

To encourage and enable the UK industry to achieve the government's target in BIM adoption the BIM Industry Working Group (2011) has recommended the application of 'push-pull' strategy, which covers both the client side and the delivery side. Nisbet and Dinesen (2010) stated that motivations for the uptake of BIM is the ability to produce leaner and more productive models facilitating the design optioneering process to construct better quality and greener building with lower cost and less risk. Supporting the delivery of BIM approach, the authors have summarised a few significant factors as follows:

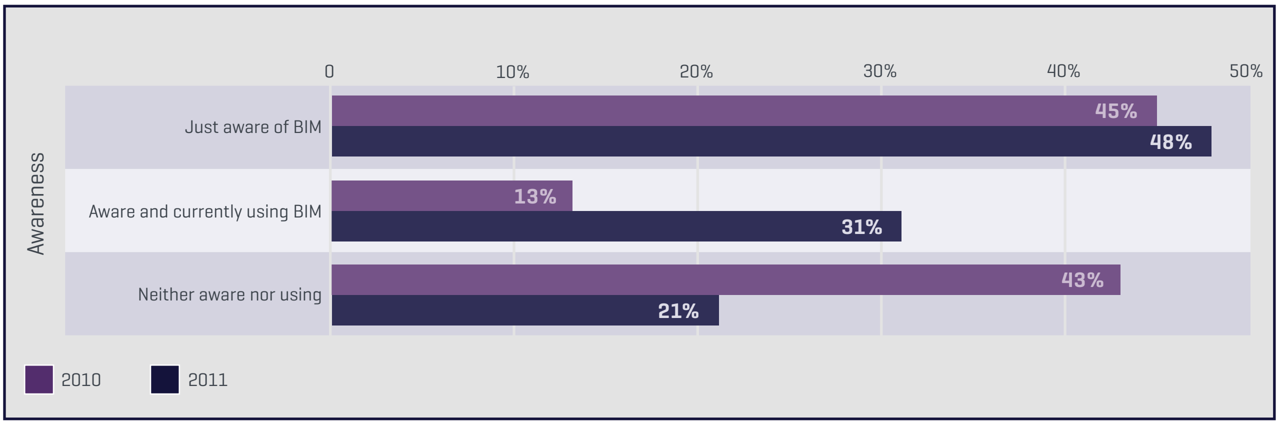
- **Governmental Push**
  Based on Wong et al.'s (2009) review on the BIM initiatives across several Scandinavian countries, it is found that a strong public sector support would be the ideal scenario for the effective implementation of BIM. Seemingly, governmental bodies around the world are setting up requirements for their supply chains to use BIM (Nisbet & Dinesen, 2010). BIM, therefore, has become an irreversible requirement in construction.

- **Client Demand**
  Client demand is identified as one of the most motivating factors for BIM uptake (Nisbet & Dinesen, 2010). Very often, clients are in the best position to force the adoption of BIM. As construction clients begin to see BIM as a powerful post-occupancy management tool, it is likely to drive strong demands for BIM (Boniface et al., 2010). It is suggested that most clients who have a better understanding of the value of BIM and its implications, will mostly require project teams to establish standards and methods for BIM adoption (Pittard, 2012). Yet, currently many clients are still unaware of their roles in construction and how improved technologies would affect their business. Therefore, this might still be the biggest potential barrier to BIM exploitation.

- **Market Competitiveness**
  Based on Boniface et al.'s (2010)'s report, it appears that many supply chain professionals are gradually being placed under pressure to develop their capability to work in the BIM environment when the major players in the industry are opening up their business gateway to begin using BIM technologies in their major projects. As BIM is serving to become the key means of construction deliverables, companies are feeling the threats of losing their market position, thus, increase their eagerness to gain further competence in BIM to maintain their competitiveness (Nisbet & Dinesen, 2010).

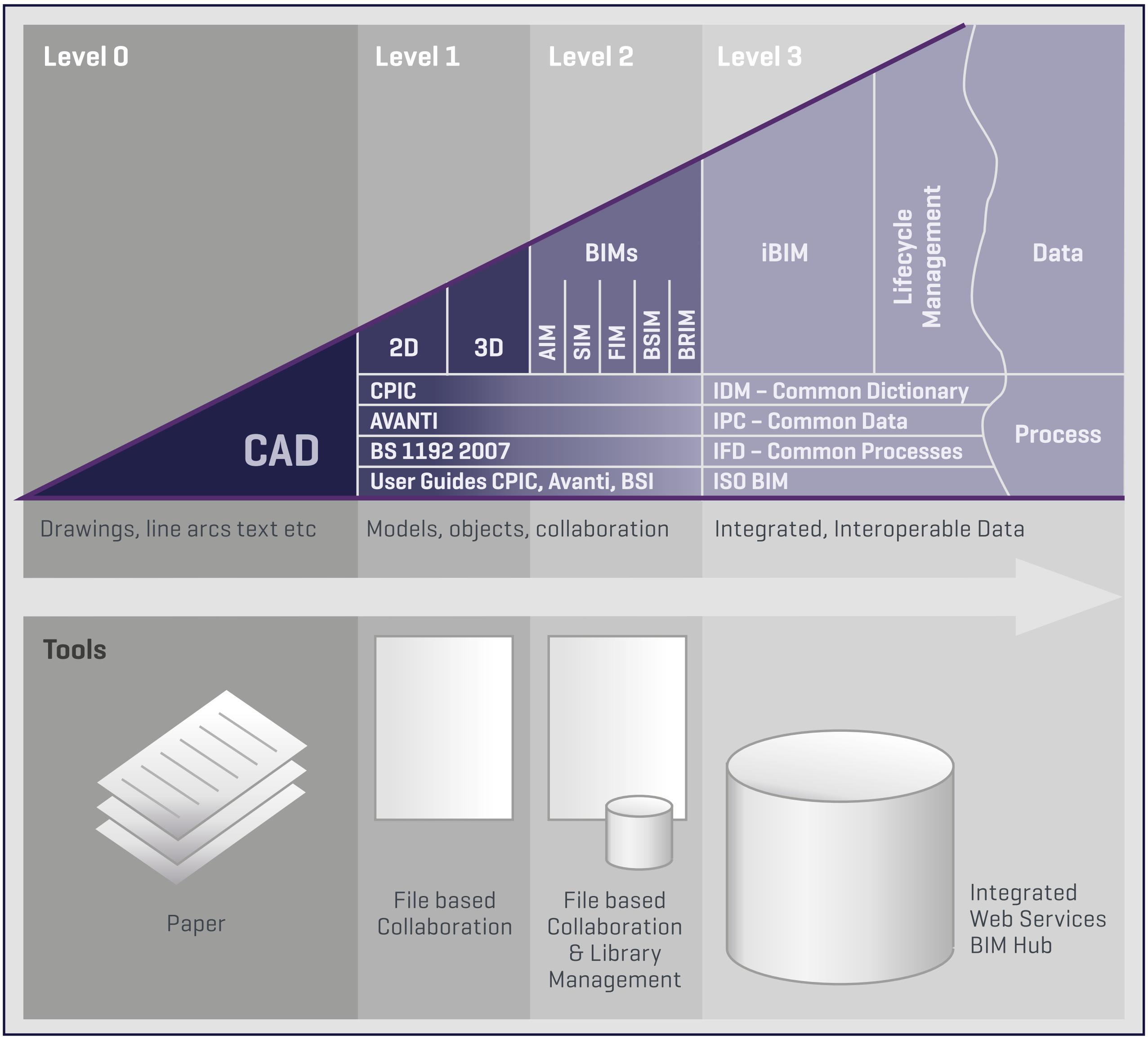
Source: Rawlinson, 2012

Figure 3: NBS Survey on BIM Uses and Awareness



Source: NBS, 2012

Figure 4: BIM Maturity Levels



Source: BIM Industry Working Group, 2011

3.1.4 Benefits of BIM adoption

BIM is emerging as an innovative way to manage projects and it promises to provide significant improvements to the industry. BIM encompasses numerous functions and purposes to support the overall projects processes, from visualisation through conflict detection, cost estimating, construction sequencing to fabrication and facilities management. Each use contributes towards enhancing the value of BIM.

More often, people are interested in the results of using BIM before deciding to implement the concept. Therefore, the best way forward is to begin with pilot projects, so that the industry will increasingly see the benefits of BIM and know what kind of effects can be expected which later could encourage and move widespread use (Nisbet & Dinesen, 2010). This section provides the realistic expectations that are likely to be found on BIM-based projects.

The results of US NIST studies compiled in BIM Smart Market Report (MacGraw Hill, 2009) claim projects that utilise the BIM technology will be able to yield better outcomes. To prove these results from the UK construction context, Nisbet and Dinesen (2010) have summarised and compiled case studies to provide evidence on project performance as recorded in Table 2.

By enabling collaborative working and information sharing, it is significant that the BIM projects are able to progress more effectively and faster because BIM has helped to address a lot of issues and the inefficiencies that existed in traditional projects. Key benefits widely promoted with BIM are often focused on time, cost and quality. Summarising the findings from Aranda-Mena et al. (2008); Azhar, Nadeem, et al. (2008); Boniface et al. (2010); Jernigan (2007), the intelligent use of BIM can offer significant benefits as follows:

- Increased building performance and quality
- Earlier collaboration of project disciplines
- Risk reduction
- Improved processes and communications between project participants
- Better green performance with improved energy efficiency and sustainability
- Reduced cycle time
- Reduced cost of change in design and construction

Essentially, BIM helps to 'improve quality and speed of project related decision making, manage supply chains; sequence workflow; improve data accuracy; reduce time spent on data entry; reduce design and engineering conflicts and subsequent rework; and improve lifecycle management of buildings and infrastructure' (McGraw Hill Construction, 2009). Boniface et al. (2010) also capture the clear wins of using BIM in design understanding, spatial and design coordination and 4D programme integration. More recently, Eastman et al. (2011) has categorized BIM benefits according to different stages of project lifecycle.

- **Feasibility Stage**
  BIM offers owners the best opportunity in early decision-making and greater assurance of desired project outcome by engaging them with the project teams earlier in a collaborative way (Jernigan, 2007). Early engagement of client and the project teams improves collaboration, encourages better understanding towards the project design and costs, and reduces wasteful effort and time to make changes in later project stages (Eastman et al., 2011).
- **Design Stage**
  BIM creates improved and innovative design solutions for clients by enabling quick evaluation, simulation and accurate analysis of design proposals (Azhar, Hein, et al., 2008). In essence, BIM dramatically reduces the project teams' dependence on 2D drawings. It is apparent that integrated BIM processes invest more design effort upfront than in the traditional approach increasing the design team's cost control ability, and decreasing the cost of design changes (Crotty, 2012). BIM manages change control well and generates low levels of corrections, thus, significantly reduces coordination errors (Eastman et al., 2011) and enhances the confidence of project teams (Aranda-Mena et al., 2008).
- **Construction and Fabrication Stage**
  BIM reduces on-site rework and shortens installation time by enabling the design models to be used for fabricated components (Eastman et al., 2011). Errors are minimised during construction due to early omissions in design stage which speeds up the delivery process. Constant synchronization between design and construction facilitates supervision and management control processes.
- **Post Construction Stage**
  Provided the information in BIM model are consistently and carefully maintained throughout the lifecycle processes, BIM can support better facilities management during the operation of facilities (Azhar, Hein, et al., 2008). Owners of the building are given the opportunity to check the building against the design before acceptance (Eastman et al., 2011).

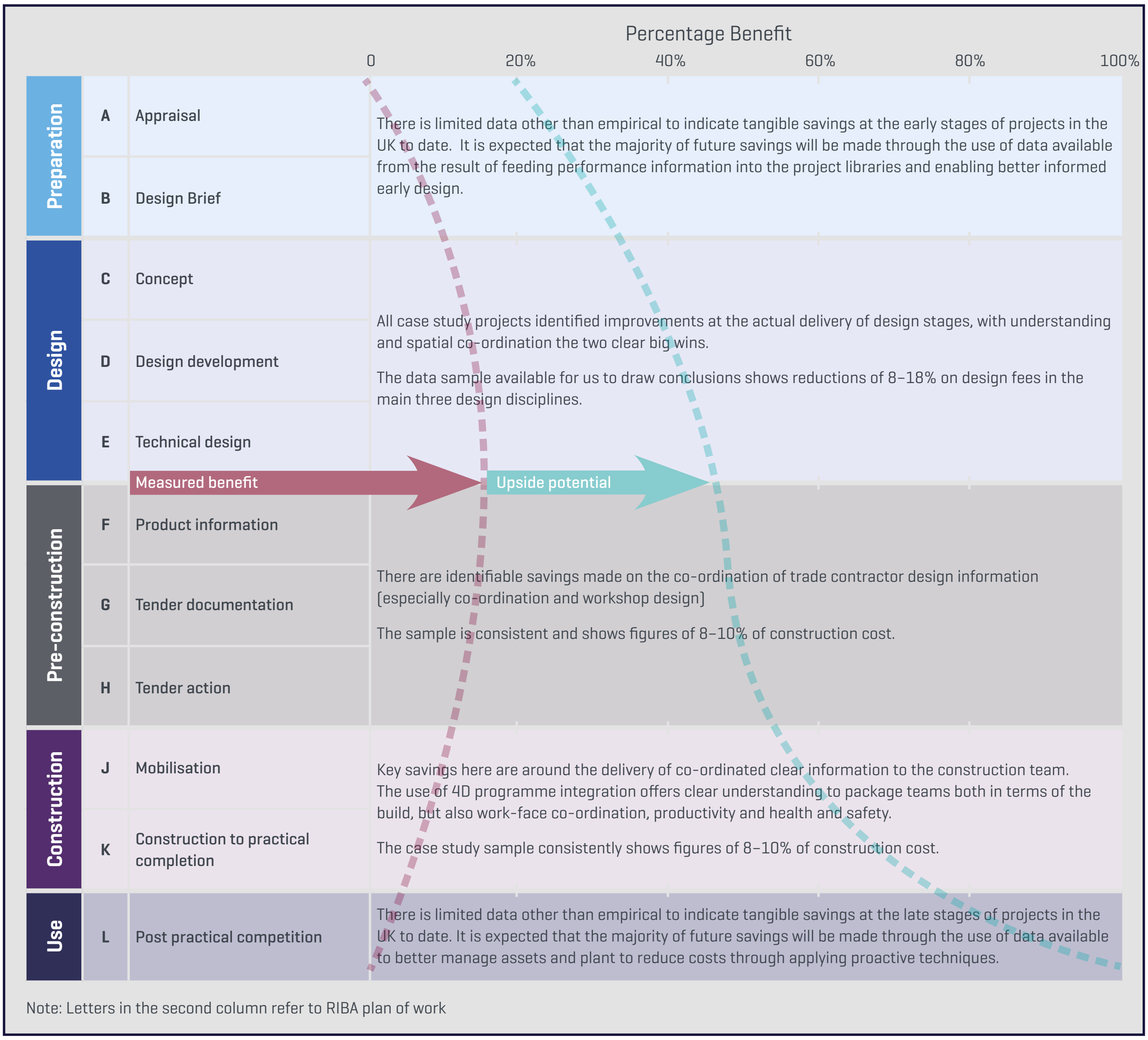
The benefits are also summarised into a more simplified diagram (as shown in Figure 5) linking to the RIBA work stages in Boniface et al. (2010). However, the benefits of BIM in the post-construction stages are yet to be included.

Table 2: Benefits of Implementing BIM Techniques in UK Projects

Project Title	Benefits
St Helens and Knowsley	Waste reduced, time saving in locating documents and design coordination, creating positive impact on critical path
Endeavour House	Savings in project cost and drawing production cost
Palace Exchange, Enfield	Improved information management, saving up the effort and man-hours; improved spatial coordination and cost certainty
Festival Place, Basingstoke	Savings in the construction phase
Heathrow Express Recovery Project	Risk reduction with the use of SME
Terminal 5, Heathrow	Savings through SME

Source: Nisbet and Dinesen, 2010

Figure 5: Benefits of BIM Measured in accordance to RIBA Work Stages



Source: Boniface et al., 2010

3.1.5 Challenges in BIM adoption

Prospective BIM users also needed to know where the pain and obstacles lied that prevents the full implementation in BIM. Understanding these challenges will help the users define quick winning strategies and long-term improvements to prepare themselves for successful BIM adoption. McAdam (2010) raised a few BIM challenges as follows:

- **Legal Issues**
  This often relates to the design liability, ownership and protection of data copyright in BIM working practices (Azhar, Hein, et al., 2008). Questions are often raised in relation to who owns the model, who should pay for the model, and who is responsible for the accuracy and information input (Eastman et al., 2011). Besides, it is also questionable as to who should be held responsible for the design if any risks arise, because BIM-based collaborative design is blurring the level of responsibilities among project participants and removes the binding contractual relationships and agreement in the project (McAdam, 2010). Contract documents therefore, need to be developed adjusted to address this issue.

- **Human/Cultural Issues**
  Human and cultural issues are by far the largest latent barriers towards BIM application (Yan and Damian, 2008). People are not always enthusiastic to learn new methods once they are comfortable with their present roles (Yan & Damian, 2008). Undeniably, many are overwhelmed with the substitution of traditional practices and the amount of change to be introduced when using BIM (Crotty, 2012), which consequently leads to resistance to change in their existing roles and practices. BIM adoption is regarded to be a major disincentive to innovation as it overlaps the existing professional boundaries (Olatunji, Sher, & Gu, 2010). This is often caused by doubts due to lack of case study evidence to show the financial benefits of BIM. Such transformation usually requires time and cost for education (Eastman et al., 2011), before significant changes can be realised in technology and work processes.

3.2 Application of BIM in quantity surveying practice

3.2.1 Changing role of the quantity surveyor in the UK construction industry

Quantity surveying (QS) has been an integral part of the UK construction industry for about 170 years (Cartlidge, 2011). However, many have been predicting the demise of the profession over the past 20 years or more (Ashworth and Hogg, 2007). Such predictions have been proven wrong when the endurance of the profession is tested through innumerable changes within the construction industry (Cartlidge, 2011).

Traditionally, the role of quantity surveyors has been mainly associating with the functions of estimating and cost planning, procurement advice, measurement, preparation of Bills of Quantities (BoQ) and tender documentation, construction cost control, and preparation of valuations, payments, contractual claims and final accounts (Ashworth and Hogg, 2007). From 1980s onwards, with the emergence of the newer procurement strategies, the roles and responsibilities of quantity surveyors evolved and expanded to fulfil the new market demands following the declining use of BoQs. As a result, new functions such as whole life cycle costing, value management, project and construction management, risk analysis and management, facilities management, and contractual disputes and litigation were added to the responsibilities of the quantity surveyor (Ashworth and Hogg, 2007).

Lately, driven by the modern technological advancements in the construction industry, quantity surveyors have seen the potential of further enhancing their role and become more efficient and productive in performing their measurement and management oriented functions. Ashworth and Hogg (2007) predict the broadening range of QS functions in the future as automated measurement and quantification, environmental and sustainability analysis, facilities management, legal services, investment advice and quality management.

3.2.2 Integrating BIM into quantity surveying practice

Following the emergence of BIM, it has been realised that some of the aforementioned QS functions are likely to be achieved through BIM more efficiently. BIM is becoming the mainstream in the UK construction industry and as a result, clients expect the QS firms to embrace BIM in order to increase the cost effectiveness and value of construction processes (BCIS, 2011). Therefore, it is important for the quantity surveyors to appreciate BIM, understand its potential, and develop and employ effective processes and tools to integrate BIM into their current practices (Cartlidge, 2011).

3.2.2.1 Business value and advantages

It has been recognised that BIM has a high potential to inspire every aspect of the QS profession (Pittard, 2012). Matthews (2011b) states that no quantity surveyor can argue BIM has negative implications for the industry. BCIS (2011) emphasises that quantity surveyors cannot afford not to use BIM having known BIM's capability. In other words, QS professionals should be fully aware of the opportunities BIM could bring in relation to their current and future roles.

The conventional functions of quantity surveyors are closely related to activities such as conducting feasibility studies, taking off quantities, cost planning, and preparation of bills of quantities and schedules (Kirkham, 2007; Olatunji, Sher, & Gu, 2010). These functions are considered time consuming and complicated due to the manually performed 2D drawing based taking off processes. Sabol (2008) also point out the prevailing issues with the manual procedures and highlight that these processes are highly susceptible to human errors and dissemination of inaccuracies considering the large amount of 2D drawings to be interpreted along the quantity measurement process. Therefore, BIM can be introduced as the correct solution to overcome these inefficiencies.

Further, Autodesk (2007) highlights a common complaint made by the QS firms regarding the significant amount of resources i.e. time and money they have wasted in performing measurement works. In this context, the extensive amount of time that could be saved through working with BIM by eliminating extensive manual numerical tasks is an enormous advantage to the QS firms. On the other hand, Matthews (2011b) note that major QS firms in the UK are looking into transforming and rebranding their companies towards more consultative and advisory roles, to offer services which require more human intelligence that is irreplaceable by technology. For example, EC Harris and Turner and Townsend are now working on providing new strategic services including advising clients on investment, energy use, carbon emissions and running costs. While large firms are adopting BIM into their quantity surveying services and becoming pioneers of BIM, smaller QS practices that are not part of large organisations can be expected to move in to legally-based roles and other management-oriented practices (Matthews, 2011b).

3.2.2.2 Challenges

ACE (2008) and Olatunji et al. (2010) assume that many industry practitioners felt threatened and considered BIM as a major challenge. This includes quantity surveyors who were wary of BIM's capability to perform automated number-crunching tasks; e.g. quantity take-offs and cost estimation (Kennett, 2010; Matthews, 2011b). Self-preservation is cited by Malone (2012) as one of the potential reasons behind quantity surveyors' slow adaption to BIM. However, quantity surveyors should not be afraid of BIM because the key deliverables of a quantity surveyor do not change regardless of using BIM or traditional approaches in a project. Clearly, the misconceptions are due to the lack of understanding of BIM. The results of RICS BIM survey (2011) confirmed there is a lack of awareness of BIM in the current industry.

Matthews (2011b) believes BIM is only 'the end of measurement' for Quantity Surveyors and definitely not a replacement of the profession (Jernigan, 2007). BIM is not able to resolve all the quantification issues or support a comprehensive taking off of all the required quantities (Kiviniemi et al., 2007) although it could enhance the efficiency and accuracy of the process. Hence, the expertise of quantity surveyors is necessary to audit the quantities extracted from BIM (Kiviniemi et al., 2007; Matthews, 2011a; Pittard, 2012). BIM requires quantity surveyors to recognise and check the information made available in BIM and utilise them effectively for the estimating and procurement processes. Accordingly, BIM is not a substitute for a professional quantity surveyor.

Cartlidge (2011) believes the key challenge for quantity surveyors is to gain the knowledge and understanding on the attributes of materials, building systems, and construction processes while continue delivering the best value for money within integrated and information-rich processes. Further, adopting BIM requires a large amount of resource. According to Matthews (2011b), large construction firms have spent a significant amount of time and money to train and guide their staff on using BIM, while attempting to transform their employees into consultants with wider knowledge of the markets. In this context, smaller QS organisations encounter greater difficulties in adopting BIM and moving away from traditional services due to the expenses that is required for staff training and BIM software (Matthews, 2011a). However, despite the challenges, Moazami (2011b) states that the quantity surveyors can gain immediate benefits if they decided to adopt BIM in their practice.

3.3 Need of BIM for cost estimating and cost planning

3.3.1 Cost estimating and cost planning practice and procedures

According to Samphaongoen (2009), cost estimating is essential for budgeting and tendering in any construction project. It reflects the inherent risks, direct costs of a project involving materials, labour, professional services, etc. (Olatunji et al., 2010).

Introduction of cost planning techniques, enabled the quantity surveyors to provide more reliable cost advice from the early stages of a project for design appraisal to offer best value and confidence for clients and project team to proceed with the project (Ashworth, 2004; Cartlidge, 2009). An early cost estimate then becomes the fundamental guideline to determine the project's feasibility and also acts as the main parameter with which the design has to conform throughout its development (Odusami & Onukwube, 2008; Raisbeck & Aibinu, 2010). It also enables alternatives to be considered at an early stage of a project (Eastman et al., 2011).

Kirkham (2007) identifies the difficulty to explain the cost estimating process concisely due to the quantity surveyor's concurrent uses of different procedures and techniques. Three distinct estimates developed during design processes are summarised from Cartlidge (2011) and Sabol (2008) as follows:

- Initial estimate, formulates the indication of approximate project cost in relation to the client's primary requirements when there are no drawings of any substance through the use of different approximate estimating methods, e.g. unit cost, superficial area method, elemental estimating method (Ashworth, 2004; BCIS, 2009). Generally, initial estimating is based on the templates from previous project experiences; thus, does not involve calculation of individual elements. However, it varies with different project types, regions, or types of construction (Sabol, 2008).
- Cost planning, proceeds as the scheme design progresses and is approved by the client. It refines the initial estimates by breaking down and allocating the project cost limit decided earlier into building elements, to show the design team how the budget is distributed and form the frame of references for further design development (BCIS, 2009; Cartlidge, 2011).
- Detailed estimate (Pre-tender estimate), also known as bid estimate (Sabol, 2008), is prepared when all drawings and documents have been completed in a project (Samphaongoen, 2009). This is when BOQ is to be produced for the tendering stage, in which the estimator has to conduct a detailed measurement of each building components or items, based on certain standard methods of measurement.

3.3.2 Inefficiencies in traditional cost estimating practices

Conventionally, cost estimating involves the need to perform detail measurement works using a series of printed or CAD drawings provided by the design team. In construction projects, design information is frequently revised and updated with the development of the project design; revising the measurements and updating the cost estimates accordingly are not easy tasks for the quantity surveyor (Cartlidge, 2009). It becomes extremely challenging and time consuming for the quantity surveyor to prepare accurate cost estimates when there is a large amount of manually produced design information such as drawings that are subject to frequent revisions. Therefore manually produced design information could result in estimates with a lower precision. Such estimates easily deviate from the client's budget as there is less accurate cost advice provided at the early stages to help clients to determine the maximum cost of the project (Bylund & Magnusson, 2011).

Olatunji et al. (2010) believe that the estimation processes in construction are susceptible to the fragmented processes in manual design procedures. Contemporary estimation can be problematic particularly in achieving accuracy according to Aibinu and Pasco (2008); Yaman and Tas (2007) as these estimates are often prepared within a limited timeframe and before the scope of the project is finalised. The level of accuracy for each stage of estimate varies as shown in Table 3. According to the table, the expected percentage of error in estimates decreases as more design information becomes available to the quantity surveyor along with the development of the design. Thus, conceptual estimates and cost plans are at higher risk and contain more errors in traditional practices since the project information is still incomplete (Sabol, 2008; Yaman & Tas, 2007).

Lee and Smith (2010) and Cartlidge (2011) highlight the absence of specific rules solely for preparing cost estimates and cost plans. Subsequently, inconsistent measurement methods are used and variable cost plan formats and descriptions are produced when different principles from SMM (Standard Method of Measurement), SFCA (Standard Form of Cost Analysis), or past practices are applied. This creates increased confusion and complications in understanding among clients and the project teams, resulting in doubts about the quantity surveyors' cost advice.

Ashworth and Skitmore (1983) claim that estimating is a subjective process which cannot be precisely technical and analytical. In addition, Serpell (2004) identifies early estimates as a "very complex domain to deal with" as it faces many restrictions and problems. It is suggested that there are many variables which need to be taken into consideration, carefully monitored and controlled at the project inception that potentially affect the reliability (Odusami and Onukwube, 2008; Raisbeck and Aibinu, 2010).

Raisbeck and Aibinu (2010) are also concerned with the understanding of dynamics between cost estimation and design to improve the accuracy of early estimates, in which effective communication and coordination are critical to help the designers and quantity surveyor know what each is doing, hence enabling better flow of information and reduced conflicts in design and costs. Logically, better estimates should be expected upon improving all these aspects.

Serpell (2005) highlighted the need to have automated processes and development of information technologies, to deal with different variables including time issues in manual cost estimating. Technologies with tasks integration are recommended to be able to make significant contributions to cost estimate processes. BIM certainly offers these features and can assist in producing more precise cost estimates and cost plans.

Table 3: Variability of Error in Different Types of Estimate

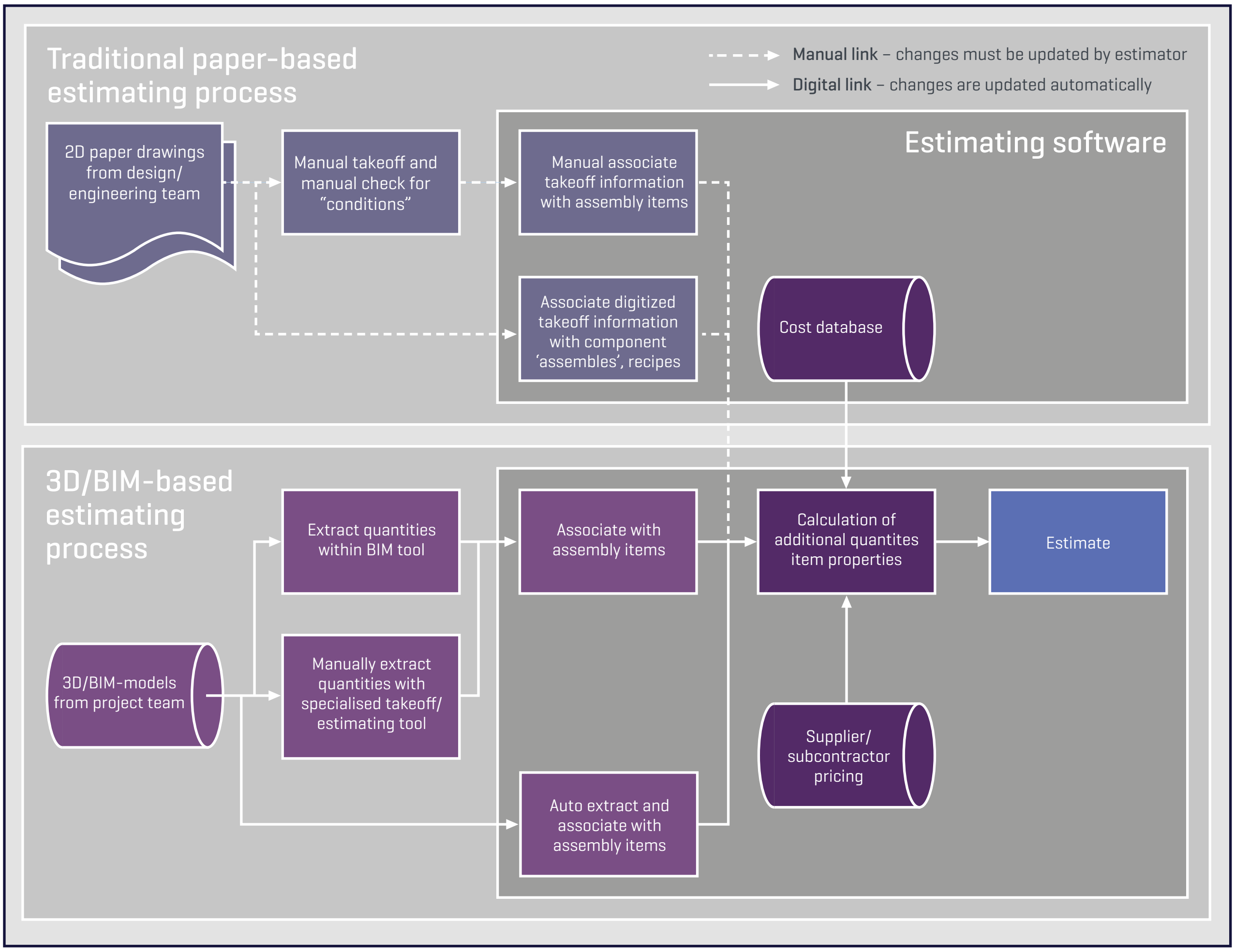
Type of Estimate	Construction Development	Expected Percent Error
Conceptual	Programming and schematic design	± 10-20%
Semi-Detailed	Design development	± 5-10%
Detailed	Plans and specification	± 2-4%

Source: Holm et al., 2005 cited in Samphaongoen, 2009

3.4 Application of BIM in cost estimating and cost planning

BIM means changes to the manner buildings are designed, documented, analysed, procured, constructed and managed as it unlocks new ways of working for all construction disciplines, (Aranda-Mena et al., 2008; Hardin, 2009). Inevitably, it includes revolutionising the way cost plans and estimates are produced as well. The main steps of a BIM based estimating process is illustrated in Figure 6.

Figure 6: Comparison between BIM Based Estimating and Traditional Paper Based Estimating



Source: Eastman, 2011

3.4.1 Process of BIM based estimating

BIM offers visualisation to ease the production of conceptual estimates (Matipa et al., 2008) and the function to automate the generation of quantities and measurements directly from a BIM model (Sabol, 2008). The intelligence in BIM allows all cost information to be linked to the model to remain consistent with the design throughout the project phases and enables changes to be readily accommodated in quantities, measurements and cost (Autodesk, 2007). The innovation also greatly reduces the time spent in manual cost estimation, when quantification process used to consume potentially up to 50-80% of the quantity surveyor's time (Autodesk, 2007; Sabol, 2008). BIM enables quantity surveyors to utilise their extra time and effort to attend to higher value project-specific factors which is more important to inform better quality estimates (Autodesk, 2007).

Cartlidge (2009) noticed that many estimating softwares are developed to speed up the labour-intensive traditional approach of quantification works only by helping to determine the dimensions from CAD drawings to be input into QTO (Quantity Take Off) templates. The software is yet to achieve a high efficiency since the selection of necessary elements from the drawings and measurement are still based on manual operations (Autodesk, 2007; Jiang, 2011).

The development of early cost estimates is widely facilitated by BIM. Eos Group (2008) acknowledges that BIM rather enhances the QS expertise in cost estimating than eliminating it as sometimes claimed, since BIM is only able to automate quantification but not cost estimates (Autodesk, 2007). BIM technology allows early design models to be linked to software that enables the quantity surveyor to extract necessary quantities at the initial stages of a project (Eastman et al., 2011). It is suggested that BIM models at early design stages contain less details in nature and are flexible to enable changes as the project develops (Sabol, 2008). A BIM model is constituted of 3D objects with geometrical information, and hence it is easier to capture the quantities of the objects; the volumes and areas can be automatically and instantly extracted (Jiang, 2011; Kymmell, 2008). Quantities extracted then form the basis of an accurate cost estimate, after linking and mapping them with the quantity surveyor's internal built-in or external cost database.

According to Lovegrove (2011), BIM models are commonly structured by designers to a hierarchical categorisation of the elements as an example shown in Figure 7. However, from the cost estimating perspective, Tocoman (2010a) suggests BIM model to be structured based on building elements and its components which are known as the construction recipes (Figure 8). These recipes will be classified into systems and trades similar to the construction viewpoint to enhance and improve queries to the information when carrying out the quantification process.

Figure 7: Hierarchical structure of BIM model in Revit Architecture

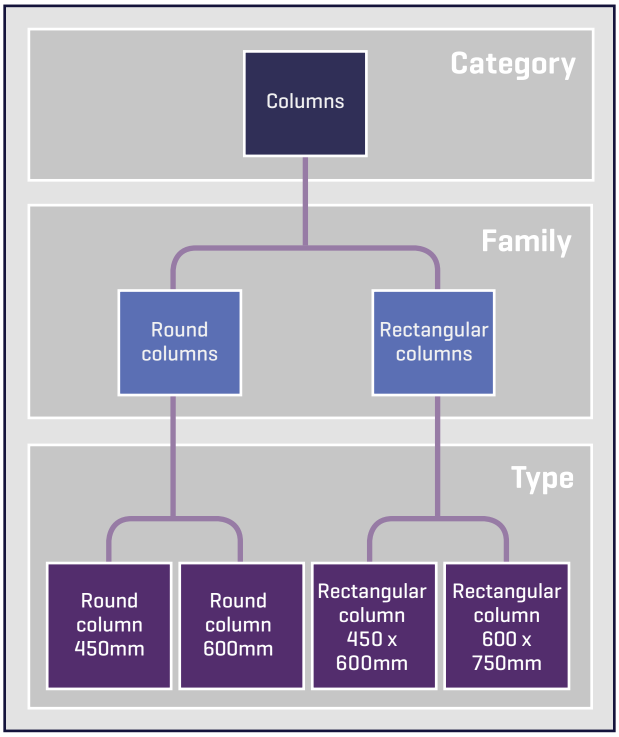
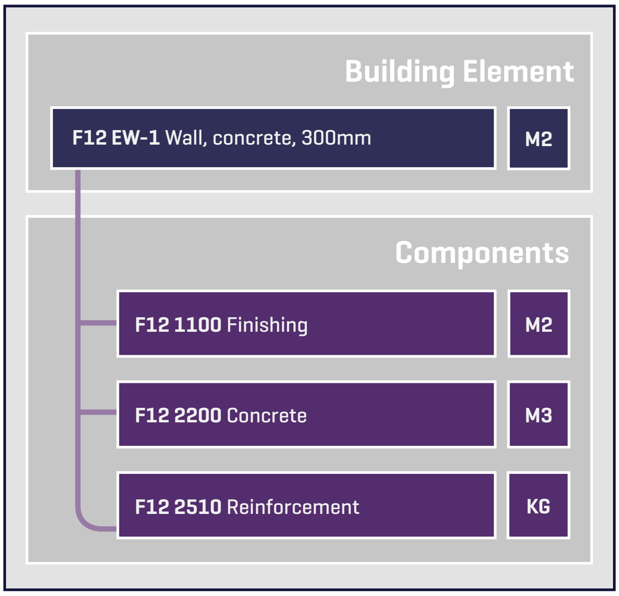


Figure 8: Classification of Building Elements and Components



Source: Lovegrove, 2011

3.4.2 Approaches of BIM based cost estimating

The capability of BIM platforms to perform automated quantification of items, areas and volumes of building elements does not produce a cost estimate. Application of BIM in cost estimating is a broader process than mere automated measurements. Eastman et al. (2011) and Autodesk (2007) suggest several approaches for BIM based cost estimating as follows:

- **Exporting building object quantities to estimating software**
  It is identified by Eastman et al. (2011) that most BIM based estimating tools are capable of exporting the quantities to a spreadsheet or external databases, enabling the quantity surveyor to then begin the pricing work. Quantity surveyors usually consider quantities that have been exported to MS Excel format are sufficient for their work in BIM. However, Hardin (2009) argues that it is inefficient to export the quantities if the BIM model and the spreadsheet or database are not linked in a way that the latter is automatically updated with the changes to the former. In contrast, Autodesk (2007) suggests such output still offers the simplicity and control that matches certain workflows. Therefore, a standardised modelling process is recommended to help to achieve better results.
- **Bridging the BIM tool directly with estimating software**
  This approach refers to the use of BIM estimating software such as Tocoman iLink which are capable of directly linking to the BIM design tools such as Revit through plug-ins (Autodesk, 2007; Eastman et al., 2011). Quantity surveyors can define the measurement rules using the plug-ins to automatically generate all the required quantities for the cost estimate from the underlying model and then map the cost data to the relevant building components (Jiang, 2011). They can also associate objects within the model instantly with the assemblies or items in the estimating software or from the external database. In this case, BIM design tools mainly serve to provide model visualisation to aid the cost estimating processes.
- **Using BIM quantity take-off tools**
  This approach associates with the use of specialised QTO software, e.g. Autodesk QTO, Vico Office, and Exactal CostX, that transfer the BIM models and their embedded information from BIM design tools into their system. Similar to the previous approach, these tools can support both the automated extraction and manual takeoff features. They can generate visual take off diagrams while providing visualisation of models whereby the quantity surveyor can mark off the building components using colours, enabling a cross check of the takeoff lists and to see which components have or have not been included in the estimate (Eastman et al., 2011). The items and assemblies are inter-linked and the quantity surveyors are able to insert additional annotations to the model to clarify the conditions whenever necessary during the quantification process. The approach provides an advantage for the quantity surveyors to work using familiar QTO software without having to possess an in-depth understanding of BIM design platforms.

Autodesk (2007) suggests that QS firms are free to choose which approach they prefer to follow among the aforementioned list depending on the estimating workflow, available software, and pricing database used in their practices. Furthermore, BIM is argued to be adding new complications to the cost estimating processes for QS; including 3D model management and navigation, identification and linking building components to estimating data, rapid responses to changes and design alternatives along design development stages (Eastman et al., 2011; Eos Group, 2008).

3.4.3 Challenges of BIM based Estimating

Agreeing with the statement "BIM has its flaws" (Yan and Damian, 2008), Kiviniemi et al. (2007) believe that BIM is unable to solve all quantification issues although it is capable of performing most manual work quickly. The following challenges still remain with BIM based estimating despite its advanced technology.

- **Substandard BIM models and inadequate information**
  Jellings and Baldwin (2009a) emphasise the importance of producing a properly configured BIM model to derive a meaningful cost estimate or cost plan. McCuen (2009), RICS (2009) and Kiviniemi et al. (2007) suggest that the accuracy and quality of BIM based estimates rely upon the extent that the project has been defined to the quantity surveyor, the quality of information included, and the details of the construction methods presented in the plans and specifications by the designer. Whether or not the assemblies and objects are well developed in the model also influences the accuracy of BIM based cost estimates (Sabol, 2008).

  Frequently, BIM models do not exactly tally the needs of the quantity surveyors in terms of quality and information. This creates difficulties for the quantity surveyors in managing and searching for the required information within the model for the development of cost estimates. Hereby, the arguments arise as to what information needs to be included in BIM models for the benefit of quantity surveyors. All these factors have to be carefully evaluated to improve the use of BIM in cost estimating. To resolve this issue, Sabol (2008, p. 2) recommends the needs of "methods and standards to support the level of design detail required for useful estimates" and a "framework" to maintain a consistent input of information into the BIM components throughout project stages.

- **Issues related to data exchange**
  Sabol (2008) claims many BIM estimating applications currently do not accommodate bidirectional data exchange. Bidirectional model linking is useful to support information flows and expansion (Hardin, 2009). It enables BIM models to stay updated along the design development process and thus, increases information integration. Accordingly, when new information is input into a model, the quantities and cost information can be simultaneously retrieved and updated within the model (Sabol, 2008). Most software enables only quantities within the model to be constantly transferred and updated during design changes, but not the cost information. However, the nature of the link between a model and its database varies depending on the type of software used (Kymmell, 2008).

- **Lack of standardisation and inappropriate pricing format**
  In practice, the most common issue raised is that even though a quantity surveyor can be provided with a full breakdown of quantities through the automation capabilities of BIM, they are rarely given in a format suitable for pricing. BIM adopted currently struggles with fragmentation and there is no industry standard yet for the link between the model and cost estimating (McCuen, 2009).

Further, Sabol (2008) noted the amount of design information that the current BIM applications are able to model is far in excess than what is actually needed for cost estimating purposes in preliminary project phases. However, it is not advisable for BIM model designers to include as much information as they desire since having inappropriate information at the wrong time in a BIM project would end up in incorrect decision making and unrealistic project planning. Therefore, it is crucial to determine and delineate what information is required to support early cost estimating processes.

Accordingly, the next section of this report examines various measurement standards which have been used in the UK for cost estimating and compares them with the NRM to highlight the importance of conforming BIM models to the information requirement of NRM1 order of cost estimating.

4.0 NRM1 for cost estimating and elemental cost planning

Measurement of work is essential in any building project regardless of the project stage to derive a price or cost for the budget, tender estimate or contract sum (Lee et al., 2011). Hence, quantity surveyors need to have standard guidelines or rules, in which the processes and procedures stipulated can be consistently depend on to produce reliable cost estimates (Serpell, 2005). As a result, several measurement standards have been developed in different countries to fulfil the requirement. The standards of measurement improve the professional judgements of quantity surveyors towards the value and accuracy of measurement works. This section describes the standards used in the UK for measurement and how these standards facilitate the cost estimating and cost planning tasks.

4.1 Traditional standards of measurement

4.1.1 The Standard Method of Measurement for Building Works

According to Matipa et al. (2010), industry practices have largely depended on the use of Standard Method of Measurement (SMM) to obtain the detail project costs in the form of BoQ during tender estimation. SMM has been in use since 1922 to provide quantity surveyors a uniform set of rules and guidelines for measuring and pricing building works (Cartlidge, 2011; RICS, 2012). It has been revised several times over the years and SMM7 is its latest version.

SMM7 rules categorise and organise the building works measurement into many trades in detail, which set out the systematic structure, layout, contents and phraseology for BoQ (Cartlidge, 2011). It utilises the Common Arrangements of Works Sections (CAWS) system as basis to define the classification and coding of items under three levels as shown in Table 4 for greater consistency and easier information distribution (Lee et al., 2011; RICS & CC, 1998).

As indicated in SMM7 (1998), a BoQ prepared according to the SMM explains the quantity and quality of work carried out in a building project comprehensively. Lee et al. (2011) comment that the rules help to maintain the consistency of BoQs in the industry resulting in an improved understanding among project participants and forming a uniformed basis for tender evaluation.

However, SMM7 which has been developed fundamentally based on the traditional procurement method does not effectively cater for variability of procurement strategies in the building industry (Cartlidge, 2011). As a result, different formats are used for measurement works, particularly when procurement methods that do not require a detailed BoQ and tender documents are employed in a project.

The format presented in SMM7 is specifically related to the preparation of BoQs, but not to cost estimates or cost plans. Therefore, SMM7 is unable to support quantity surveyors in providing cost advice due to its failure to suit the new approach of cost planning, particularly when capturing cost information (Cartlidge, 2011). However, there has been a tendency of adopting the SMM for cost estimating and cost planning in the absence of a specific set of standards to serve the practices, (Matipa et al., 2010; RICS, 2012). As a result, approaches that have been used by quantity surveyors for the measurement and description of building works for estimates and cost plans were inconsistent and frequently created doubts about the cost advice provided among the other project team members (Lee and Smith, 2010; RICS, 2012). The ambiguities in cost estimates caused by the absence of an appropriate standard triggered the RICS's move towards deriving a new set of rules for measurement known as New Rules of Measurements (NRM) to encompass the purposes of trades based measurement and cost planning, and to sustain the needs of current construction market

Table 4: Classifications and coding of elements in SMM7

Level	Classification	Elements/Items	Coding
Level 1	Group	Groundwork	D
Level 2	Sub-group	Piling	D30
Level 3	Work Sections	Driven Sheet Piling	D30.27

Source: Holm et al., 2005 cited in Samphaongoen, 2009

4.1.2 BCIS Standard Form of Cost Analysis

Building Cost Information Service (BCIS) developed a document named Standard Form of Cost Analysis (SFCA) to set out how to analyse the cost of a project into elements based on the costing documents from the procurement process (BCIS, 2009). Elemental costs provide a basis for generating a robust estimate for a client based on very little information (BCIS, 2009). Thus, before the NRM were published, SFCA was considered as the existing industry standard for the presentation of elemental cost planning and cost advice (Cartlidge, 2009; Lee et al., 2011). The BCIS way of producing cost plans is strictly dependent on the availability of accurate and well-documented cost information from previous similar projects which are then adjusted for the new project in terms of price, quantity and quality (Cartlidge, 2009).

SFCA outlines the elements of a building project by their functions and provides ways of capturing, analysing, storing and distributing the historical cost data over the building elements to deliver a complete cost plan for early cost advice (BCIS, 2009). The elements are not supposed to be altered according to the design or specification of a project because they are standardised and fixed for the use in all types of projects (BCIS, 2009). In addition, Gross Internal Floor Area (GIFA) is used as the basis for the cost data together with element unit quantities and element unit rates to build up the required elemental-formatted cost plan. This type of cost plan format is meant to help the design team and client to know the cost allocation of the project at a glance (Cartlidge, 2009).

According to Cartlidge (2011), SFCA performed the role as the industry standard for cost planning since 1961 when BoQ was extensively used. There have been no revisions made to its original elemental format for forty years since it first introduced to the industry. Hence, it was insufficient to address the modern business needs without further improvements. The elemental cost data captured could not be readily used in the new construction procurement processes. Consequently, a revision was made to the BCIS SFCA in 2008 (Lee and Smith, 2010) and it is believed that it can now create more positive implications on the pre-contract cost control processes together with the adoption of NRM.

4.2 New Rules of Measurement (NRM)

Upon reviewing the SFCA and SMM7, there was a growing intention within the RICS working group to bridge the gap in the existing standards. Accordingly, a new set of rules known as the New Rules of Measurement (NRM) was drawn up in three separate volumes in 2011 to be applied at various stages of the construction process from early feasibility to building occupation through completion and handover (Cartlidge, 2011). The three volumes are named as follows.

- NRM 1: Order of cost estimating and cost planning for capital building works
- NRM 2: Detailed measurement for building works
- NRM 3: Order of cost estimating and cost planning for building maintenance works

NRM1 provides vital guidance on the quantification of building works for the purpose of preparing cost estimates and cost plans. NRM2 has been prepared to guide the detailed measurement and description of building works for the purpose of obtaining a tender price while NRM3 extends indispensable guidance on the quantification and description of maintenance works for the purpose of preparing initial order of cost estimates during the preparation stages of a building project, cost plans during the design development and pre-construction stages, and detailed, asset-specific cost plans during the pre-construction phases of a building project (RICS, 2012).

Hence, NRM is considered as a comprehensive guide to good cost management of construction projects. In addition to introducing a standard set of measurement rules to provide a consistent approach for cost management, it facilitates an improved understanding of measurement rules for any participants involved in a construction project (Lee et al., 2011; RICS, 2012). NRM is illustrated as a more universal approach that facilitates a worldwide application as opposed to SMM7 that was used to be more UK centric. The following sub-section discusses NRM1 in detail as it is the focus of the research. The research focuses on NRM1 as the basis to identify the information requirement from BIM for cost estimating and cost planning since it is the latest industry standard to be adopted by the UK construction industry.

4.2.1 NRM1 for Order of cost estimating and cost planning for capital building works

A Steering Group set up by the RICS Quantity Surveying and Construction Professional Group to research the problems associated with the measurement of building works at all stages of the design and construction process arrived at the conclusion that it was essential to develop a common and consistent basis that can be used to measure areas and building works items for the purpose of order of cost estimates and cost plans (Lee and Smith, 2010; RICS, 2012). It also recognised the necessity of providing a structured approach for dealing with the other constituents which are not reflected in the measurable building work items, i.e. preliminaries, overheads and profit, project team and design team fees, risk allowances, inflation, and other development and project costs in deriving cost estimates, cost limits or cost targets. Accordingly, NRM1 was developed as the standard measurement rule to guide the quantification of building works for preparation of order of cost estimates and elemental cost plans (BCIS, 2009; RICS, 2012). Although the first edition of the RICS new rules of measurement: Order of cost estimating and elemental cost planning was published in February 2009, a combination of number of factors urged the need for a second edition which was published in April 2012 (RICS, 2012).

NRM1 provides a structured basis for preparing order of cost estimates and elemental cost plans including all the costs and allowances forming part of the cost of the building to the client but which are not reflected in the measurable building work (BCIS, 2009). An order of cost estimate is necessary to examine the affordability of a proposed building project and, if affordable, to establish a realistic cost limit for the building project. The cost limit is the maximum expenditure that the employer is prepared to make in relation to the completed building project, which will be managed by the project team (RICS, 2012). The cost limit is established prior to preparation of complete set of working drawings or BoQ and forms the initial build up to the cost planning process (BCIS, 2009). NRM1 provides guidance for the preparation of order of cost estimates using three methods of estimating; namely, floor area method, functional unit method and elemental method. Figure 9 demonstrates the components of an order of cost estimate according to NRM1.

Elemental cost planning is the breakdown of the cost limit into cost targets into each element of the building. It provides a statement of how the design team proposes to distribute the available budget among the elements of the building, and a frame of reference from which to develop the design and maintain cost control (BCIS, 2009).

Figure 9: The key constituents of an order of cost estimate

	Constituent
(1)	Facilitating works estimate
(2)	Building works estimate
(3)	Main contractor's preliminaries estimate
(4)	Sub-total [(4) = (1) + (2) + (3)]
(5)	Main contractor's overheads and profit estimate
(6)	**Works cost estimate [(6) = (4) + (5)]**
(7)	**Project/design team fees estimate** (if required)
(8)	Sub-total [(8) = (6) + (7)]
(9)	**Other development/project costs estimate** (if required) (9)
(10)	**Base cost estimate** [(10) = (8) + (9)]
(11)	**Risk allowances estimate** [(11) = (11(a)) + (11(b)) + (11(c))+ (11(d))]
	(a) Design development risks estimate
	(b) Construction risks estimate
	(c) Employer change risks estimate
	(d) Employer other risks estimate
(12)	**Cost limit (excluding inflation)** [(12) = (10) + (11)]
(13)	**Tender inflation estimate**
(14)	Cost limit (excluding construction inflation) [(14) = (12) + (11)]
(15)	**Construction inflation estimate**
(16)	**Cost limit (including inflation)** [(16) = (14) + (15)]
	VAT assessment

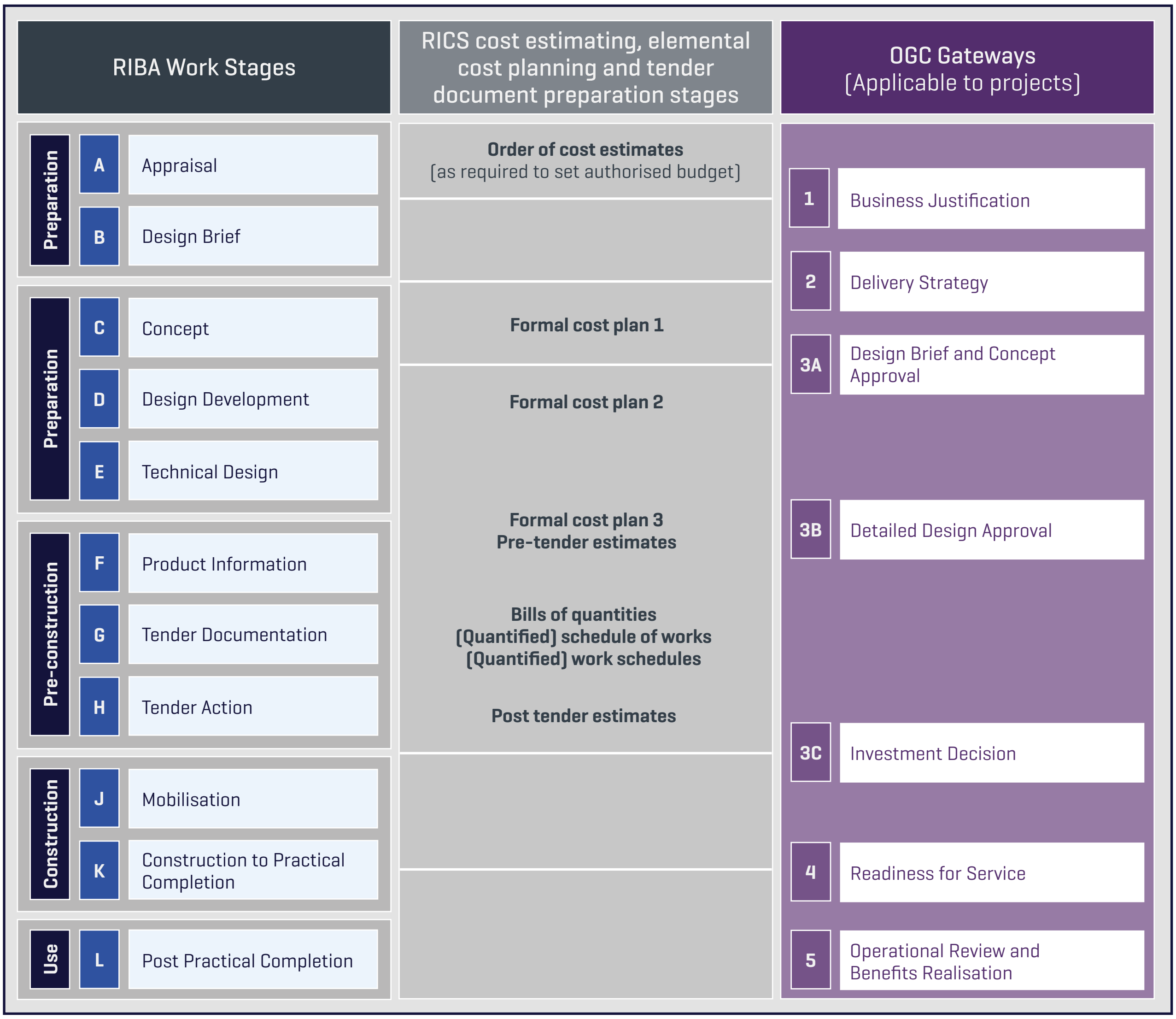
Source: RICS, 2012

RICS (2012, p.2) introduces NRM1 as "the 'cornerstone' of good cost management of construction projects – enabling more effective and accurate cost advice to be given to clients and other project team members, as well as facilitating better cost control". The rules in NRM1 can also be used for the preparation of cost analyses and benchmark analyses (RICS, 2012). With the ability of using as a basis for capturing historical cost data in the form required for order of cost estimates and elemental cost plans, NRM1 completes the entire cost management cycle. Lee and Smith (2010) point out five usages of NRM1 as follows.

- Pre-construction cost management
- Order of cost estimates
- Cost planning
- Construction phase cost management
- Analysis of cost data

Further, NRM1 makes references to both the RIBA (Royal Institute of British Architects) Plan of Work and the OGC (Office of Government Commerce) Gateway Process throughout the document. RIBA Plan of Work and the OGC Gateway Process are recognised frameworks for managing and designing building projects. Cost estimates and cost plans are necessary to be prepared by the quantity surveyor/cost manager at various stages of the RIBA Plan of Work or at various gateways in the OGC Gateway Process, whichever management process is applicable (RICS, 2012). Hence, RICS has determined a series of formal cost estimating and elemental cost planning stages as shown in Figure 10 in the context of the RIBA Work Stages and OGC Gateways. Order of cost estimates are produced as a fundamental part of RIBA Work Stages A: Appraisal and B: Design Brief, or OGC Gateways 1 (Business Justification) and 2 (Delivery Strategy).

Figure 10: Cost estimating, elemental cost planning and tender document preparation stages in context with the RIBA Work Stages and OGC Gateways



Source: RICS, 2012

In addition, the format of NRM1 which offers a way of dealing with cost allowance that is not reflected in measurable building work, provides a greater range of cost information to clients compared to the SFCA format (Cartlidge, 2011). BCIS (2009) identifies three main differences between NRM and SFCA as follows:

- NRM covers the non-physical aspects of a project that the client may require as part of his overall budget for the project, while the SFCA relates to the physical construction and contractors charges.
- Pragmatic changes to presentation and allocation
- Different coding system

NRM1 classification is aligned in a constant numeric coding system which is distinctive from the CAWS arrangement; that can be used from early estimate to cost planning and life cycle costing, e.g. '2.6.1 External Windows'. An example for the NRM1 classification and coding of elements is shown in Figure 11. BCIS (2009) found that the NRM structure is evolved and developed from SFCA's elemental format, with some pragmatic changes in terminology, structure presentation, and element classifications.

Figure 11: Classification and coding of elements in NRM1

Level 1	Level 2	Level 3
Superstructure	Frame	Steel frame
		Space decks
		Concrete casings to steel frames
		Concrete frames
		Timber frames
		Specialist frames
	Upper floor	Concrete floors
		Precast/composite decking systems
		Timber floors
		Structural screeds
		Balconies

4.2.3.1 Information requirement in NRM1

In addition to the improved features that were previously indicated, NRM1 contains a unique feature that further uplifts it to a more comprehensive standard for cost estimating and cost planning. It specifies the basic information requirement from the employer and other project team members to prepare the order of cost estimate. In addition, lists the rules of measurement and parameters to inform each project participant what information is to be supplied to the quantity surveyor in the preparation of accurate cost estimates and cost plans.

However, the information requirement outlined in Figure 12 only serves the purpose of conceptual estimating and the requirements continue to expand throughout the cost planning process as the design develops and more details become available. The more information is provided to the quantity surveyor, the more accurate the estimates are, and therefore, it is important to understand the information requirement which is necessary for the latter stages of the cost planning process as well.

Similarly, it is vital for a quantity surveyor to have access to the required type of information from a BIM model in BIM based estimating. Thus, identifying and specifying the type of information required from a BIM model at different stages of cost estimating and planning is extremely important. Although the NRM1 does not specify the extended information requirement, its classifications and the measurement rules can be used as the basis to specify the type of information required for latter stages of cost planning. Accordingly, an information requirement for different stages of BIM based estimating that has been developed based on NRM1 is presented in the next section of this report.

Figure 12: Basic Information Requirements for the Order of Cost Estimates in NRM

Project participants	Information requirements
Clients	• Site location and availability • Building Use • Initial requirements on the building quality, sustainability, 'fit-out' • Key dates or programme for the project • Site conditions • Budget constraints • Preferable procurements options • Targeted building lifespan • Proposed storey height of the building • Specific M&E services requirement • Requirements on professional fees, inflation and VAT treatment • Other considerations e.g. capital allowances, land remediation and grants
Architects	• Design sketches including plans, elevation and sections • Information on GEA, GIFA, NIA and SA • Minimum storey height • Schedule of accommodation (in conjunction with client) • Number of car park spaces • Indicative specification and design intent for building options • Indicative sustainability strategy • Likely site and planning constraints • Initial risk register/log

Source: RICS, 2009

5.0 Findings

5.1 Information requirement for BIM to support NRM1 order of cost estimating

5.1.1 Introduction

The aim of the information requirement specification for BIM models is to guide the quantity surveyor how a BIM model can be used to support NRM 1 order of cost estimate and cost plan. It also intends to provide a technical modelling requirement to the design team from a cost estimating point of view.

The scope of the study mainly focuses on the building work section of the cost estimate and cost plan. Autodesk Revit 2013 model is used as the primary BIM format in this report.

5.1.2 Order of cost estimating

According to NRM 1, Order of cost estimates is produced as part of RIBA Work Stages A: Appraisal and B: Design Brief, or OGC Gateways 1 (Business Justification) and 2 (Delivery Strategy).

The information requirement of the order of cost estimates is specified in the section of 2.3 of NRM1.

- The information from the employer will not be available through a BIM model at this stage (2.3.1)
- The information from the architect is most likely to be provided through a conceptual BIM model and a Preliminary BIM model. A conceptual BIM model is modeled as three dimensional space objects in the BIM authoring tool, such as Autodesk Revit. Autodesk Revit 2013 has a Conceptual Design Environment and a Mass family to produce Conceptual BIM models. The Site design can also be included in a Conceptual BIM model to represent the parking, plants and topographical surface (2.3.2)
- The information from the M&E (Mechanical and Electrical) engineer and the structural engineer are unlikely to be available through a BIM model at this stage (2.3.3 and 2.3.4)

5.1.2.1 Conceptual BIM model requirement

- A conceptual BIM model must be modelled as 3D space objects. In Autodesk Revit, Mass family objects should be used.
- Mass floor should be used to divide a mass based on the defined level to enable Revit to calculate the floor area, external surface area, volume and perimeter and the information can be exported through schedules.

5.1.2.2 Preliminary BIM model requirement

- A Preliminary BIM model is developed from a conceptual BIM model by converting the 3D space objects to the major building elements.
- In Autodesk Revit, the major building elements can be created from Mass instances. Standard building element objects should be used to create the building elements. The following building elements should be included in the model:
  - Ground floor (floor element)
  - Upper floor (floor element)
  - Internal and external wall (wall element)
  - Windows (window element)
  - Door (internal and external) (door element)
  - Roof (roof element)
- The material information of the building element might not be included in the model at this stage
- The type definition of the building element might not be included in the model at this stage
- Space definitions might be included in the model. In Autodesk Revit, it is defined as the Area or Area Plan. The quantity of area or area plan can be exported from the model.

5.1.2.3 Measurement Rule

- Quantities for facilitating work shall be based either on the site area, or the area affected. Site area can be obtained through a Spatial BIM model if the site design is included in the model. (2.5)
- Quantities for building works shall be determined by measuring the total gross internal floor area (GIFA) if the floor area method is used. The GIFA is to be measured in accordance with the core definition of GIA of the RICS code of measuring practice. In a Conceptual BIM model, area of the Mass floor can be exported, in a preliminary BIM model, quantity information of the area /area plan object can be exported. However, a careful attention need to be paid to ensure the area calculation comply with the RICS measurement standards. (2.6)
- Where the external works is to be measured separately, the site area (SA) can be used. Site area can be obtained through a Spatial BIM model if the site design is included in the model.

5.1.2.4 Elemental method

The elemental method is an alternative approach for calculating the total estimated cost of building works (i.e. the building works estimate). The elemental method considers only the major elements of a building and provides an order of cost estimate based on an elemental breakdown of the building project.

5.1.2.5 Information Requirement from BIM model for elemental method

The following information requirement has been developed based on Rules of Measurement for Elemental Method of Estimating of NRM1 (RICS, 2012, p.27) to specify the required information from a BIM model for elemental method of cost estimating.

Table 5: Information Requirement

Group Element	Element	Unit	Required Information from BIM	Autodesk Revit Model information
0 Facilitating works		m^2	N/A	It is usually not included in the BIM model. Site Area can be obtained if the site design is included in the model
1 Substructure	**1 Substructure**	m^2	• Area of the lowest floor • Areas of basements	Floor element in Revit. Dimensions included in Floor element: • Slope Angle • Perimeter • Area • Volume • Thickness If area is defined in basement, area property can be used. Dimensions included in area element: • Area • Perimeter
2 Superstructure	**1 Frame**	m^2	• Area of the floors related to the frame.	Floor element in Revit. Dimensions included in Floor element: • Slope Angle • Perimeter • Area • Volume • Thickness If areas are defined in upper floor, area property can be used. Dimensions included in area element: • Area • Perimeter
	2 Upper floors	m^2	• Area of upper floor(s) • Areas for balconies, galleries, tiered terraces, service floors, walkways, internal bridges, external links, and roofs to internal buildings.	Floor element in Quantity information needed in Floor element: • Slope Angle • Area

Group Element	Element	Unit	Required Information from BIM	Autodesk Revit Model information
2 Superstructure (continued)	**3 Roof**	m^2	• Area of the roof on plan	Quantity information needed in Roof element: (please note, the area in roof element is the actual area of the roof element, not the roof on plan). • Area
	4 Stairs and ramps	nr	• Total number of storey flights • Total vertical rise of each staircase or ramp	Stair tool / element
	5 External walls	m^2	• Area of the external wall • Area of windows	Wall element in Revit. Dimensions included in Floor element: • Length • Area • Thickness Window element in Revit. Dimensions included in Floor element: • Height • Width
	6 Windows and external doors	m^2	• Area of windows and external doors	Window element in Revit. Dimensions included in Floor element: • Height • Width Door element in Revit. Dimensions included in Floor element: • Height • Width • Thickness
	7 Internal walls and partitions	m^2	• Area of internal walls and partitions	Wall element in Revit. Dimensions included in Floor element: • Length • Area • Thickness
	8 Internal doors	nr	• Total number of internal doors	Classification according to the door type is not necessary at this stage
3 Internal finishes	**1 Wall finishes**	m^2	• Total area of wall to which finishes are applied	Room element, definition of the finishes and dimension in wall elements
	2 Floor finishes		• Total area of floor to which finishes are applied	Room element, definition of the finishes and dimension in floor elements
	3 Ceiling finishes		• Total area of ceiling to which finishes are applied	Room element, definition of the finishes and dimension in ceiling elements
4 Fittings, furnishings and equipment		m^2	• Gross internal floor area (GIFA)	If area/ area plan is defined in the model, area property can be used. (please check if the definition of the area plan is comply with RICS GIA definition.) Dimensions included in area element: • Area • Perimeter
5 Services			Not include in the scope of the study	

Group Element	Element	Unit	Required Information from BIM	Autodesk Revit Model information
6 Prefabricated buildings and building units	**1 Prefabricated buildings and building units**	m^2	• Gross internal floor area (GIFA) of the complete buildings or prefabricated room units	If area/ area plan is defined in the model, area property can be used. (please check if the definition of the area plan is comply with RICS GIA definition.) Dimensions included in area element: • Area • Perimeter
7 Work to existing buildings	**1 Minor demolition and alteration works**	m^2	N/A	This information is not included in BIM
8 External works	**1 Site preparations works**	m^2	N/A	This information is not included in BIM
9 Main contractor's preliminaries		%	N/A	This information is not included in BIM
10 Main contractor's overheads and profit		%	N/A	This information is not included in BIM

5.1.3 Formal cost planning

Elemental cost plans are produced as part of RIBA Work Stages C: Concept, D: Design Development, E: Technical Design and F: Production Information; or, when the OGC Gateway Process is used, Gateways 3A (Design Brief and Concept Approval) and 3B (Detailed Design Approval).

There are a number of formal cost planning stages, which are comparable with the RIBA Design and Pre-Construction Work Stages and OGC Gateways 3A (Design Brief and Concept Approval) and 3B (Detailed Design Approval) for a building project.

- **Formal cost plan 1** – RIBA Work Stage C- Concept / OGC 3A
- **Formal Cost Plan 2** - RIBA Work Stage D- Design Development / OGC 3B
- **Formal Cost Plan 3** - RIBA Work Stage E, F- Technical Design, Production Information / OGC 3B

The degree of detail to be measured for building work in formal cost plan is determined by the available design information and cost significance of the elements in the particular design. Cost significant elements with sufficient design information can be measured by means of approximate quantities. GIFA is used as the relevant quantity where sufficient design information is unavailable to quantify the building work in accordance with the rule of measurement.

The BIM model at this stage will be evolved to include more detailed building elements in addition to spatial elements from the preliminary BIM model. Information on materials and element type will be included in accordance with the specification. The BIM based quantity take-off process can be used to obtain the approximate quantities for the formal cost plans.

5.1.3.1 BIM model requirement

In order to take full advantage of the BIM technology, a BIM model needs to meet the following requirements in relation to cost estimating and planning. It is important that the requirements are agreed by the project team and documented at the beginning of the project.

- **Walls**
  All walls should be modelled using a wall element in BIM tool. It should be modelled from slab to slab, except for the enclosure walls and walls of staircases, which must be modelled according to their story heights. Internal or external wall should be specified in the wall property.

  Walls with a height spanning multiple stories must be modelled separately for each story with the height of the respective story.

- **Doors and windows**
  Doors and windows should be modelled using a door element and windows element in the BIM tool. The type and fitting information must be included in the model as part of their properties. The dimensions of window and door frames must be indicated in a consistent manner using either frame or opening dimensions.

- **Curtain walls, large windows**
  Curtain walls and large windows are usually modelled as windows in some of the BIM tools. If it is the case, the host wall must be modelled first, before the glass walls are inserted. In Autodesk Revit, the curtain element should be used to model curtain walls.

- **Floor (ground floor, upper floors)**
  The ground floor and upper floor slabs of the building must be modelled using a floor element. The joining of floor and walls are usually modelled such that the floor ends to the surface of the load-bearing wall structure without extending inside it. This is to ensure that the quantity extracted is consistent with the GIFA measurement rule. Floors must be modelled so that they extend to the internal surface of the external wall. Special checks are required to ensure the model complies with this requirement as the practice of the design team might be different from the QS team.

- **Beams and Columns**
  Beams should be modelled using a beam element in the BIM tool. Columns should be modelled using a column element in the BIM tool. Column with a height spanning multiple stories should be modelled separately for each story with the height of the respective story. Special checks are required for the column beam joint and beam wall joint as the practice of the design team might be different from the QS team.

- **Stairs**
  Stairs must be modelled using a stair tool or stair object, separately for each story. If required, the resting, story and stair platforms may be modelled as slabs.

- **Other building elements**
  All building elements with different types should be modelled as separate elements and provided with information, so they can be extracted separately. If the standard building element tool in the BIM tool is not sufficient to support the element required, generic element should be developed, the naming and the presentation style of the generic element should be agreed by the project team.

5.1.3.2 BIM Model quantity takeoff requirement

- **Element naming convention and presentation**
  It is significant to ensure that all building elements are modelled in the same style as agreed and documented by the project team. It will be problematic when the same element is modelled differently in different parts of the building. The standard naming convention for building elements and their type information should be established. All different building elements should be identifiable through the type information from quantity takeoff point of view. It is important to note that different disciplines might view the type information differently. Therefore, an identification system for each element type must be established and documented by the project team.

- **Quantity information of elements**
  The measurement rules of the cost plan require specific quantity information of each element. For example, windows can be taken off by count or by area, which both can be provided by the windows element.

  Quantity takeoff typically uses the following quantity information:

  - Count
  - Length measure
    - Length
    - Perimeter
    - Height
  - Area measure
    - Net area
    - Gross area
  - Volume measure
    - Net volume
    - Gross volume
  - Weight

  For quantity takeoff, it is essential that BIMs are created using elements which provide the quantity information required by quantity takeoff. The easiest solution is to model each building element using the modelling tool for that specific building element, for example, modelling walls with the wall tool. If a building element is modelled using a tool that is incompatible with the requirements of quantity takeoff, the quantity for that building element cannot be taken off automatically. Table 6 provides the list of main building elements and quantity information available in the Autodesk Revit 2013.

- **BIM Quantity takeoff methods**
  - Automated takeoff

    The quantity information of the building elements from BIM model is automatically extracted by using quantity takeoff tools or BIM authoring tool. This is the most efficient way for quantity takeoff by gaining full advantage of BIM. However, this requires the BIM model to be developed in accordance with takeoff requirement.
  - Derived takeoff

    If the BIM model does not contain an element which is required to include in the quantity takeoff, it can be derived from other building elements. For example, quantity information for concrete formwork, can be derived from a corresponding concrete element such as columns or beams.
  - Manual takeoff

    If the BIM model does not contain an element, which is required to include in the quantity takeoff and it cannot be derived from other building element, the traditional manual takeoff process can still be used together with BIM based quantity takeoff.

- The data exchange between the quantity takeoff tool and BIM tool has a major impact on the reliability of the quantity information. It is important to ensure the quantity takeoff can import the BIM model reliably. It needs to be emphasised that quantity takeoff is only the first step of completing a cost plan, the quantity information from the BIM model requires organising and grouping to match the NRM format of cost plan. Most of the BIM takeoff tools are flexible enough to create new categories to meet any specific requirement, although it is a manual process.

- NRM 1 Measurement rule for formal cost plans

Table 7 (Group element 2 – Superstructure) has been generated to illustrate how the BIM information is used to support the measure rules of the formal cost plan.

Table 6: Building Elements in Autodesk Revit

Building Elements	Description	Quantity information
Wall	Architectural wall or structural wall	Length of the wall, area of the wall, the volume of the wall
Doors	Door (hosted component) can be added on any wall, it can be external or internal.	Thickness of the door, height of the door, width of the door,
Windows	Windows (hosted component) can be added on any wall or roof	Height of the opening of the windows, width of the windows,
Roofs	Standard roof elements, can't cut through windows or doors	Slope, thickness of the roof, volume of the roof and area of the roof, please note, this is the actual area, not the area on plan.
Ceilings	Ceiling are level based elements, created at a specified distance above the level which they reside	Slope, Perimeter of the ceiling, area of the ceiling and volume of the ceiling
Floors	Floor element, can be a structural element	Slope Angle, perimeter of the floor, area of the floor, volume of the floor and thickness of the floor
Stairs by components	Stair is assembled with common components, such as run, landing and support	Desired number of risers, actual number of risers, rise height and tread depth
Stairs by sketch	Stair is created by defining the run of the stairs	Width of the stairs, Desired number of risers, actual number of risers, rise height and tread depth
Curtain Elements	Curtin element is used to create building façades, such as curtain wall.	Length of the curtain wall and area of the curtain wall
Column	Architectural columns and structural columns	Column width, column depth and column volume.
Beam	Beams are structural elements for load bearing applications.	Length of beam, volume of beam Steel Beam Section area, nominal weight, Flange width, depth of section, k distance, k2 distance, Flange thickness, web thickness
Foundation	Wall Foundations Isolated Foundations Foundation Slabs	Elevation at bottom for all foundations: Length, width and volume of the wall foundation Width, length and thickness of isolated foundations Slope, perimeter, area, volume of the foundation slab

Source: Autodesk, 2013

Table 7: Information requirement from BIM for elemental cost planning

Group element 2: Superstructure					
Element	**Sub-element**	**Component**	**Unit**	**Required Quantity Information from BIM** (in accordance with the rules of measurement)	**Notes/remarks**
2.1 Frame	1 Steel frames	1 Structural steel frame	t	The total mass of the steel frame including, • Structural components - columns, beams, composite columns and beams, lattice beams, braces, struts and the like • Fittings and Fixtures • Roof trusses which are an integral part of the frame • Floor and roof members or decks forming an integral part of the frame	It will be modelled in structural element with steel as the property type and the nominal weight of the element is available from the element quantity information
	2 Space frames/ decks	1 Space frames/decks	m^2	• Area of the upper floors	Quantity information from area / area plan
	3 Concrete casings to steel frames	1 Column casings	m	• Number and size of columns • Type of formwork finish	Quantity information is available from column element, formwork finish is not usually in the model
		2 Beam casings		• Number and size of beams • Type of formwork finish	Quantity information is available from column element, formwork finish is not usually in the model
	4 Concrete frames	1 Columns	m	• Number and size of columns • Type of formwork finish	Quantity information is available from column element, formwork finish is not usually in the model
		2 Beams		• Number and size of beams • Type of formwork finish	Quantity information is available from beam element, formwork finish is not usually in the model
		3 Walls		• Area and thickness of walls	Quantity information is available from wall element, formwork finish is not usually in the model
		4 Extra over walls for forming openings in walls for doors, windows, screens and the like	nr	• Sizes and number of openings	Quantity information from opening object or doors and window object
		5 Designed joints	m		
	5 Timber frames	1 Timber frames	m^2	• Area of the upper floors	Quantity information from area / area plan
	6 Specialist frames	1 Specialist frame	m^2	• Area of the upper floors	Quantity information from area / area plan
2.2 Upper floors	1 Floors	Concrete floors: 1 Suspended floor slabs	m^2	• Area of the upper floors • Area of each floor construction type • Areas for balconies, galleries, tiered terraces, service floors, walkways, internal bridges, external links and roofs to internal buildings	Quantity information from floor element with different type information
		2 Edge formwork	m	• Length of edge formwork	Quantity information from floor element (perimeters)
		3 Designed joints		N/A	
		4 Surface treatments	m^2	• Area of the upper floors	Quantity information from area / area plan or floor element

Group element 2: Superstructure					
Element	**Sub-element**	**Component**	**Unit**	**Required Quantity Information from BIM** (in accordance with the rules of measurement)	**Notes/remarks**
2.2 Upper floors *(continued)*	1 Floors *(continued)*	**Precast/composite decking systems:** 5 Suspended floor slabs	m^2	• Area of the upper floors • Area of each floor construction type • Areas for balconies, galleries, tiered terraces, service floors, walkways, internal bridges, external links and roofs to internal building	Quantity information from area / area plan or floor element
		Timber Floors: 6 Timber Floors	m^2	• Area of the upper floors • Where more than one type of floor construction type, area of each floor construction type • Areas for balconies, galleries, tiered terraces, service floors, walkways, internal bridges, external links and roofs to internal buildings	Quantity information from area / area plan or floor element
		Structural screeds: 7 Structural screeds		• Area to which screed is applied	Quantity information from floor element with different type information
	2 Balconies	1 Balconies	nr	• Number and area of balconies	Quantity information from the actual object if it is modelled separately.
	3 Drainage to balconies	1 Rainwater pipes	m	• Length of rainwater pipes	Quantity information from the actual object if it is modelled separately.
		2 Floor outlets	nr	• Number of floor outlets	Quantity information from the actual object if it is modelled separately.
		3 Testing of installations	%	N/A	
		4 Commissioning of installations			
2.3 Roof	1 Roof structure	1 Roof structure- pitched roofs	m^2	• Area of the roof on plan • Design load, span, and angle of pitch	Quantity information from roof element, please note the area information from the element is the actual roof area, not the area on plan.
		2 Extra over roof structure- pitched roofs for forming dormer			
		3 Prefabricated dormers	nr		
		4 Roof structure-flat roofs	m^2		
	2 Roof covering	1 Roof coverings, non-structural screeds, thermal insulation, and surface treatments	m^2	• Surface area of the roof covering • Where more than one type of roof covering, area of each roof covering system	Detailed roof element can be added in the overall roof element, quantity information is available from the individual elements
		2 Extra over roof coverings for coverings to dormers, including cladding to dormer cheeks		• Area of rooflights, skylights and openings • Surface area of the dormer roof coverings	
		3 Eaves, verge treatment to pitched roofs	m	• Lengths of eaves, verge, edges	

Group element 2: Superstructure					
Element	**Sub-element**	**Component**	**Unit**	**Required Quantity Information from BIM** (in accordance with the rules of measurement)	**Notes/remarks**
2.3 Roof *(continued)*	**2 Roof covering** *(continued)*	4 Edge treatment to flat roofs	m	• Lengths of eaves, verge, edges	Detailed roof element can be added in the overall roof element, quantity information is available from the individual elements
		5 Flashings			
	3 Specialist roof systems	1 Specialist roof systems	m^2	• Area of the glazed roof on plan	
	4 Roof drainage	1 Gutters	m	• Length of gutters • Length of pipes	
		2 Rainwater pipes			
		3 Testing of installations	%	N/A	
		4 Commissioning of installations			
	5 Rooflights, skylights and openings	1 Rooflights, skylights and openings	nr/ m^2	• Number of rooflights, skylights and openings • Area of rooflights, skylights and openings	
	6 Roof features	1 Roof features	nr	• Number of components	
2.4 Stairs and ramps	**1 Stair/ramp structures**	1 Stair structures	nr	• Number of storey flights • Vertical rise	Quantity information from the stair element.
		2 Ramp structures			
	2 Stair/ramp finishes	1 Stair finishes	nr	• Number of storey flights • Vertical rise	
		2 Ramp finishes			
	3 Stair/ramp balustrades and handrails	1 Wall handrails	nr	• Number of storey flights • Vertical rise	
		2 Combined balustrades and handrails			
	4 Ladders/ chutes/ slides	1 Ladders	nr	• Number of ladders/chutes/slides	Quantity information from the actual object if it is modelled separately
		2 Chutes			
		3 Slides			
2.5 External walls	**1 External enclosing walls above ground level**	1 External walls	m^2	• Area of the external wall • Where more than one external wall system is employed, area of each external wall system	Quantity information from wall element with different type
		2 Extra over external walls for plinths, cornices, ornamental bands and the like		• Details of plinths, cornices, ornamental bands and the like	Quantity information from the actual object if it is modelled separately.
		3 Extra over external walls for quoins	m	• Length of quoins	
		4 Extra over external walls for forming openings for windows	nr	• Number and dimensions of windows • Number and dimensions of external doors	Quantity information from the relevant door and window element
		5 Extra over external walls for forming openings for external doors			

Group element 2: Superstructure					
Element	**Sub-element**	**Component**	**Unit**	**Required Quantity Information from BIM** (in accordance with the rules of measurement)	**Notes/remarks**
2.5 External walls *(continued)*	**1 External enclosing walls above ground level** *(continued)*	6 Extra over cladding or curtain walling system for integral photovoltaic panels	nr	• Number integral photovoltaic panels	Quantity information from the actual object if it is modelled separately.
		7 Extra over cladding or curtain walling system for integral opening vents and panels	nr/ m^2	• Area of cladding or curtain walling system • Number and dimensions of integral opening vents and panels	
		8 Projecting fins to cladding or curtain walling system	nr	• Number of projecting fins	Quantity information from the actual object if it is modelled separately
		9 Extra over projecting fins for applied artwork	item	• Details of applied artwork	
		10 Safety barriers, handrails or combined balusters and handrails to facetted glazing or cladding systems	nr/m	• Number of safety barriers, handrails or combined balusters and handrails • Length of facetted glazing or cladding systems	
		11 Finishes applied to external walls	m^2	• Surface area of the external wall finishes	Quantity information from the relevant wall element
	2 External enclosing walls below ground level	1 External walls	m^2	• Area of the external wall • Where more than one external wall system is employed, area of each external wall system	Quantity information from wall element with different type
		2 Extra over external walls for plinths, cornices, ornamental bands and the like	m	• Details of plinths, cornices, ornamental bands and the like	Quantity information from the actual object if it is modelled separately
		3 Extra over external walls for quoins		• Length of quoins	
		4 Extra over external walls for forming openings for windows	nr	• Number and dimensions of windows • Number and dimensions of external doors	
		5 Extra over external doors walls for forming openings for external doors			
		6 Finishes applied to external walls		• Surface area of the external wall finishes	Quantity information from wall element
	3 Solar/rain screening	1 Vertical solar/rain screening	m^2	• Area of the overcladding system • Where more than one type of overcladding system is employed, the area for each overcladding system	Quantity information from the actual object if it is modelled separately.
		2 Horizontal solar/rain screening	m	• Length of horizontal solar/rain screening	
	4 External soffits	1 External soffit	m^2	• Area of each type of external soffit	
		2 Cornices, covings and the like	m	• Length of cornices, covings and the like with details	

Group element 2: Superstructure					
Element	**Sub-element**	**Component**	**Unit**	**Required Quantity Information from BIM** (in accordance with the rules of measurement)	**Notes/remarks**
2.5 External walls *(continued)*	4 External soffits *(continued)*	3 Shadow gaps and the like	m	• Length of shadow gaps and the like with details	Quantity information from the actual object if it is modelled separately.
		4 Access hatches and the like	nr	• Number of access hatches and the like with details	
		5 Finishes applied to external soffits	m^2	• Area of finishes to external soffit	
	5 Subsidiary walls, balustrades and proprietary balconies	1 Walls	m	• Length of walls	Quantity information from wall element with different type
		2 Walls forming planters		• Length of walls forming planters	
		3 Combined balustrades and handrails	m	• Length of combined balustrades and handrails	
		4 Wall mounted handrails		• Length of wall mounted handrails	Quantity information from the actual object if it is modelled separately.
		5 Parapet railings		• Length of parapet railings	
		6 Proprietary bolt-on balconies		• Length of proprietary bolt-on balconies	
		7 Rainwater pipes	nr	• Number of rainwater pipes	
		8 Floor outlets		• Number of floor outlets	
		9 Testing of rainwater drainage installation	%	N/A	
		10 Commissioning of rainwater drainage installation			
	6 Façade access/ cleaning systems	1 Facade cleaning systems	nr	• Number of facade cleaning systems	
		2 Testing of installations	%	N/A	
		3 Commissioning of installations			
2.6 Windows and external doors	1 External windows	1 Windows	m^2	• Area of each type of windows with dimensions	Quantity information from windows element with different type information
		2 Louvers		• Area of each type of louvers with dimensions	
		3 Shop fronts		• Area of each type of shop fronts with dimensions	
		4 Roller shutters, sliding shutters, grilles and the like to window openings	nr	• Number of roller shutters, sliding shutters, grilles and the like with dimensions of each type	
	2 External doors	1 External doors	nr	• Number of each type of door • Dimensions of each type of door leaf • Dimensions of overall openings	Quantity information from door element with different type information and door property set as exterior
		2 Revolving doors		• Number of Revolving doors • Dimensions of overall opening	

Group element 2: Superstructure					
Element	**Sub-element**	**Component**	**Unit**	**Required Quantity Information from BIM** (in accordance with the rules of measurement)	**Notes/remarks**
2.6 Windows and external doors *(continued)*	2 External doors *(continued)*	3 Shop front doors	nr	• Number of each type of shop front door • Dimensions of each type of door leaf • Dimensions of overall openings	Quantity information from the actual object if it is modelled separately
		4 Roller shutters, sliding shutters and the like to external door openings		• Number of roller shutters, sliding shutters and the like to external door openings • Dimensions of overall opening	
		5 Garage doors		• Number of garage doors • Dimensions of overall opening	
		6 Canopies		• Number of canopies	
		7 Grilles		• Number of grilles	
		8 Architraves	m	• Length of architraves	
2.7 Internal walls and partitions	1 Walls and partitions	1 Internal walls	m^2	• Area of internal walls • Where more than one type of internal walls is employed, area of each type of internal walls	Quantity information from wall element with wall property set as internal.
		2 Extra over internal walls for forming openings in walls for internal doors and the like	nr	• Number of openings in walls for internal doors and the like • Overall size of openings	
		3 Fixed partitions	m^2	• Area of partitions • Where more than one type of partitions is employed, area of each type of partitions	
		4 Extra over fixed partitions for forming openings in partitions for internal doors and the like	nr	• Number of openings in partitions • Overall size of openings	
	2 Balustrades and handrails	1 Combined balustrades and handrails	m	• Length of internal balustrades/ handrails/ other fixed non-storey height divisions • Where more than one component is used, length of each component	Quantity information from the actual object if it is modelled separately
	3 Moveable room dividers	1 Moveable room dividers and partitions	m	• Length of moveable room dividers/ partitions • Where more than one component is used, length of each component	
	4 Cubicles *(continued)*	1 Cubicles	nr/ m/m^2	• Number of cubicles • Dimensions	
		2 Fixed partitions		• Number of fixed partitions • Dimensions	
2.8 Internal doors	1 Internal doors	1 Internal doors	nr	• Number of internal doors • Dimensions of each type of door leaf • Dimensions of overall openings	Quantity information from door element with different type information and door property set as interior

Group element 2: Superstructure					
Element	**Sub-element**	**Component**	**Unit**	**Required Quantity Information from BIM** (in accordance with the rules of measurement)	**Notes/remarks**
2.8 Internal doors *(continued)*	1 Internal doors *(continued)*	2 Fire resisting doors	nr	• Number of fire resisting doors • Dimensions of each type of door leaf • Dimensions of overall openings	Quantity information from door element with different type information and door property set as interior
		3 Door sets		• Number of door sets • Dimensions of each type of door leaf • Dimensions of overall openings	
		4 Composite door and sidelights/over panel units		• Number of door composite door and sidelights/over panel units • Dimensions of each type of door leaf • Dimensions of overall openings	
		5 Roller shutters, sliding shutters, grilles and the like		• Number of Roller shutters, sliding shutters, grilles and the like • Dimensions of overall openings	
		6 Architraves	m	• Length of architraves	

6.0 Technical review for BIM based estimating tool to support NRM

Quantity surveyors will have to select and use a BIM based estimating tool in order to be part of a BIM based project and to benefit from the advantages of BIM technology. In this context, the following sections review the functional and technical capabilities of four BIM based estimating applications in UK market.

- Solibri Model Checker 8
- Autodesk QTO 2012
- CostX 3.5
- BIM Measure 16.4

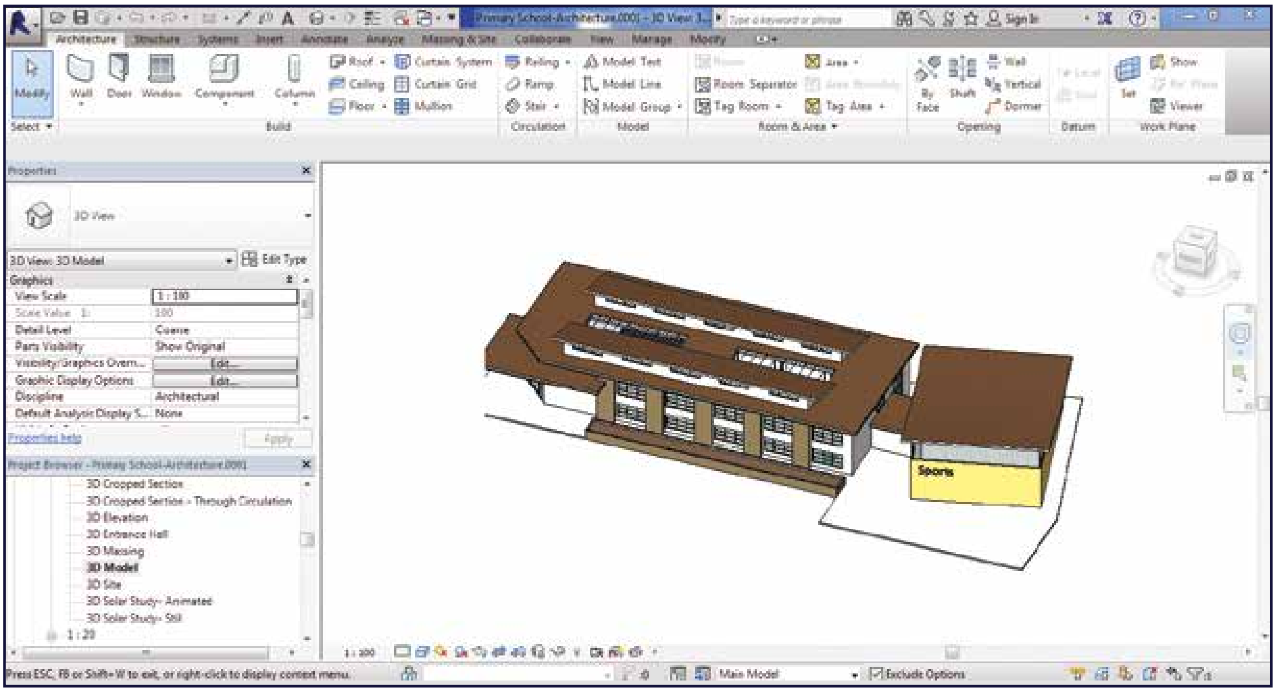
6.1 Review methodology

BIM based estimating tools vary in their functionality and working processes and it is not the intent for this review to compare the performance of tools against each other or to disapprove their potentials among the others. Rather, it intends to present an overview on how different BIM estimating tools can facilitate quantity surveyors to take advantage of their quantity take-off capabilities and how well each tool could adapt to the latest NRM requirements.

The research first explored the information published by software suppliers and product reviews by existing users to observe and collect variable opinions towards the aforementioned software solutions. Trials were later undertaken on all the tools to further verify and distinguish their useful functions and features towards the QS profession. To ensure high quality results and findings, it is important to base the experiment on a standard structure; for instance, a common BIM model and a set of well-defined criteria.

Owing to the reason that the use of Autodesk Revit model is dominating in the Architecture, Engineering and Construction (AEC) industry (Monteiro & Martins, 2013), the majority of industry practitioners in UK are familiar with the interface and object assemblies of Revit. Hence, a Revit model (Figure 13) is used as the BIM model in this exercise.

Figure 13: Revit Model used in the review



The following seven criteria have been developed for the review on the selected BIM estimating tools.

6.1.1 Model information exchange

It refers to the file types or formats of BIM models that can be supported by the tools. This criterion investigates whether the software tools are capable of supporting the original Revit model directly or an exported model format is required, e.g. IFC, DWG, PDF. This also includes an assessment of any possible information loss during the import and export process.

6.1.2 Model Visualisation

It refers to the capability to support 3D visualisation of the whole BIM model including the ability for users to navigate, manipulate, toggle or highlight the objects or building elements within the model when preparing estimates.

6.1.3 Reliability of information production

It refers to the capability of tools to transfer and extract accurate information from BIM models with a minimum loss of valuable object properties or data. It also examines the availability of any mechanism that is able to check whether the models meet the requirements prescribed from the quantity take-off point of view.

6.1.4 Quantification process

This refers to the level of simplicity, and speed of the tools in generating cost estimates or quantity take-offs. In selecting a tool, it is also important to examine whether a particular tool provides users the necessary flexibility to choose which information to take-off from the model along with the ability to produce accurate outcomes. It also reviews the tools' ability of performing partial or full automatic quantification, hence, reducing the efforts and time in manual estimating routines.

6.1.5 Customisation of built-in categories/classifications for standard estimating format

It refers to the availability of in-built standard measurement rules or parameters within the tools that enable users to generate quick quantity take-offs from BIM models. This includes the capability of incorporating the UK standards or parameters such as NRM within the tools to ease the export of required data, and later map them against the correct NRM classifications.

6.1.6 Report generation and export

It refers to the ability of tools to process the output of cost estimates into reports and export them into users' desired file format and structure, e.g. excel, pdf, txt, etc.

6.1.7 Change management or revision control

It refers to the ability of tools to recognise and record changes in BIM models accurately, before linking the changes with cost estimates. In other cases, it also explores whether the estimating tools enable view and highlight of new revisions in the model including allowing users to make comparison with previous model versions.

6.2 Review of BIM Estimating Tools

6.2.1 Solibri Model Checker (SMC) Ver. 8

SMC is not a BIM authoring tool, but a model checking application that helps to verify and determine the quality of BIM models produced by the architect/engineer using specific set of rules. SMC is initially introduced to the industry with functions mainly to perform rule checks to BIM models, including visualisation, navigation and presentations compilation (Khemlani, AECbytes Product Review: Solibri Model Checker v7, 2011). Solely as collision detection and model checking tool, SMC is a valuable application that supports testing and control of the quality and accuracy of BIM models for various uses: energy analysis, information take off, and spatial coordination. Later, SMC's interface has enhanced and expanded to include new 'Information Take-off' capabilities in its version 8 which is the main functionality that is reviewed and discussed in this report.

6.2.1.1 Model Information Exchange

SMC only supports BIM models in IFC and DWG formats, which in this case, the Revit model has to be exported or converted into IFC or DWG format prior to be opened in the SMC application. However, IFC model format is found to be better option than DWG as it supports interoperability and allows conversion and merging of most information from BIM model into one single format rather than having it all split up into different DWG files. In addition, Khemlani (2009) has also pointed out the compression capability in SMC application whereby it allows models to be saved in the native SMC format, providing smaller file sizes compared to the original Revit and IFC versions without losing its information or data.

SMC effectively reads all the information from the IFC model, refines all the components and categories into groups in the model tree section. It intelligently recognises and identifies the attributes and properties of each object under the 'Info' section. According to Khemlani (2009), SMC maintains the same object attributes from Revit model within the IFC format. However, it also depends how well Revit translates the model into IFC format. If the model does not convert properly, it will be difficult to avoid information loss during the conversion.

6.2.1.2 Model Visualisation

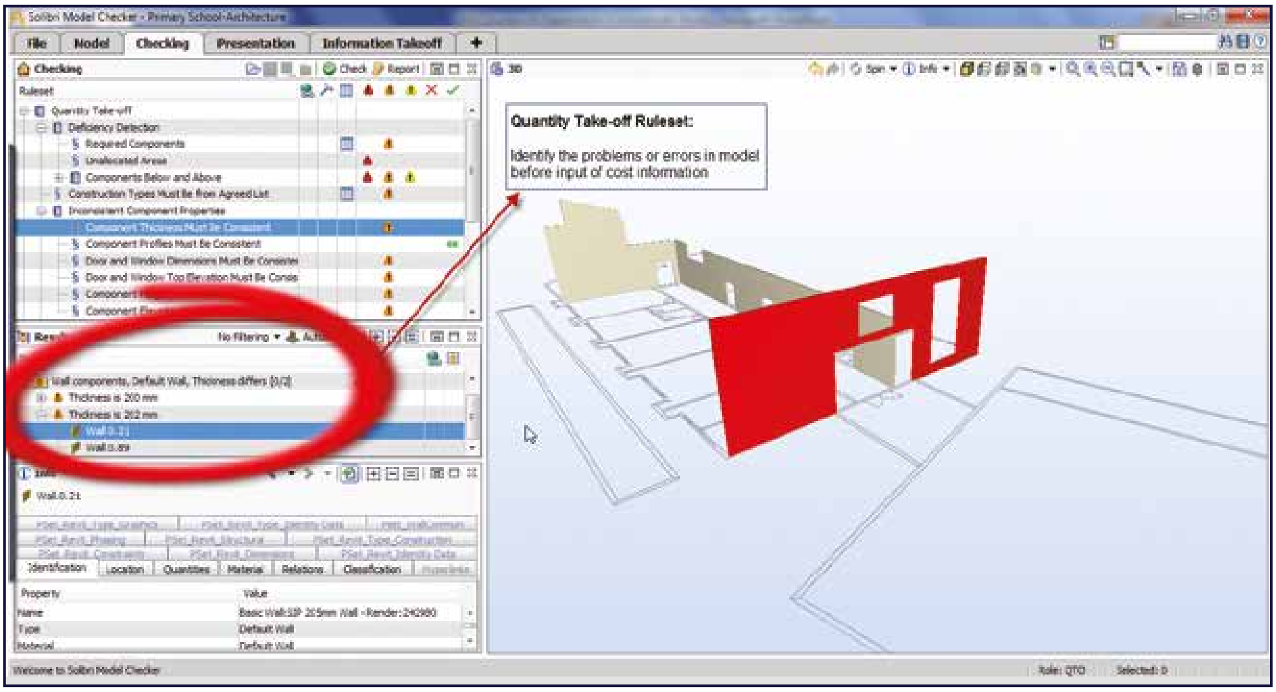
SMC supports visualisation of the BIM models effectively similar to the visualisation in BIM authoring tools. It enables stacking of views from different windows under one task pane, e.g. under the model tab, users will have the view of the 3D graphics of the model, the model tree – which shows all the object attributes within the model, and the information about the selected component. Users also have the flexibility to decide which views to add into the window, e.g. presentations, checking etc. to have the ease of making comparisons and multi-tasking.

SMC also allows users to navigate and explore around the models using the elements breakdown in the model tree and the navigation map on the bottom right hand corner. It automatically zooms up to the selected objects in the model when any component is chosen in the model tree (Khemlani, 2009). Navigation map helps users to identify their locations in the model and to control their viewing angles, adding extra credits to the usual Zoom, Pan, Spin and Walk tools. Concurrently, users are given the choice to filter or highlight certain views or elements within model by deciding whether to show or hide any particular elements.

The same visualisation applies even while the users were performing rule-checks and information take-off in SMC (Figure 14). Highlighting capability helps users to filter and detect the problems within the model easily based on the error results compiled from the checks. Users can then capture the view and save it into slides in Presentation to coordinate the problems with the designers (Khemlani, 2009).

In the information take-off process, visualisation and highlights functionality (Figure 15) enable users to clearly identify the right components to take-off and determine the correct classification for each components.

Figure 14: SMC quantity take-off Ruleset



Source: Khemlani, 2009

Figure 15: SMC coordination and communication view

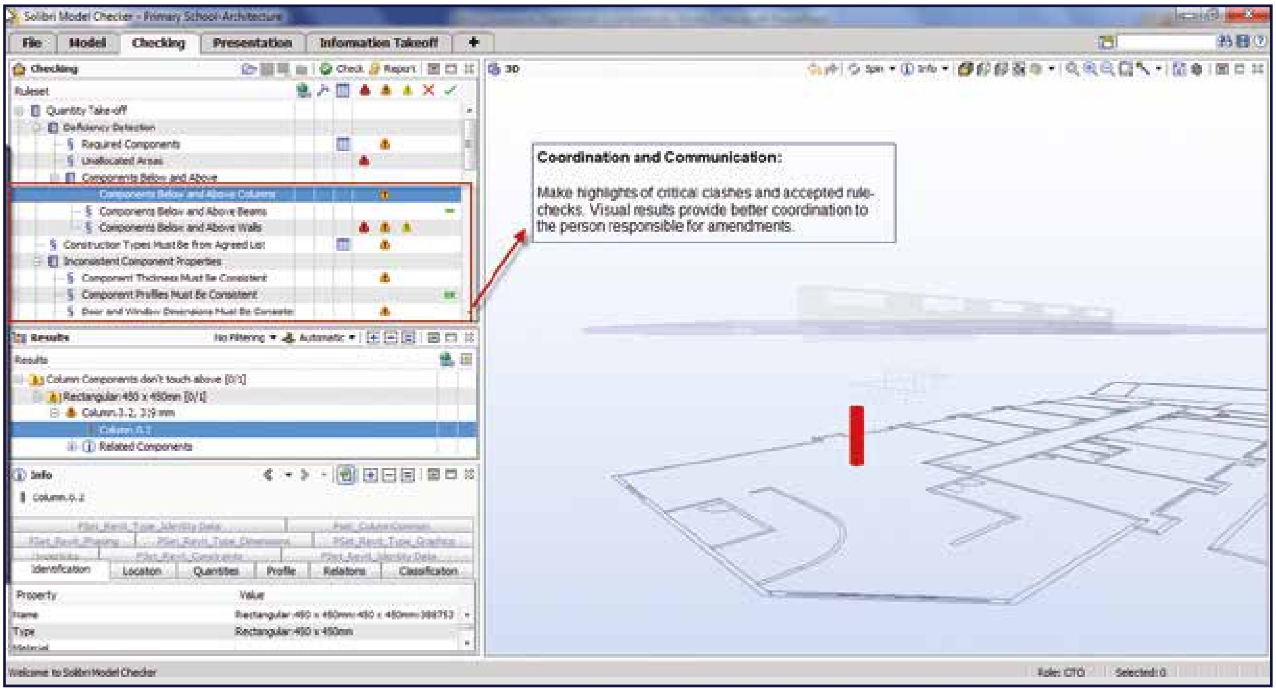
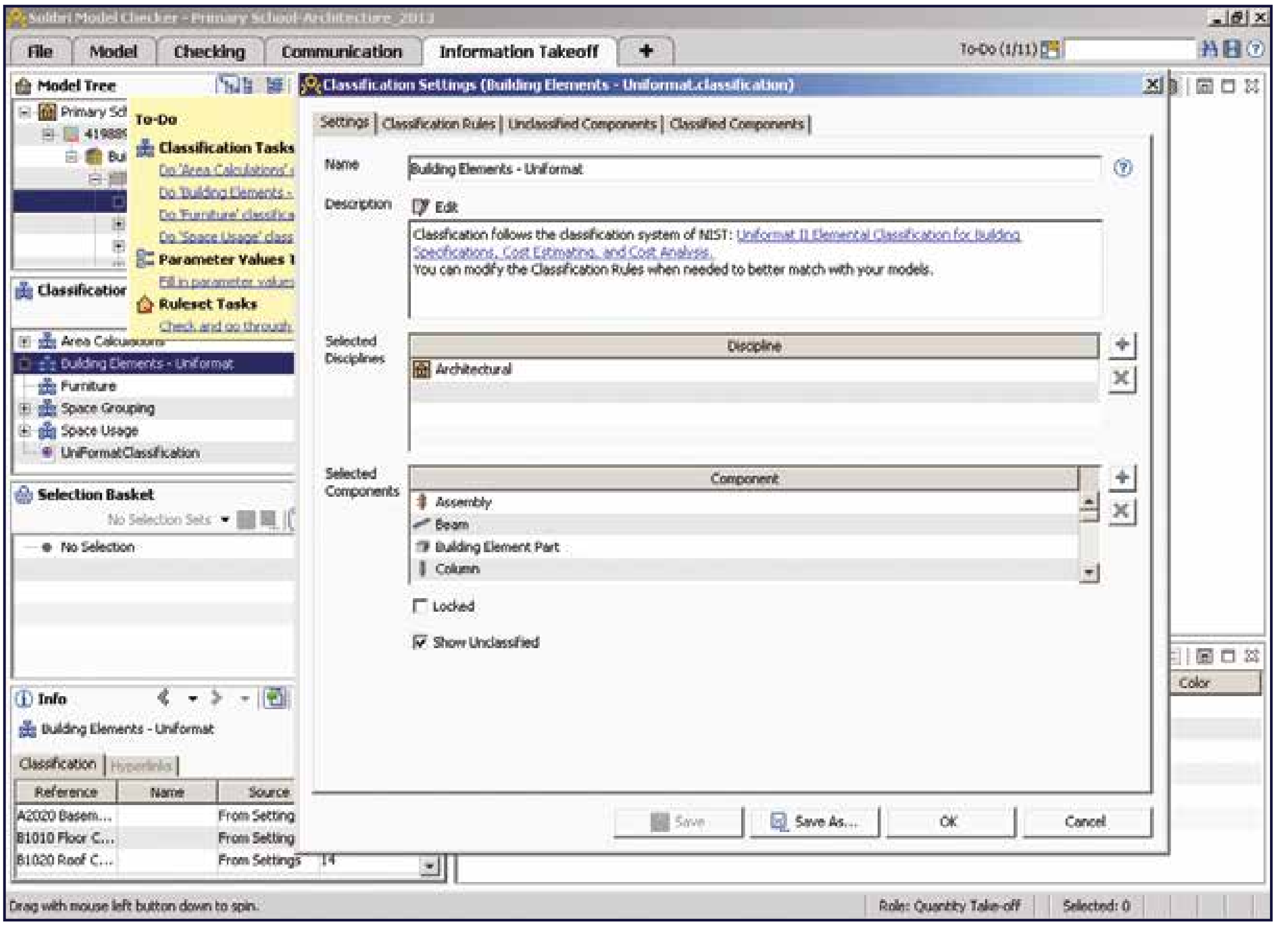


Figure 16: SMC classification settings



Source: Khemlani, 2009

6.2.1.3 Quantification Process

SMC Information Take off depends upon the use of classifications and definitions to decide the type of information to be extracted from the model and to create structures and organisation to the data within the BIM model prior to quantity take-off process. SMC supports the flexibility of making modifications or changes to its standard built-in classifications to suit the users' requirements, so that the components can be restructured to the desired category and information extracted will be more accurate. Upon defining the classifications, users can also decide on either to take-off the whole model or only specific components that were chosen and added to the selection basket. The take-off process will then automatically begin and users will be able to see the results in seconds.

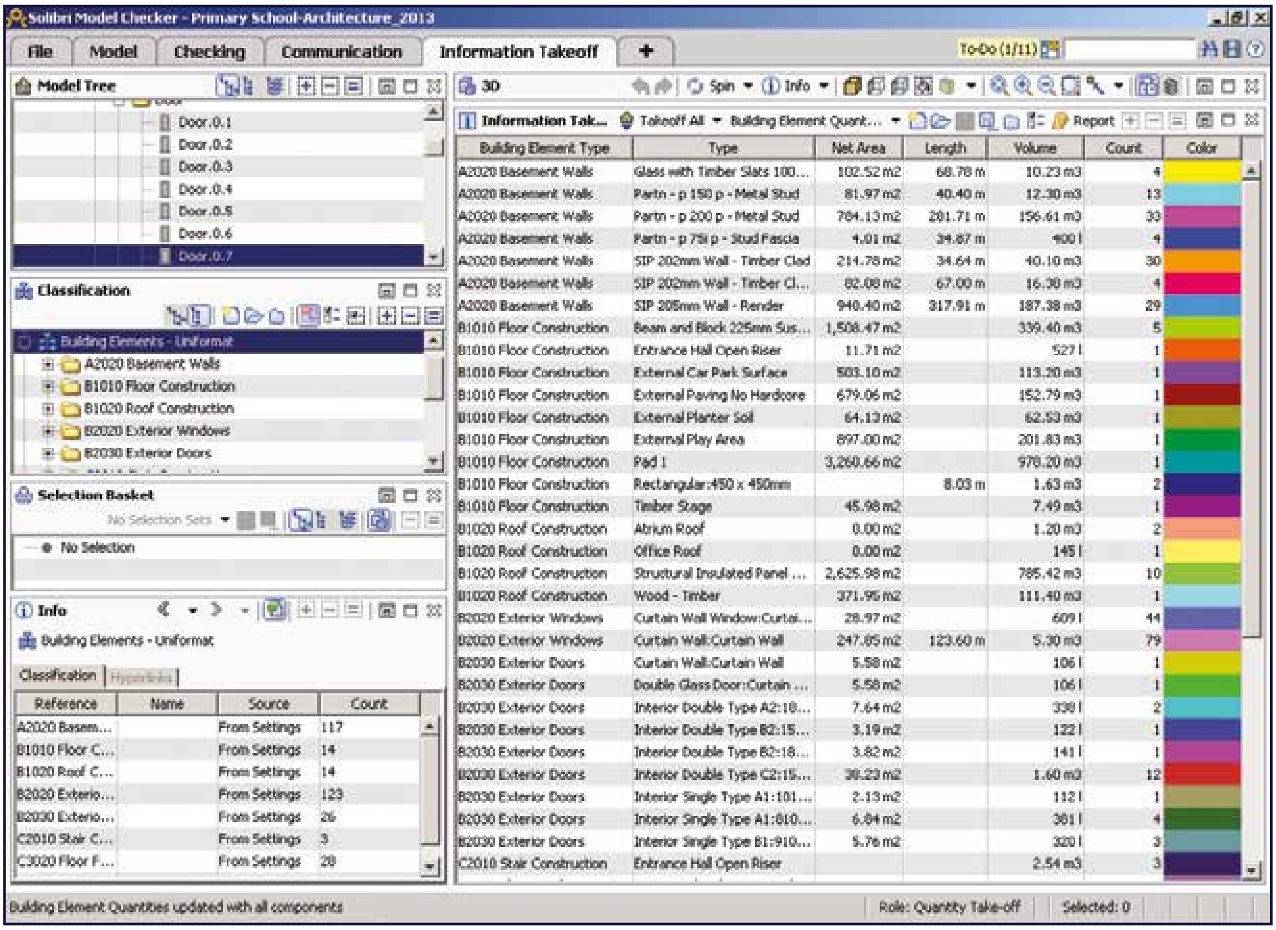
6.2.1.4 Reliability of Information Production

In order to make sure the BIM models produced by designers are up to the desired standards, SMC is an effective application to help quantity surveyors to perform checks before the quantification process. Users can either select from the range of parameter/rules/standards (Figure 16) pre-defined in the application to perform checks to the model or customise the rules based on their preferences and purpose. Generally, quantity surveyors are able to run quick checks to see if there is any missing components or information in the BIM model as well as discrepancies in the design, using the Quantity Take-off rule set in SMC. Upon identifying the potential problems and errors, the quantity surveyor can later transfer the results to the designers to request for changes to the design. With this functionality, quantity surveyors can ensure that the quantity information to be produced will be more reliable and accurate.

6.2.1.5 Customisation of built-in categories/ classifications for standard estimating format

SMC contains a series of classification rules and take-off definitions which users can utilise to generate standard estimating format quickly. Although this might not be according to the UK standards, but it helps to give users the overview of the quantity and understand what information is held within the model. SMC does not come with the standard classification rules that automatically organise and align the components to match with the NRM format. The original

Figure 17: SMC coordination and communication view



classification system predefined is in accordance with Uniformat classification – common framework used in the United States. Therefore, if users were to rely solely on the standard built-in parameters, the take-off results extracted from the BIM model might not fully comply with the requirements and classification in NRM.

According to Corke (2013), SMC allows data to be appended to the BIM models. In general, SMC does not support additional input from users to the BIM model which would change the design of the model, the original value and properties of the elements. SMC enables users to perform manual input, but only in the aspects of manually creating new classifications or new taking off definitions. This includes adding in the 'classification name' with the required NRM codings, renaming the type of the components, which helps to restructure the information within the model to suit the NRM requirements.

6.2.1.6 Change management/revision control

SMC generally does not support automatic updates of BIM models as there is no bidirectional links between Revit and the external application. However, if the revised BIM model is manually loaded into the application in IFC format, SMC has the features of enabling automatic identification and locating of any alterations made to the model while retaining unchanged information within the model (Corke, 2013). With this capability, it provides users with the benefits of comparing the older model with the new one, to clearly identify the differences which affect the quantity and cost of certain components from the QS perspective.

6.2.1.7 Report generation and export capabilities

SMC enables export of taking off results into Excel files with the choice of standard templates available in the system, e.g. area calculations, building elemental quantities etc to match with the results. In Excel, users can then modify the layout of the report generated, e.g. add in rows to create the level structures for NRM format, add in columns to input rates and prices to generate cost estimates.

6.2.2 Autodesk Quantity Take-Off (QTO) 2012

Autodesk QTO first released in 2007, is a standalone cost estimating tool developed by the same software vendor as Revit, to assist estimators and surveyors in quantifications and cost estimates via the process of gathering and coordinating accurate design information from both 3D BIM and traditional 2D environment (Autodesk, 2008; Brisk, 2008). According to Alexander (2010), Autodesk QTO emphasizes the simplicity of its interfaces which enables users to easily understand and familiarise themselves with the tool to perform required taking off and cost estimates.

6.2.2.1 Model Information Exchange

Autodesk QTO is able to create take-offs from a variety of file formats, regardless whether it is 2D drawing or 3D model format. However, the original Revit file is not directly supported. Alternatively, Revit BIM model can be brought in through 3D DWFx and DWF file to fully integrate with the application. This then requires BIM model to be exported using Revit's internal built-in export feature in order to enable the application to leverage the object properties and information within the model. (Figure 18)

Besides 3D models, QTO also enable non intelligent 2D contents to be generated into the program including DWG, PDF and images, e.g. JPG, BMP etc. Autodesk QTO being capable of coordinating both 2D and 3D information, is known to have seamlessly bring designs and information together into a single environment (Autodesk, 2008; Brisk, 2008).

6.2.2.2 Model Visualisation

The visualisation capability in Autodesk QTO mainly involves the basic model navigation features such as pan, select, zoom and rotate. These features enable users to easily explore and identify their required viewing position and location around the BIM model. Similar to other estimating tools, Autodesk QTO supports adjustments of objects visibility and transparency based on building elements to allow precise inspection of the BIM model and increase the accuracy of quantity take-off process. It also automatically highlights the object using different colour coding whenever a particular element is selected. This is useful to help users in examining the object properties and scope for measurement. (Figure 19)

However, the research has identified Autodesk QTO's inability to support model walkthroughs and section cutting. Although it does not have huge impact onto the quantity take-off or estimating processes, having these capabilities in place will effectively improve the accuracy of cost estimates by helping users to understand the internal build-up and other items which might have cost implications but are not modelled within the BIM design.

It also enables several different windows such as model document list, model tree breakdown, workbook, take-off schedule etc. to be pinned into one viewing panel based on the users' preferences. The multiple viewing capability helps to increase the working efficiency of users and productivity by enabling synchronisation of workflows and multi-tasking. (Figure 20)

Figure 18: Revit DWF export settings

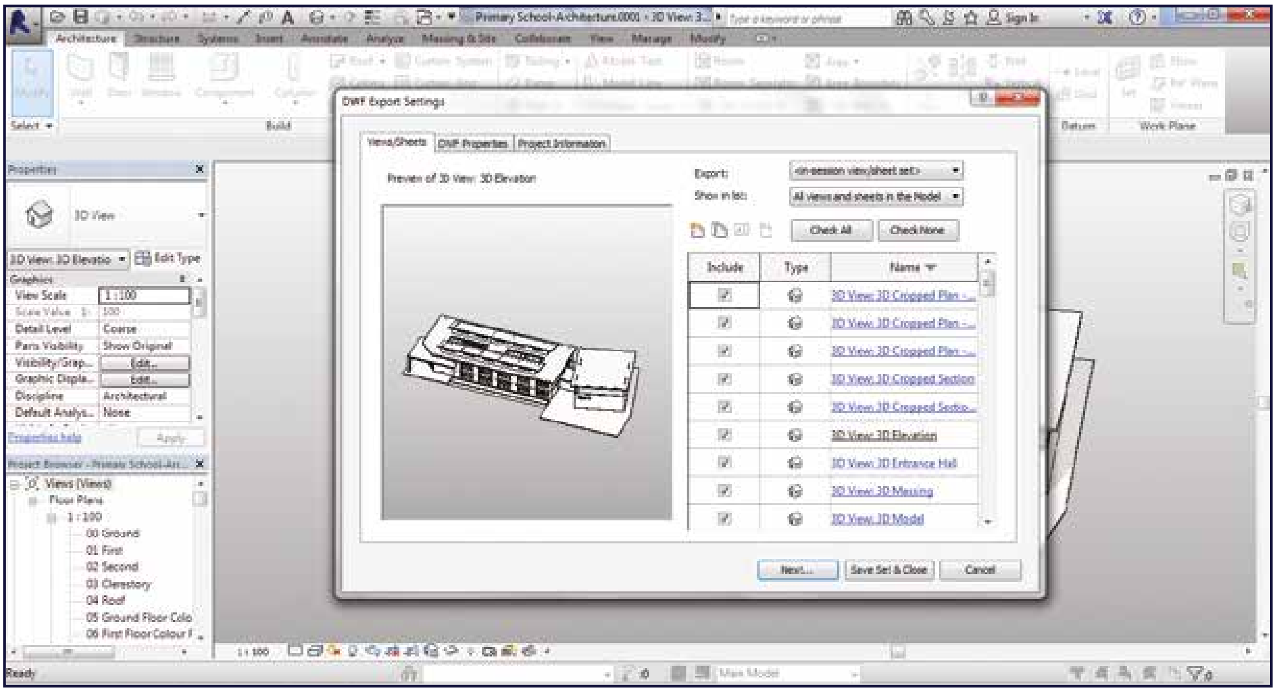


Figure 19: QTO model visualisation

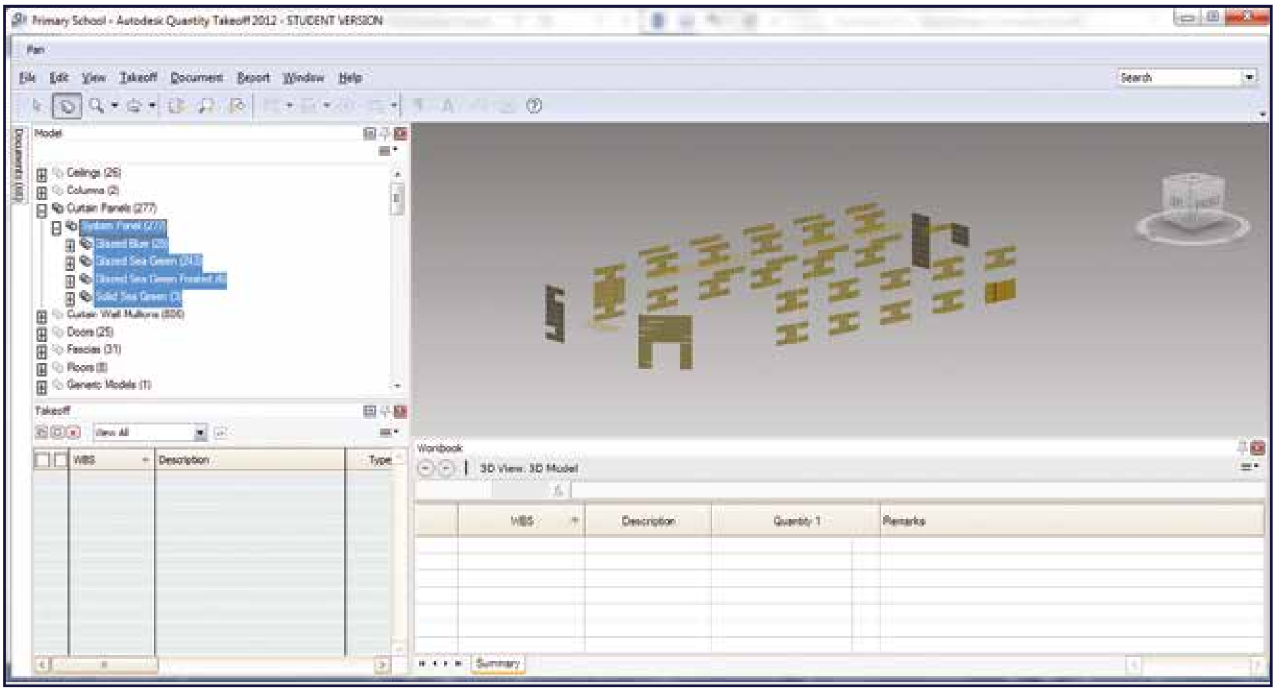
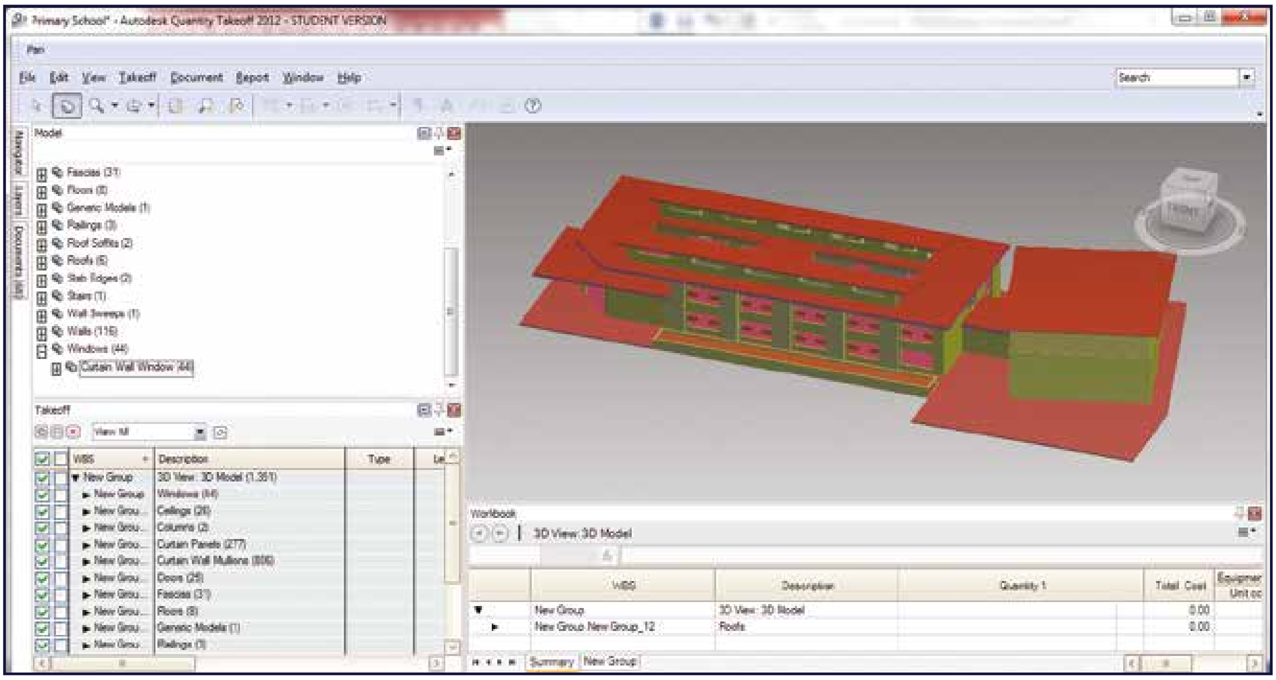


Figure 20: QTO take-off view



6.2.2.3 Quantification Process

Autodesk QTO supports automatic measurement of the entire BIM model. However, it is not a fully automated process on the first time of using the take-off tool in this software, Autodesk QTO does not have the ability to automatically define the types of measurement or assign the objects to the required assembly to extract the correct quantity and create a valid take-off.

Therefore, users are required to manually assign the objects to items and later adjust the measurement methods for each object element. Once completing this process for the first time, the automated quantity take-off process will run effectively under Autodesk QTO as it has the capability of remembering past element assignments and allow similar definition to be predictively applied in subsequent BIM projects.

6.2.2.4 Reliability of information production

Known as the only cost estimating tool produced by Autodesk, the application is claimed by Alexander (2010) to be able to support great level of integration with Revit model. However, Autodesk QTO which solely operates as cost estimating software does not contain any checking feature that helps to assess and examine the quality of information within the BIM model. The application also will not be able to detect any duplications or missing quantities in the model.

In order to determine the reliability of cost estimates, users will need to incorporate the use of alternative model checking tools in conjunction with Autodesk QTO to assess the quality of the BIM model before running the taking off process.

6.2.2.5 Customisation of built-in categories/ classifications for standard estimating format

Autodesk QTO comes with a selection of catalogues which are made available for users to choose at initial project setup in the application. The catalogues define the organisational structure or parameters for grouping the dimensions extracted from BIM projects and also contain the associated rates for costing purposes. However, all the standard classification format incorporated from the catalogues is based on the US construction industry standards, such as 'Masterformat' and 'Uniformat'.

Although the take-off format using Autodesk QTO's built-in catalogues (Figure 21) will not be compliant to the UK NRM standards, but users can still later adopt these structure as a typical format and make modifications and customisation to meet the correct standard and users' requirement.

On the other hand, users can also choose not to incorporate any built-in format for the taking off process. Autodesk QTO will then extract quantities from BIM model and places them into groups within the take-off view based on categories in the model tree breakdown (SAGE, 2009). Users are given the flexibility to make adjustments including renaming the group and descriptions, adding in new coding system and structure to map the BIM content and take-off information into the correct groups and level of detail.

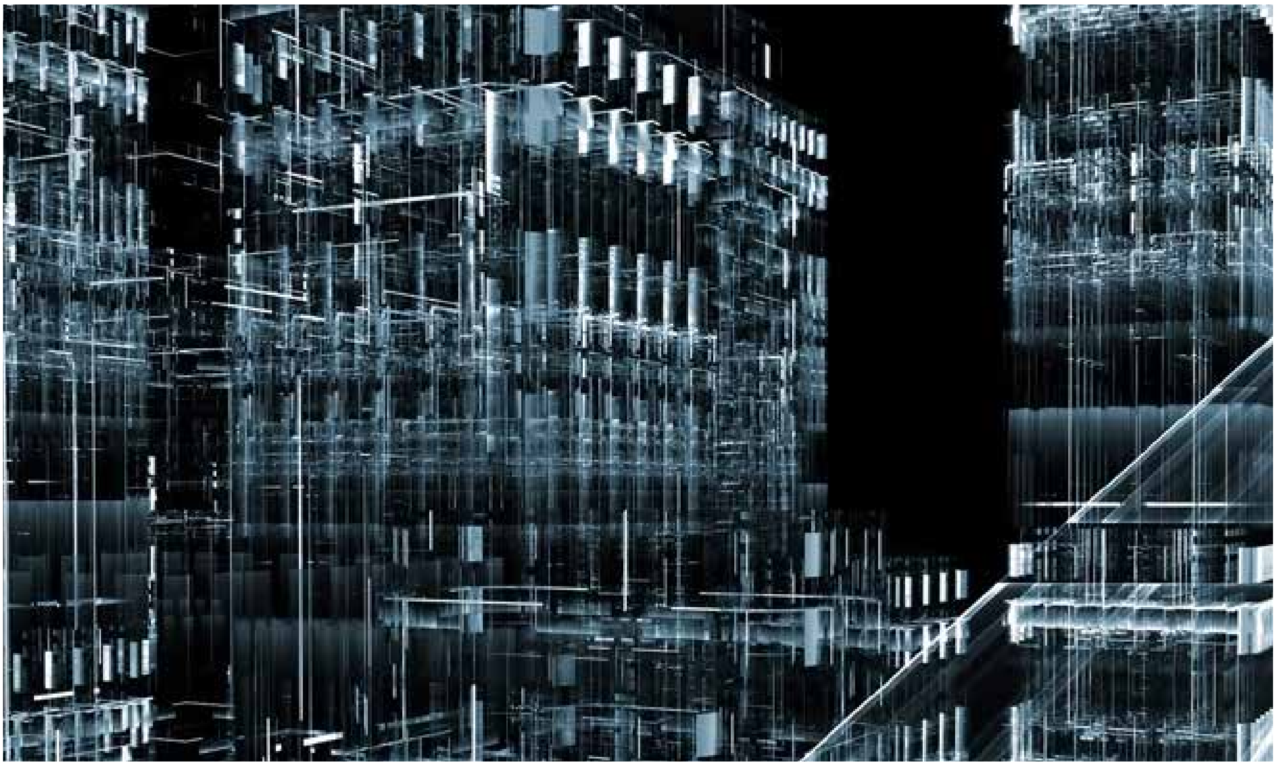
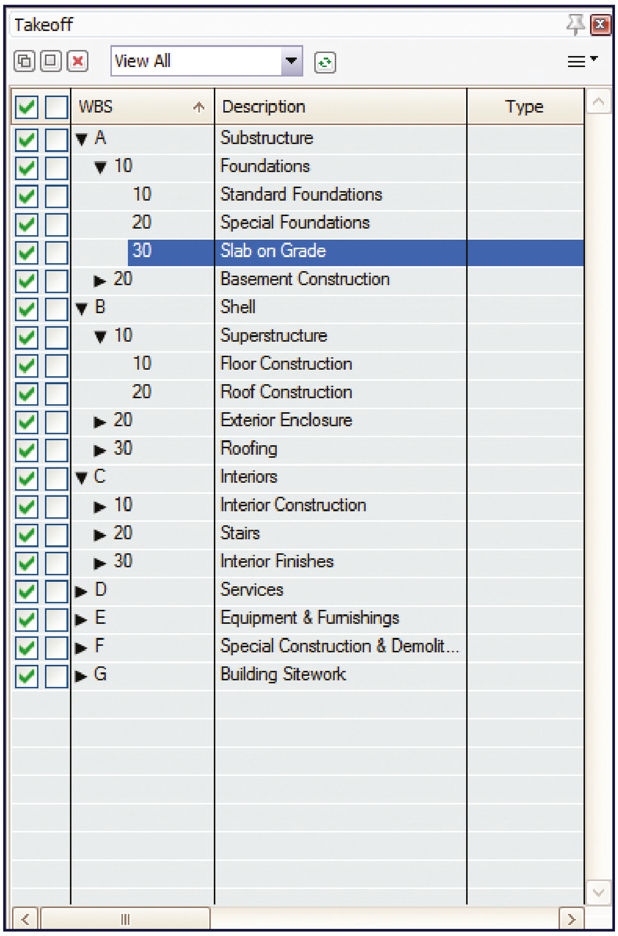


Figure 21: QTO category



As discussed above, Autodesk QTO enables user to perform manual information input to reconfigure the classification of quantity data to suit the NRM requirements. This allows all data attached to specific model objects to be built into the same configuration as Autodesk enables automatic mapping and linking between quantities and BIM objects. Besides that, the software also supports the capability to allow users to manually create take-off item groups based on the NRM categories and later export the complete structure into QTO catalogue to speed up cost estimating process when reuse in other future project.

Users can perform manual manipulation to the BIM model using Autodesk QTO including selecting BIM objects for take-off, performing manual measurements of drawing geometry and inputting cost information, e.g. material, labour and resources against each item. Given this freedom, it helps to improve the accuracy of quantity information and cost estimates.

6.2.2.6 Report generation and export

The flexible reporting capabilities in Autodesk QTO is crucial towards the digitised BIM working environment, as it enables measurement or cost results to be easily transferable into another file format e.g. excel, word, PDF and etc. This allows digital compilation of results into work documents which is significantly faster than traditional paper-based processes (Autodesk, 2008).

Users are given the flexibility to customise the type, style, content, layout and presentation of the reports using the standard built-in reporting tool in Autodesk QTO to tailor their needs before exporting into users' chosen format. Users can also opt to publish the quantities into BIM models through common DWF files format, which can be easily accessed using viewer tools. The capability to link cost information into the design supports 5D data integration within a single BIM model and encourages better collaboration when the model is distributed and shared among construction professionals.

6.2.2.7 Change management or revision control

According to Autodesk (2008), Autodesk QTO enables fast and efficient change management processes. During the taking-off process, the software enables all quantity information to be cross-referenced and mapped to the specific BIM objects. In order to enable effective revision control, users are encouraged to create new project within the application to maintain record of design history and object data history whenever a new updated model is issued. Quantities from the new revised BIM model can be automatically updated with single click on the model and align into item types predictively based on the earlier take-off settings on the previous model version. New items in revised model require to be taken-off separately using the automatic take-off process.

Although Autodesk QTO comes with the compare feature within its application, it is not applicable for 3D DWF models but only for the comparison of 2D drawings. This enables 2D drawings generated from the 3D BIM model to be compared against another drawing or previous revisions to assist users in visualising the extent of changes before deciding whether to modify the original quantities. 2D comparison is useful but it can be problematic when the changes are too extensive.

6.2.3 Exactal CostX Estimating Software Ver 3.5

CostX first produced by an Australian based software developer in 2004, claimed itself to be a powerful estimating tool that promotes BIM based cost management by enabling full integration of 2D and 3D digital design data with cost estimates (Day, 2008; Exactal, 2010). Day (2008) explained that CostX enables to capture and extract of BIM information, e.g. object properties, dimensions, descriptions and etc; all in a single platform, including electronic measurements, spreadsheet calculations and estimates.

6.2.3.1 Model Information Exchange

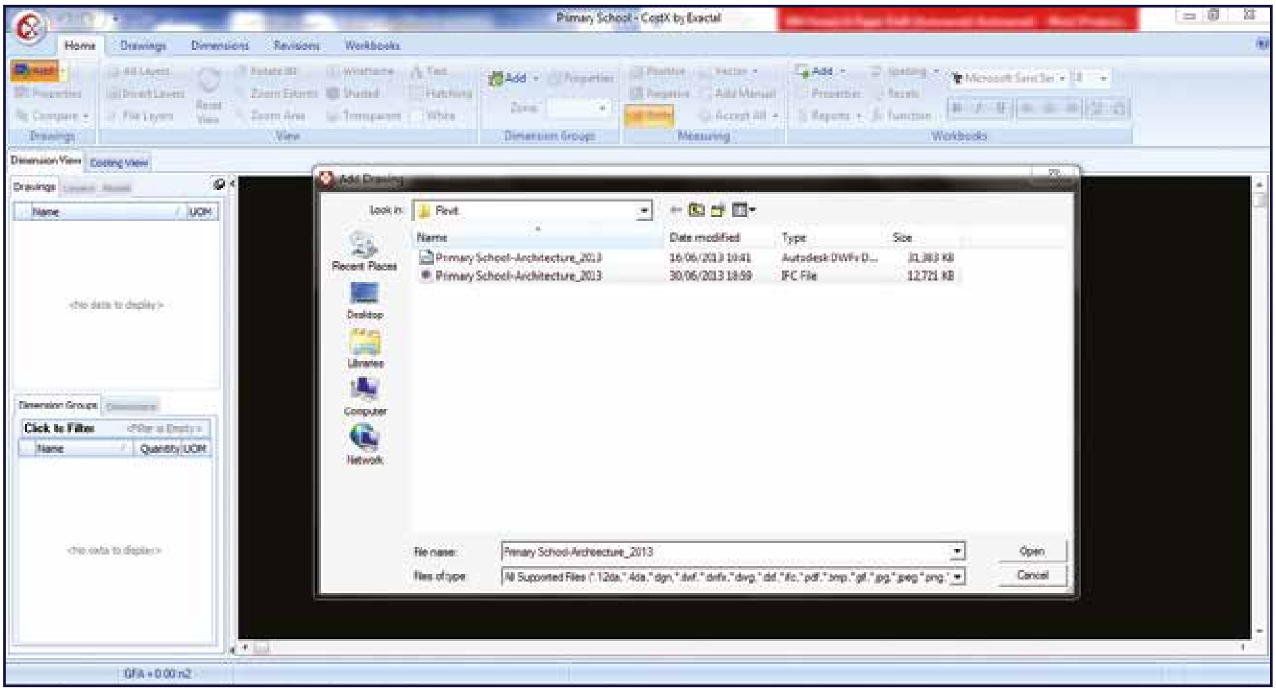
CostX provides integration with Revit BIM model not only through 3D DWF and DWFx file; but also, IFC file format (Figure 22). Besides 3D file format, CostX can also read design information from 2D images, e.g. JPEG, BMP, JPG and also standard industry 2D drawing formats, e.g. PDF, DWG and etc. Whichever file format is used, they all require users to go through model conversion process using Revit's internal export feature.

Given two options of BIM model format, authors have opted to run a short initial test on both model formats to assess their feasibility for CostX applications. Although IFC standard is the common product data structure that governs the definition, classification and organization of project information to enable wide support of software applications (Eastman et al., 2011), it does not ensure the quality of information transferred into estimating software. CostX cannot fully support or interpret all the information contained within the IFC model. The IFC object mapping structure has also caused all BIM elements to group under one layer, which affects the efficiency of the application to manipulate the object information for quantification purposes. DWFx model format on the other hand, allows import of multiple views of a BIM model whereby each individual drawing is associated with one another, to smoothly deliver BIM data within CostX.

In addition, Lee (2011), Ma et al. (2006) and Zhiliang et al. (2011) cited in Monteiro and Martins (2013) have justified the current instability of IFC file format which will likely lead to loss of valuable BIM data during file conversion process. However, it is not a focus of this research to examine the application of IFC standards in depth. Therefore, considering IFC's potential weaknesses in data exchange, DWFx file is chosen to be incorporated in CostX rather than IFC model to eliminate any unexpected variations on the research outcome.

CostX effectively transfers the object attributes and properties from 3D virtual BIM model into its internal databases and reads these information similar as it is in BIM authoring software(Exactal, 2010). It enables information that are attached to the BIM objects including the naming conventions; e.g. family names, instances, type name to be grouped into the same hierarchy as in Revit. CostX also maintains the object intelligence and dimension properties to enable efficient 3D model links and population of quantities for the use of cost estimation.

Figure 22: CostX open models



6.2.3.2 Visualisation Capability

CostX provides an excellent visualisation of the BIM model similar as it is in Revit. The drawing manipulation tool gives the ability to easily rotate, pan, zoom, spin and navigate around the model. The navigation button on the top right hand corner helps to identify the position of the model views and secure the desired viewing perspective in any angle.

CostX also allows users to filter, highlight, hide or invert the layers in the model as appropriate to emphasis on a single building element, all model objects or combination of several BIM components as shown in figure below. CostX enables adjustments to the viewing mode on BIM models, either wireframe, shaded or transparent. It also provides further interrogation of the BIM model with its exceptional user viewing control such as section cut-through and model walkthroughs, which effectively displays the internal structure and zones of the model. (Figure 23)

The visual interface is a great support towards the quantification process as users can easily capture the view and understand the objects they are measuring. The model tree breakdown in dimension viewing enables quantity surveyors to clearly recognize the scope of works included in a BIM project at early stages and identify the important building components for measurement purposes. (Figure 24)

6.2.3.3 Quantification Process

Quantification process in CostX is simple and does not require in-depth technical knowledge or CAD experience to operate (Day, 2008; Exactal, 2010). CostX is capable for both automatic and manual take-offs under the same working process; by means of capturing dimensional properties from BIM objects and classifying them into dimension groups and folders. (Figure 25)

Figure 23: CostX model visualisation

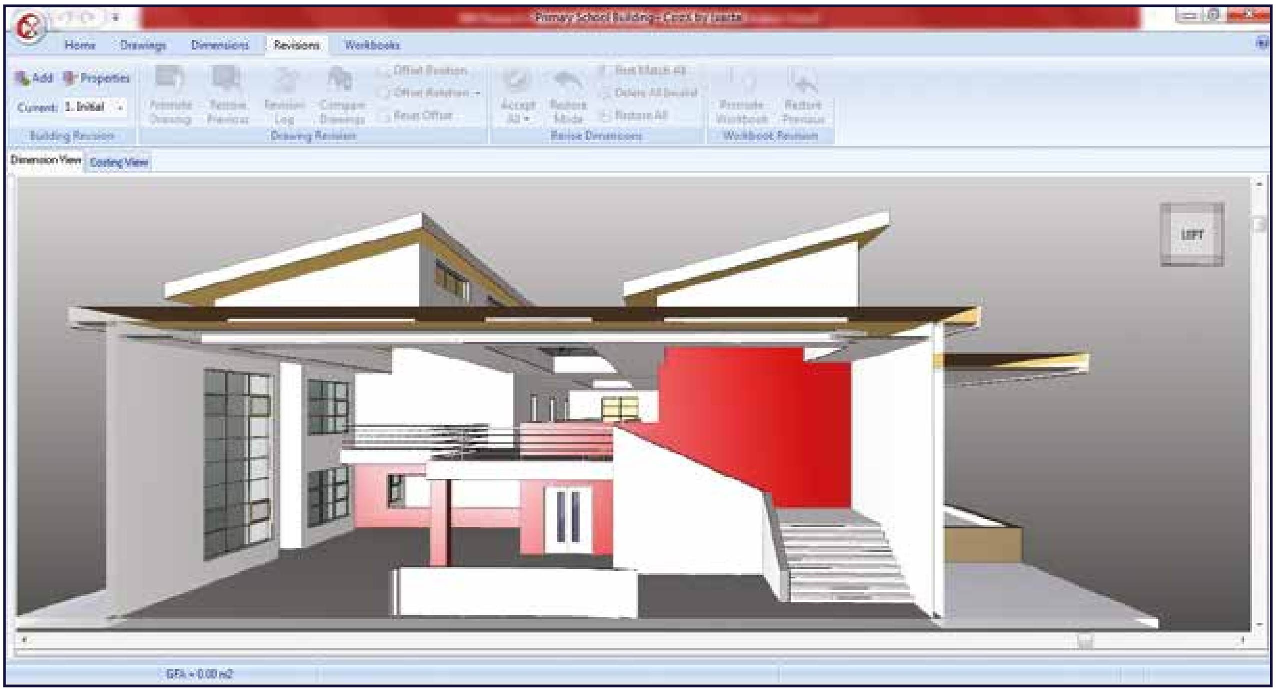


Figure 24: CostX element view

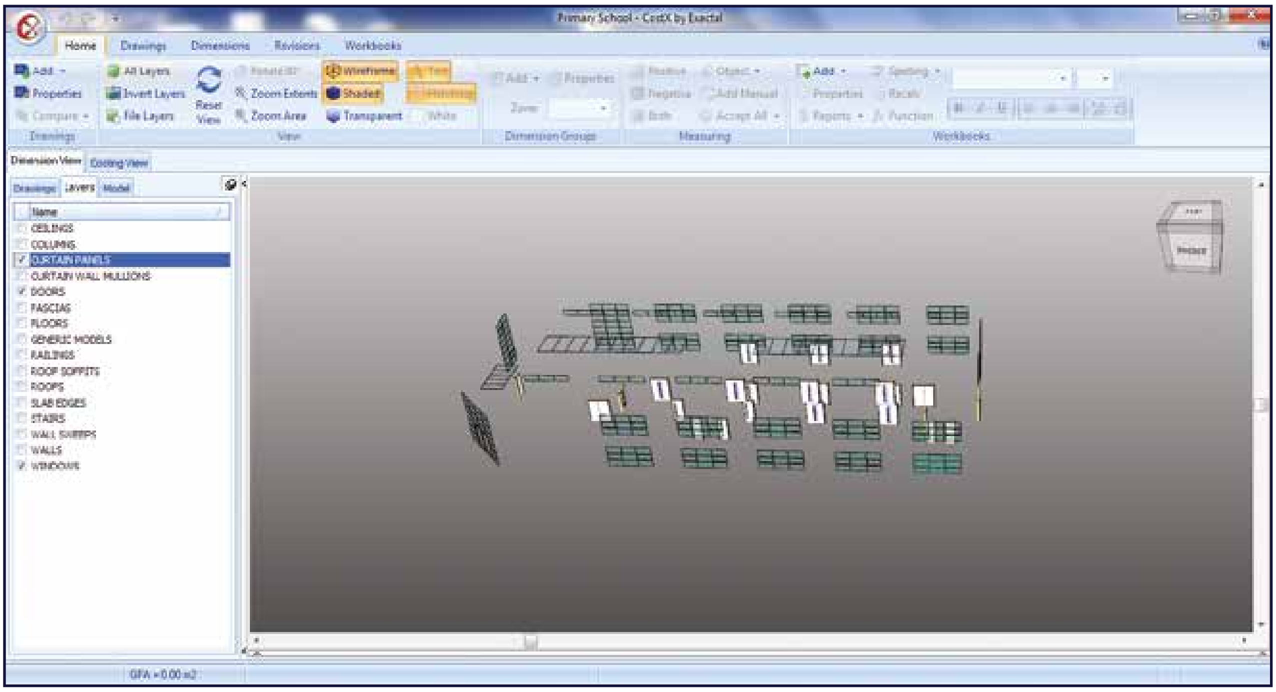
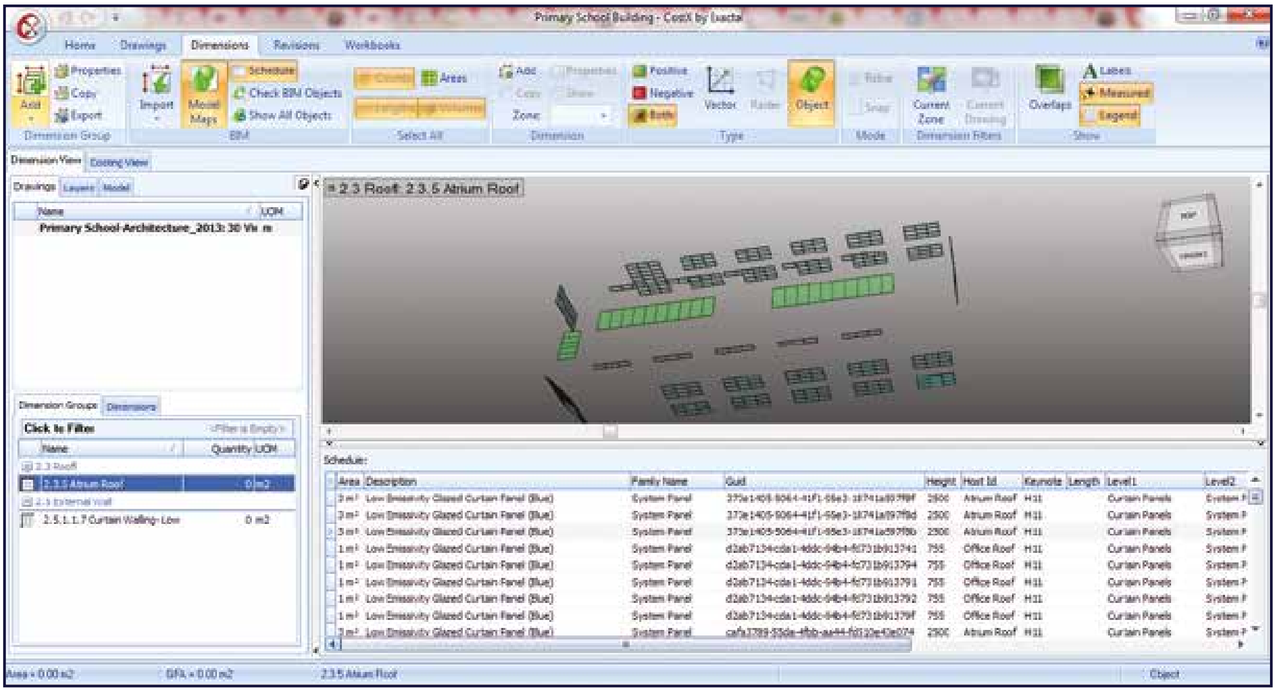


Figure 25: CostX measurement schedule



6.2.3.4 Reliability of information production

Quality and content of a BIM model can be validated and assessed quickly and thoroughly using CostX. CostX is capable to perform quick and effective tests to check and identify any unmeasured objects or possible duplications. (Figure 26).

Besides, visual on-screen checking in CostX allows users to view all the items within the model which have been quantified through colour codes and labels. Upon justifying the errors on the tests results, users can then determine whether there is any need to create new dimension groups to incorporate the objects which are not populated through automated process or to remove the duplicated elements or dimensions.

6.2.3.5 Customisation of built-in categories/classifications for standard estimating format

As discussed earlier, CostX uses its standard BIM templates to categorize the object quantities and information into a typical elemental breakdown. These classification is not fully compliant with UK standard and likewise do not map the BIM components and assemblies to the NRM format. However, this can be achieved through manual customisation of the estimating format.

CostX greatly supports the manual intervention capability, which is known by Eastman et al. (2011) to be the critical feature in BIM estimating tools. In order to align the quantities and costs to the NRM format, CostX enables users to add user defined properties, such as NRM codes, change of dimension grouping name of the standard dimension groups.

In most cases, the standard information organization structure based on the application's built-in BIM template might not fully meet the users' requirement. With flexibility of performing manual modifications and customisation, BIM components can be restructured to the right level of estimating detail.

Alternatively, users are permitted to manually create their own dimension groups based on the NRM classification and indicate the measurement type for the objects they required to measure. BIM elements can later be selected and drawn into dimension groups to build up the quantities.

On the other hand, for cost estimating purposes, CostX contains workbook spreadsheets function which is similar to excel interface. It enables users to manually input functions from a list of predefined formulas within the applications to populate the required take-off information into the worksheet. Otherwise, the measured quantities can be individually dragged into the workbook structure. Users are able to incorporate rates into the workbook, which will later be automatically calculated to arrive at a total cost sum. (Figure 27)

Figure 26: CostX model checking

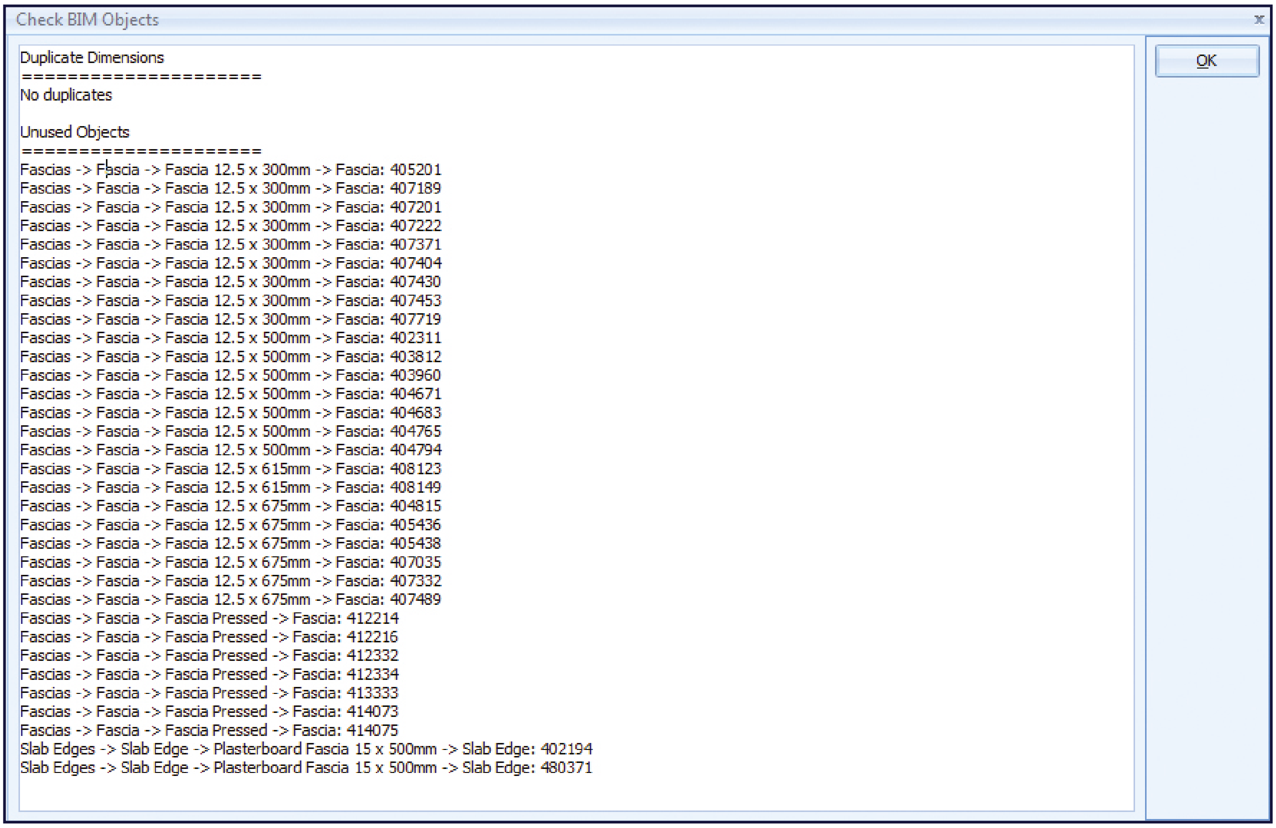


Figure 27: CostX measurement schedule

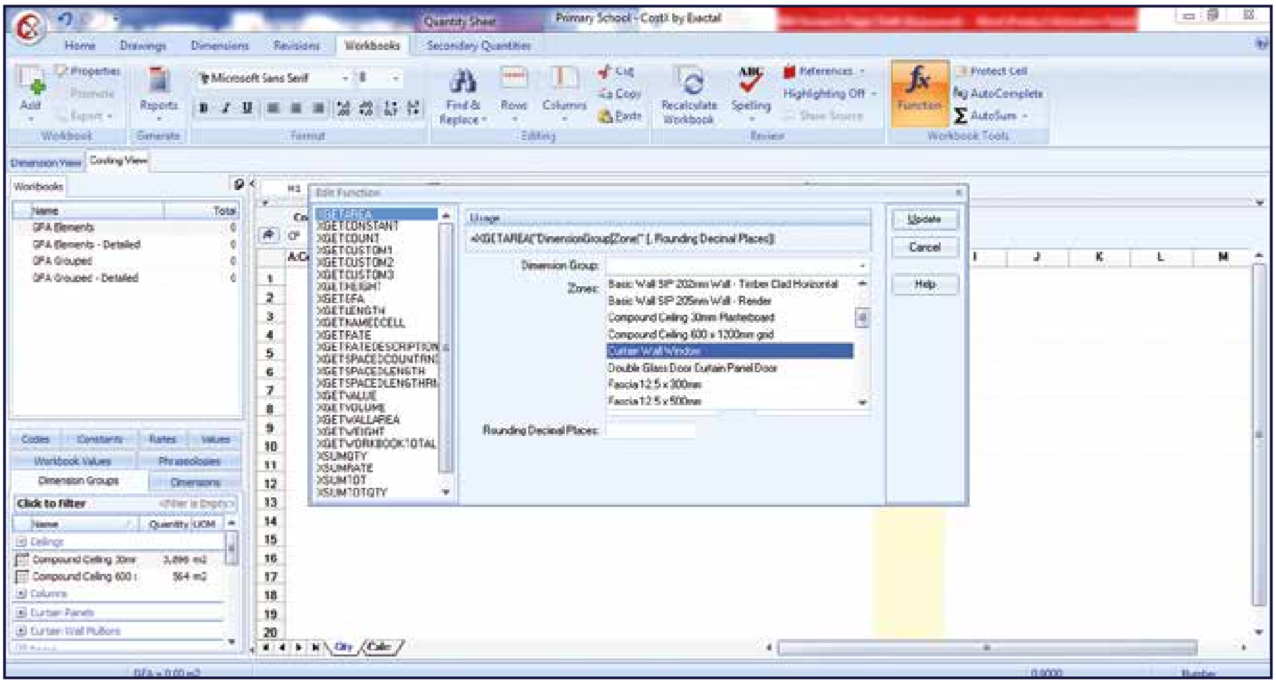
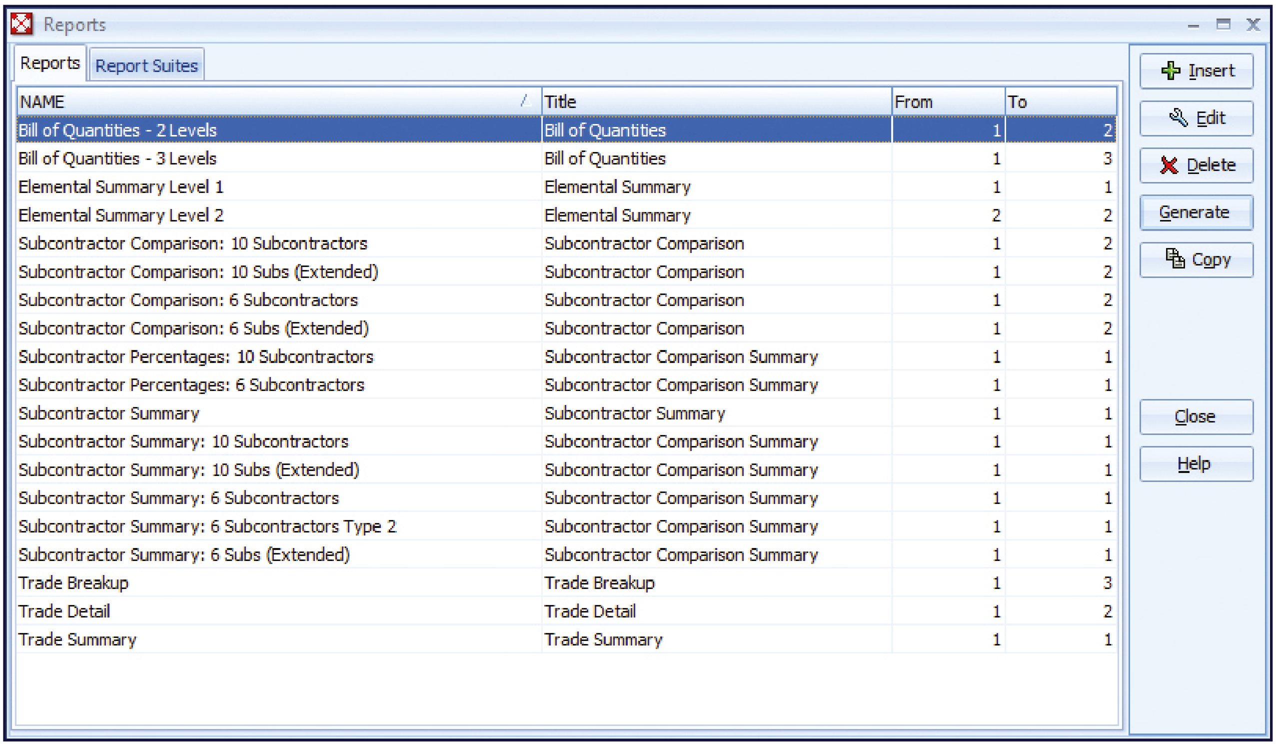
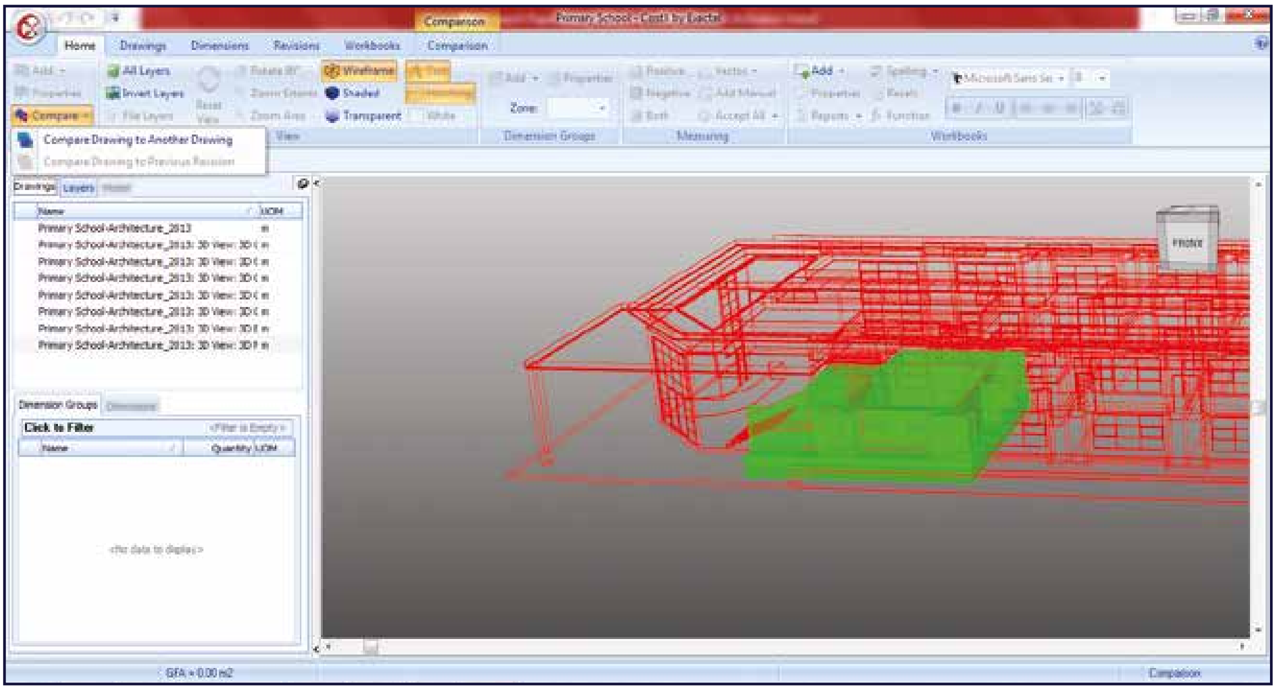


Figure 28: CostX model checking



NAME	Title	From	To
Bill of Quantities - 2 Levels	Bill of Quantities	1	2
Bill of Quantities - 3 Levels	Bill of Quantities	1	3
Elemental Summary Level 1	Elemental Summary	1	1
Elemental Summary Level 2	Elemental Summary	2	2
Subcontractor Comparison: 10 Subcontractors	Subcontractor Comparison	1	2
Subcontractor Comparison: 10 Subs (Extended)	Subcontractor Comparison	1	2
Subcontractor Comparison: 6 Subcontractors	Subcontractor Comparison	1	2
Subcontractor Comparison: 6 Subs (Extended)	Subcontractor Comparison	1	2
Subcontractor Percentages: 10 Subcontractors	Subcontractor Comparison Summary	1	1
Subcontractor Percentages: 6 Subcontractors	Subcontractor Comparison Summary	1	1
Subcontractor Summary	Subcontractor Summary	1	1
Subcontractor Summary: 10 Subcontractors	Subcontractor Comparison Summary	1	1
Subcontractor Summary: 10 Subs (Extended)	Subcontractor Comparison Summary	1	1
Subcontractor Summary: 6 Subcontractors	Subcontractor Comparison Summary	1	1
Subcontractor Summary: 6 Subcontractors Type 2	Subcontractor Comparison Summary	1	1
Subcontractor Summary: 6 Subs (Extended)	Subcontractor Comparison Summary	1	1
Trade Breakup	Trade Breakup	1	3
Trade Detail	Trade Detail	1	2
Trade Summary	Trade Summary	1	1

Figure 29: CostX revision control



6.2.3.6 Report generation and export capabilities

All the measurements or quantities can be exported to Excel format easily using CostX. The reporting feature in CostX enables the end results – cost estimates to be compiled into hard copies based on a selection of report format as required. [Figure 28].

It eliminates the tedious tasks of manual report writing including format outlining, quantity duplications, rate inputs and cost calculations. Customization of report format and detail can be straightforward to suit users' needs. The output of the reports are also of professional quality and highly presentable for use in industrial practices (Day, 2008) to benefit the decision making processes throughout the project cycle.

6.2.3.7 Change management or revision control

CostX includes the change management and revision control function. It allows users to add a new revised BIM model or drawing into the software and changes can be automatically detected. Before deciding whether to move on with the latest BIM design, CostX offers the ability to make comparisons between two different model design scenarios or versions. It overlays the models and uses different colour coding to highlight and create the contrast between the models. This enables users to easily visualise and track the differences or changes within the model. (Figure 28)

The visual comparison in CostX is beneficial for quantity surveyors as it saves the hassle of performing time-consuming cross-referencing on each measured elements within model to the quantity breakdowns and rate build up whenever the design is amended (PDS, 2009). This gives users more confidence into the production of up-to-date and accurate costs for their BIM projects.

Revisions from every design changes can be kept into logs using CostX to assist quantity surveyors in performing cost controls through cost comparisons and analysis throughout the project. CostX manages the drawings or models efficiently as it provides the feature for users to manually insert the drawing properties; e.g. drawing number, revision references and date received, whenever a new model is added into the application.

CostX provides bidirectional links between models' information and costing workbooks (Day, 2008; Exactal, 2010). The live links allows all changes to the BIM model to be captured and all related quantities or costs in the workbook to be updated automatically. CostX, therefore, benefits user into understanding the cost impact of each design changes.

Users nevertheless, are allowed to review the revisions before enabling the automatic update on the costing workbooks. This is a useful tool for quantity surveyors in practice as users are given full control of the changes in which they have the flexibility to accept or reject the new revised quantities of each element. In cases where quantities are mistakenly revised or deleted accidentally, the 'restore mode' allows users to view and bring back the previous quantities of a particular or all element groups.

6.2.4 BIMmeasure

BIMmeasure is the Building Information Modelling component in the Causeway's CATO Enterprise suite. It adds dynamic and automated measurement from BIM model to the pre-existing functionality of CADMeasure. BIMmeasure enables users to incorporate multiple modelling and drawing files in a single session and the integration of BIMmeasure with other modules in the CATO suite allows costs to be planned simply and effectively for BIM based project.

6.2.4.1 Model Information Exchange

BIMmeasure supports a variety of the drawing format, such DWF, DWFX, IFC, PDF, and several image formats. BIM model from Autodesk Revit needs to be exported as DWF, DWFX or IFC file formats. In this review, DWFX file format is used. (Figure 30)

IFC file is also tested, opening an IFC model took a significantly longer time than the DWFx model, as the size of the IFC file is much larger. There are also several discrepancies on the model elements between the IFC model and DWFx model. It is mainly due to the exporting process in Revit. In our experiment, the DWFx format worked more smoothly.

6.2.4.2 Visualisation Capability

BIMmeasure provides good visualisation capability, it can easily rotate, pan, zoom, and navigate around the model. Model highlighting features (highlight, standout, isolate) are also very useful while investigating individual item and a group of items. (Figure 31)

The model content window on the left and property window on the right provide a good visual interface for user to interrogate the model during the quantification process.

6.2.4.3 Quantification Process

The quantification process in the BIMmeasure is simple and user-friendly. The user can create the measurement element by element, or by using the dynamic measurement tool based on the element type or object property. The element quantity information is extracted from the BIM model element, so no manual measurement is required. Elements can also be scheduled in a table together with the quantity information for further analysis. (Figure 32)

BIMmeasure does not provide fully automated takeoff process from the model as each element's measurement type (such as area, count or linear measurement) needs to be defined during the quantification process. The measured elements in the measurement table are labelled or coloured in the model. This is very similar to the practices used by the quantity surveyors on the paper based manual measurement.

Figure 30: BIMmeasure model view

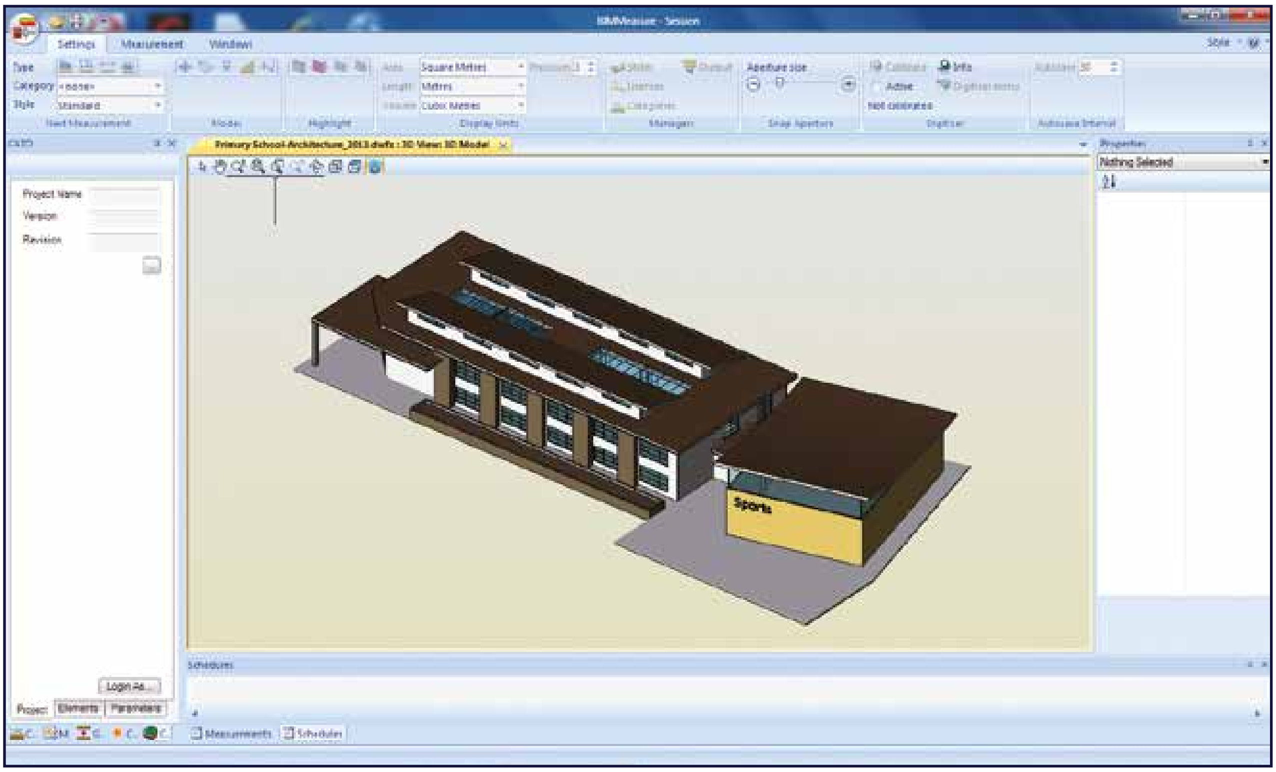


Figure 31: BIMmeasure model view

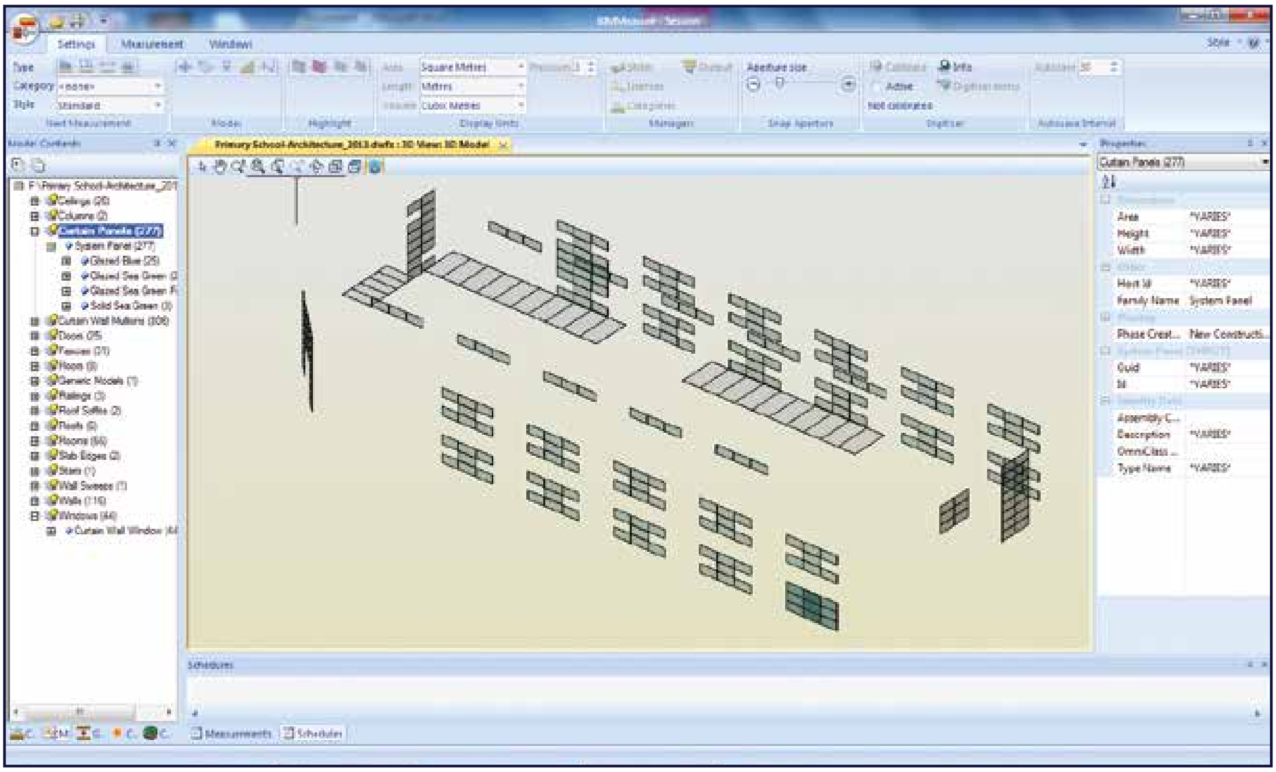


Figure 32: BIMmeasure measurement schedules

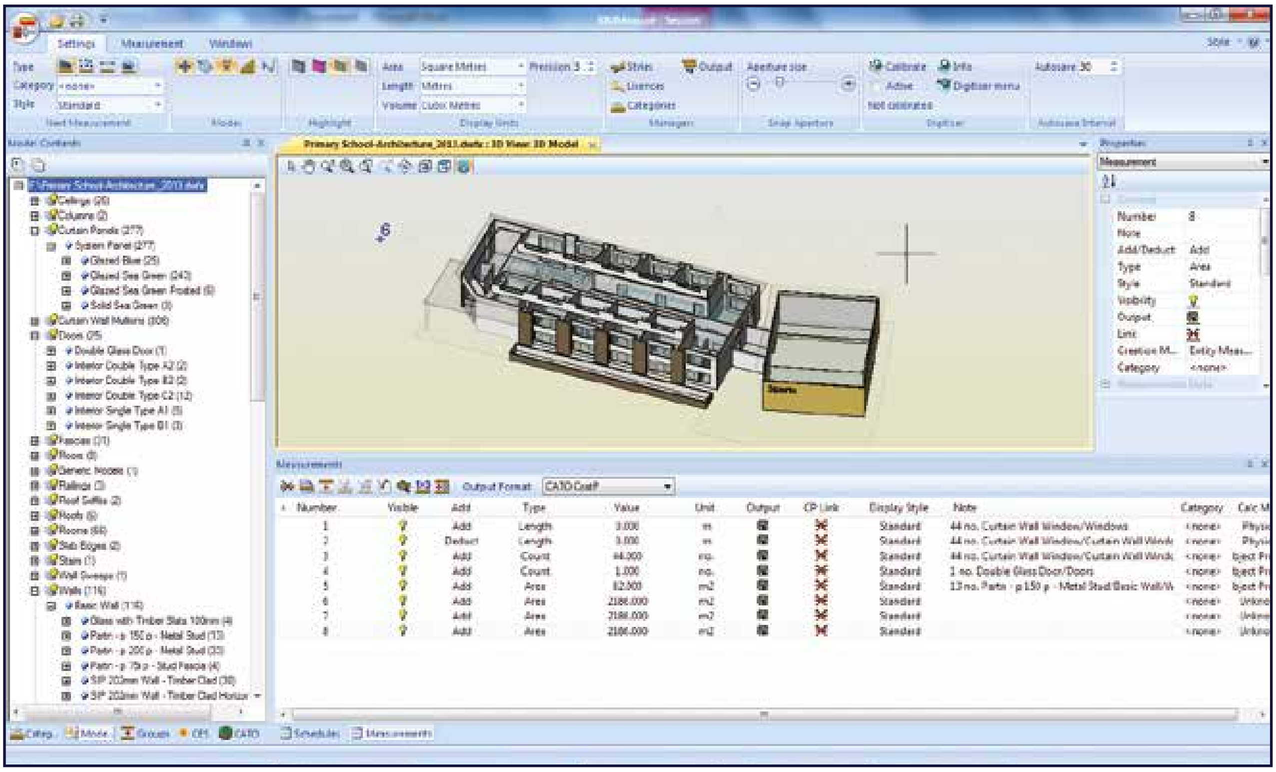
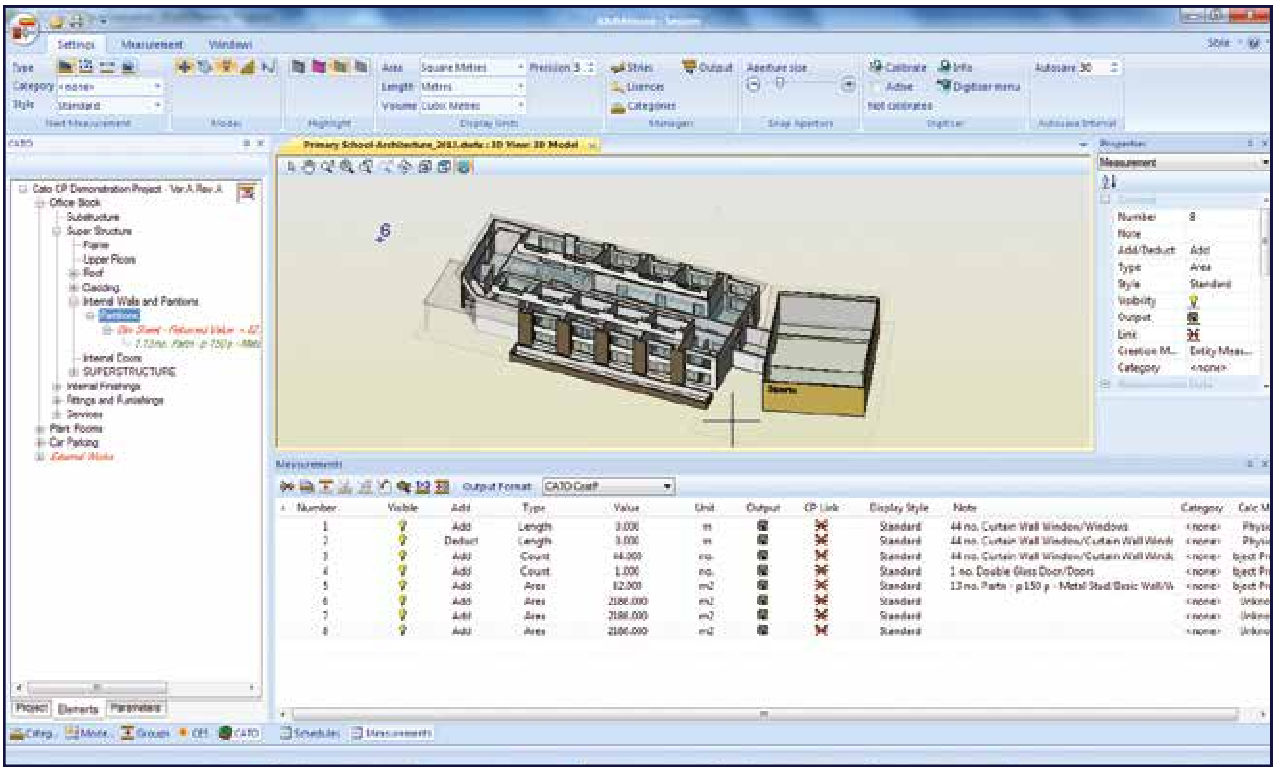


Figure 33 : BIMmeasure link to CATO cost plan



6.2.4.4 Reliability of information production

BIMmeasure doesn't provide the functionality to evaluate the quality and contents of the BIM model. Missing or unmeasured elements can't be automatically identified, although users can do it manually through its colour codes and labels.

In order to assure the reliability of cost estimates, it is advisable that users will need to incorporate the use of alternative model checking tools in conjunction with BIMmeasure to assess the quality of the BIM model before running the taking off process.

6.2.4.5 Customisation of built-in categories/ classifications for standard estimating format

BIMmeasure doesn't provide standard templates to categorise the element quantity information into a typical elemental breakdown. As part of CATO suites, the cost plan structure is provided within CATO. The measurement information in BIMmeasure can be easily linked with the relevant cost plan in CATO suite (Figure 33) . NRM 1 and 2 are currently supported by the CATO suite as one of the built-in libraries.

6.2.4.6 Report generation and export capabilities

All the measurements or quantities created in BIMmeasure can be exported in Excel and CATO format, the reporting facility is primarily provided through CATO suite.

6.2.4.7 Change management or revision control

BIMmeasure does not provide change management or revision control, change management is facilitated through the CATO suite.

7.0 Conclusions

There is no universally agreed definition of BIM. However, BIM can be summarised as the process and technology for producing, managing and sharing physical and functional data of a facility in a collaborative environment using digital representative models throughout project lifecycle processes. The main advantage of BIM is its capability to capture, manage and deliver information. From the QS point of view, BIM's capability of automating measurement is its key benefit and it clearly speeds up the traditional estimating process. It is evident that BIM delivers a more efficient operational solution for the quantity surveyors, for cost estimating, with its ability to link the relevant quantities and cost information to the building model and update them simultaneous to design changes. BIM based estimating can be executed in three ways, by exporting the measurements to Excel, by directly linking modelling tools with estimating plug-ins, and using specialised BIM estimating tools.

However, the implementation of BIM based measurement and cost estimating practices in the UK is still at its early stages. Many QS practices in the UK construction industry are still struggling to develop the best way of utilising BIM. The study identifies that quantity surveyors encounter difficulties in taking full advantage of BIM due to the substandard quality of BIM models, inconsistent level of design information included, data exchange issues in BIM tools, and inconsistent formats used for estimating. All these conditions need to be significantly improved to increase the confidence of QS professionals in BIM based estimating, and encourage a higher level of adoption of BIM within QS practices.

BIM estimating software tools are one of the important resources necessary for quantity surveyors to perform automated measurements. There are a number of BIM based cost estimating tools available on the market and choosing the most appropriate tool is significant for the QS companies since different tools are designed by different software developers to best perform only in certain environments or scenarios. In this context, the research reviewed the four most well known tools in the UK market, namely, Solibri model checker, Autodesk QTO, CostX and Causeway BIM measure in order to provide a holistic picture based on a set of criteria, which are most relevant to the NRM cost estimating and planning exercise. The research did not intend to identify which one is the best tool in the market as each tool has its own unique features and shortcomings. Nevertheless, these tools should not be considered as the ultimate solution for QS tasks as they only speed up the processes and increase the accuracy of estimates.

NRM1 is going to be the standard to govern the information and rules for cost estimating and planning processes in UK. Thus, considering the relatively low maturity level of BIM implementation within the QS practices, many companies have looked into ways of improving the current issues in BIM based estimating, and have realised supporting the NRM1 format through BIM as the way forward. In addition, a commonly agreed definition of information requirements and a standard protocol for the process are also important to improve the prevailing situation. The efficiency and accuracy of QS functions can be significantly improved by aligning the BIM based cost estimating and planning processes with NRM1, as it resolves the problems related to the quality of the BIM models and the issues created by the variations of design details.

The research investigated the information requirement of BIM models for the NRM1 cost estimating and cost planning. It provides overall guidance for the QS professionals on what they can expect from a BIM model and how the quantity information in BIM model can be used in cost estimating and planning. The study concludes that it is essential for the project team to agree on a set of requirements which is defined from the viewpoint of cost estimating and planning to enable the quantity surveyor to use BIM more effectively.

8.0 References

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