A TECHNICAL REVIEW OF BIM BASED COST ESTIMATING IN UK QUANTITY SURVEYING PRACTICE, STANDARDS AND TOOLS

Song Wu, Prof,
School of Art, Design and Architecture, University of Huddersfield;
s.wu@hud.ac.uk

Gerard Wood, Dr,
School of Built Environment, University of Salford;
g.d.wood@salford.ac.uk

Kanchana Ginige, Dr,
School of Art, Design and Architecture, University of Huddersfield;

Siaw Wee Jong
ISG plc

SUMMARY: In light of recent technological advancements over the decades especially with Information Technology (IT), the 'Building Information Modelling' (BIM) is one of those advancements that have attracted significant attentions in UK construction industry. The UK government has 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 have BIM ready by 2016. For Quantity Surveying (QS) profession, 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 digital model of a building, a process that traditionally is very time consuming for quantity surveyors. However, there is little evidence that BIM is systematically introduced in quantity surveying profession in UK largely due to majority of the BIM based cost estimating or take-off tools developed outside UK and adopted the different practice and rules in quantification.

In this paper, we examine the cost estimating practice and procedure in UK and the impact of the use of BIM. A number of key challenges have been identified in term of information exchange, model quality and UK standards. It also reviews the existing BIM based cost estimating tools in the context of UK quantity surveying practice. A review methodology is developed to evaluate the ability of the existing BIM technology to support the UK QS practices. The methodology is applied to a number of leading BIM based estimating tools. The review assesses the technical and process approach of each tool and their ability of adapting to UK quantity surveying practice, particularly with the New Rules of Measurement (NRM), which is aimed to provide a holistic view of the technologies for the Quantity Surveying professions to make informed decisions.

KEYWORDS: BIM, Cost Estimating, NRM, Quantity Surveying

1. INTRODUCTION

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). 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 advices and quality management. Following the emergence of Building Information Modelling (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). 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 the opportunities BIM could bring in relation to their current and future roles.

1.1 Research process

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, 2011b), 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 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. In this paper, the authors aims to bridge the knowledge gap of BIM based estimating or take-off technology and the UK standards and practices of measurement and cost estimating, this research investigates how a BIM model to support the estimating process according to the RICS standard of NRM1 order of cost estimating and elemental cost planning, and reviews the technical requirement for BIM based software tools to support NRM1. In order to achieve this aim, the following three objectives have been established:-

• 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 review technical requirement for BIM based software tools to support NRM order of cost estimating

Having recognised the significance needs of developing a comprehensive understanding of how to support the cost estimating/planning processes through BIM, the study deployed two main research methods to achieve its objectives. - Literature review and BIM estimating tools review.

1.2 BIM application for cost estimating and cost planning

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 projects' 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 early stage of a project (Eastman et al., 2011).

BIM means changes to the manner buildings are designed, documented, analysed, procured, constructed and managed as it unlocks new way of working for all construction disciplines, (Aranda-Mena et al., 2008; Hardin, 2009). Inevitably, it includes changing the way cost plans and estimates are produced as well.

1.2.1 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). Cartlidge (2009) noticed that many estimating software 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). A BIM model contains 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.

1.2.2 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 quantification tools

This approach associates with the use of specialised Quantity TakeOff (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 take-off 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 to cross check the take-off 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. According to our study, this is also the most likely approach that will be adopted by QS in UK.

Furthermore, BIM is argued to be adding new complications to the cost estimating processes for QS; including 3D model management, navigation and model export, 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).

1.2.3 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 is contended to be fragmented 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 paper examines various measurement standards, which have been used in the UK for cost estimating and planning.

2. UK MEASUREMENT AND COST ESTIMATING STANDARDS

2.1 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 1 for greater consistency and easier information distribution (Lee et al., 2011; RICS & CC, 1998).

Table 1: 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

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.

2.2   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.

2.3 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.

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

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. Fig.1 illustrates 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).

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

		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

Fig. 1 The key constituents of an order of cost estimate (Source: RICS, 2012)

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 (Fig 4) 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).

RIBA Work Stages			RICS cost estimating, elemental cost planning and tender document preparation stages	OGC Gateways (Applicable to projects)	
Preparation	A	Appraisal	Order of cost estimates (as required to set authorised budget)	1	Business Justification
Preparation	B	Design Brief		2	Delivery Strategy
Design	C	Concept	Formal cost plan 1	3A	Design Brief and Concept Approval
Design	D	Design Development	Formal cost plan 2		
Design	E	Technical Design	Formal cost plan 3 Pre-tender estimate	3B	Detailed Design Approval
Pre-construction	F	Production Information			
Pre-construction	G	Tender Documentation	Bills of quantities (Quantified) schedule of works (Quantified) work schedules		
Pre-construction	H	Tender Action	Post tender estimate		
Construction	J	Mobilisation		3C	Investment Decision
Construction	K	Construction to Practical Completion		4	Readiness for Service
Use	L	Post Practical Completion		5	Operational Review and Benefits Realisation

Fig. 2 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

It is worth noting that the measurement standards in UK (SMM or NRM) are developed independent of the BIM development process. They are designed for the presentation of the building cost during the design and construction process. Inevitably, their classification system and measurement rules have not been taken into consideration of the BIM development and their information structure is not fully compatible with the BIM data structure (i.e. IFC structure or Revit object structure). Therefore, in order to for QS to embrace the BIM based estimating and cost planning, the BIM estimating tools have to provide the flexibility to support for the abovementioned UK cost estimating practice. In the next section of the paper, the study reviews a number of BIM based cost estimating tools available and their capability to support UK estimating practice.

3. BIM BASED COST ESTIMATING TOOLS REVIEW

QS firms would have to choose BIM based estimating tools depending on the estimating workflow, available software, and pricing database used in their practices in order to be part of a BIM based project and to benefit from the advantages of BIM technology. In this context, this paper reviews the functional and technical capabilities of the following four BIM based estimating applications currently available in UK market.

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

BIM based estimating tools vary in their functionality and working processes, therefore, 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 each tool could adapt to the latest NRM requirements.

3.1 Review methodology

This review first explores the information published by software suppliers and product reviews by existing users and collect variable opinions towards the aforementioned software application. Trials are later undertaken on all the tools to further verify and distinguish their functions and features towards the QS profession. In order to develop a consistent and objective review, it is important to base the experiment on a standard structure; for instance, a common BIM model and a set of defined criteria.

The use of Autodesk Revit application packages 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 the BIM model produced by Revit. Hence, a Revit 2013 model is used as the testing BIM model in this review.
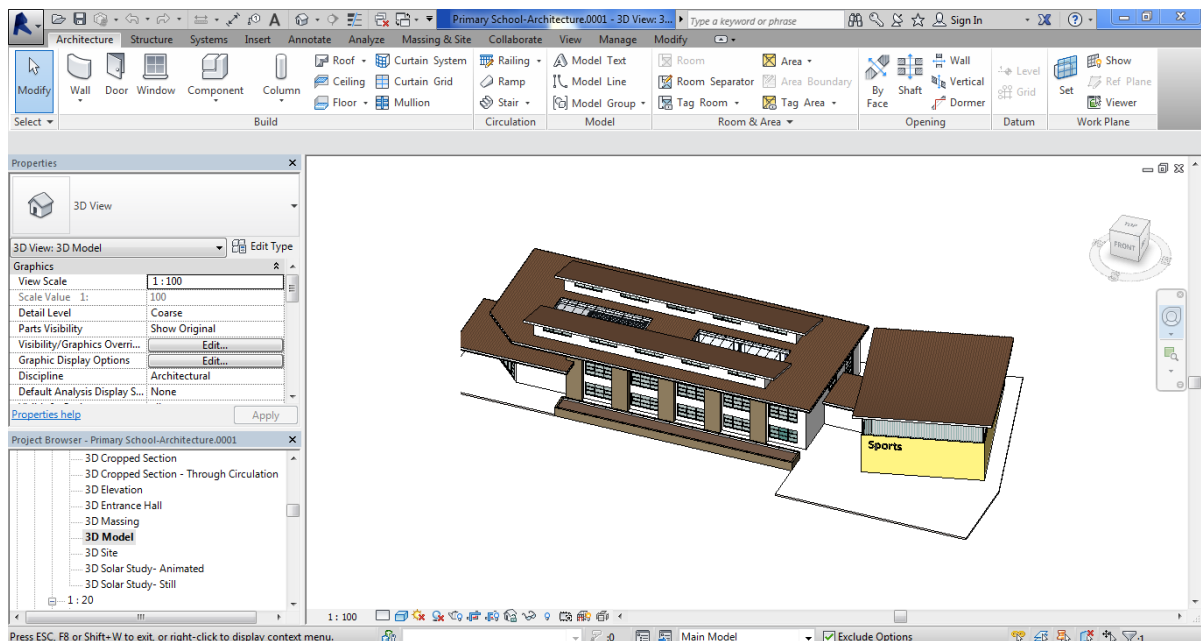

Fig. 3 Revit Model used in the review

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

1. **Model information exchange** (Exchange) - 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.

2. **Model Visualisation (Visualisation)** - 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.

3. **Quantification process (Quantification)** - the level of simplicity, and speed of the tools in generating cost estimates or quantity take-offs. 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.

4. **Reliability of information production (Reliability)** - capability of tools to transfer and extract 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.

5. **Customisation of built-in categories/classifications for standard estimating format (Customisation)**- 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. **Change management or revision control (Change)** - 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.

7. **Report generation and export (Report)**- 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.

3.2 Review of BIM based estimating tools

3.2.1 Solibri Model Checker (SMC) Ver. 8

SMC is not a BIM authoring tool or cost estimating 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 quality checks to BIM models, including visualisation, navigation and presentations compilation (Khemlani, 2011). SMC is a valuable application that supports test 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 paper.

3.2.1.1 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.

3.2.1.2 Model Visualisation

SMC supports visualisation of the BIM models effectively similar to the visualisation in BIM authoring tools. It provides 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.

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.

In the information take-off process, visualisation and highlights functionality (Fig.4) enable users to clearly identify the right components to take-off and determine the correct classification for each components.

Fig. 4 SMC information take-off sheet

3.2.1.3 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 changes to its standard built-in classifications to suit the users' requirements, so that the components can be restructured to the desired category, i.e. NRM 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 instantly.

3.2.1.4 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 5) pre-defined in the application to perform checks to the model or customise the rules based on their preferences and purpose. 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.
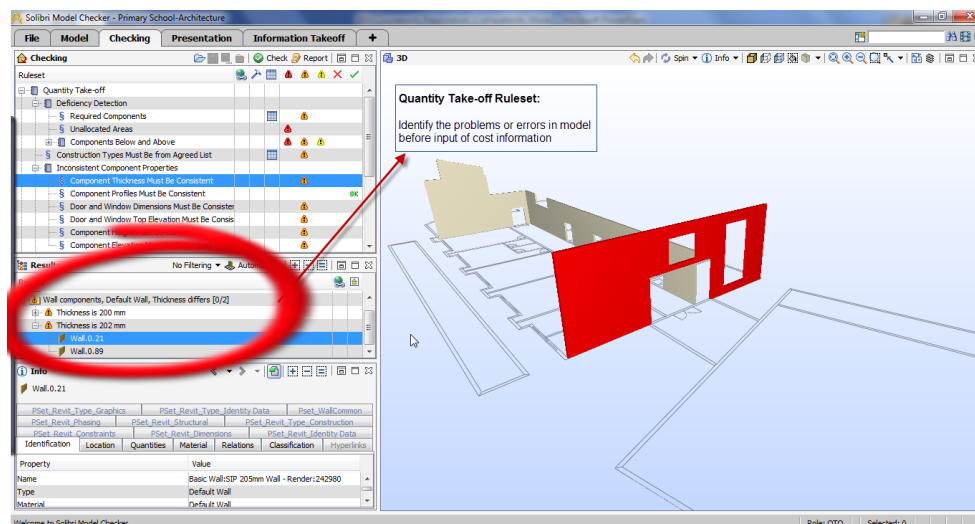

Fig. 5 SMC information take-off ruleset

3.2.1.5 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 organize and align the components to match with the NRM format. The original 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 coding, renaming the type of the components, which helps to restructure the information within the model to suit the NRM requirements.

3.2.1.6 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.

3.2.1.7 Report generation and export

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.

3.2.2 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.

3.2.2.1 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.

Besides 3D models, QTO also enables traditional 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).

3.2.2.2 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 6)
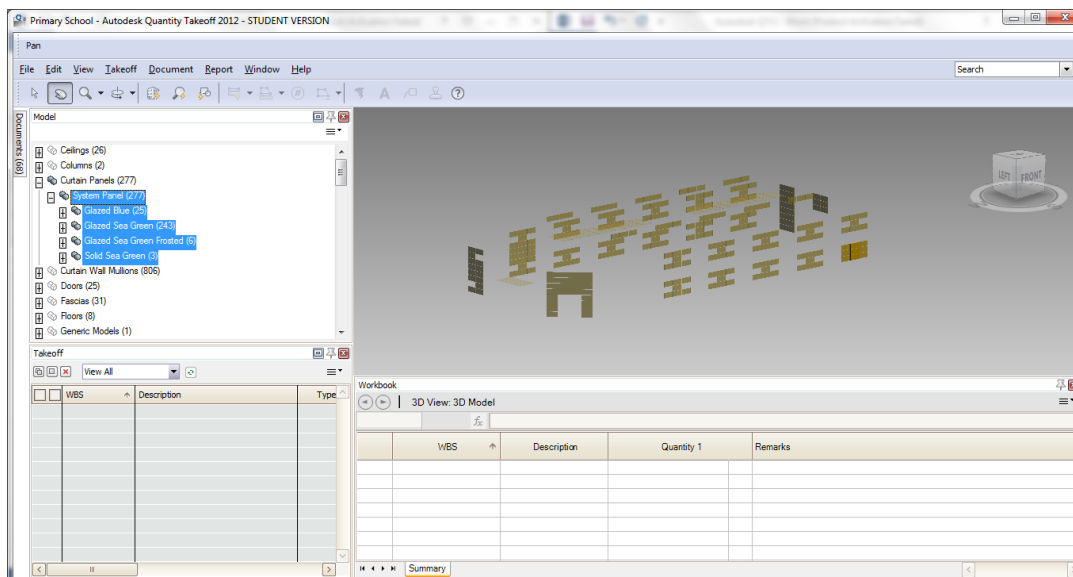
Fig. 6 QTO model visualisation

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, but having these capability 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 not modelled within the BIM design. (Figure 7)
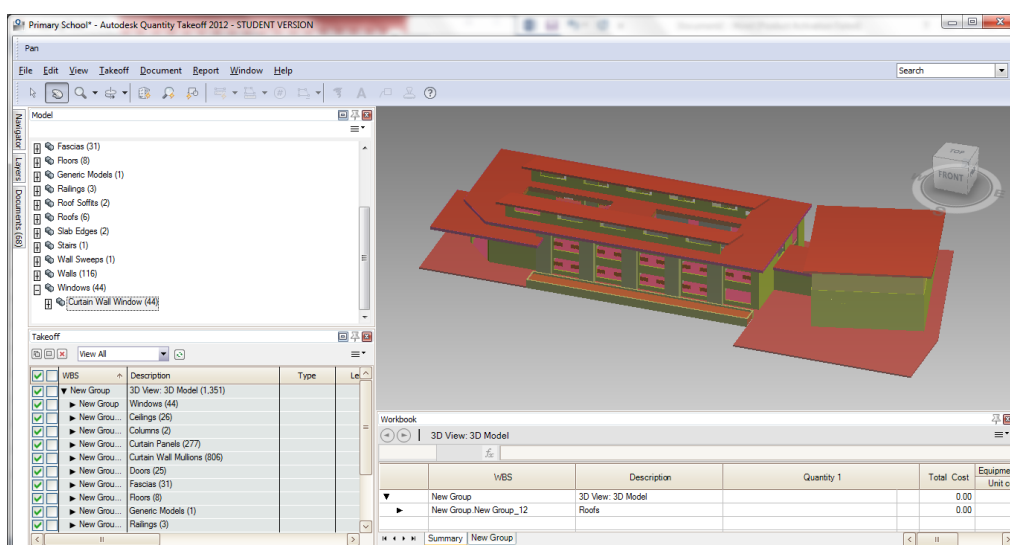

Fig. 7 QTO take-off view

3.2.2.3 Quantification Process

Autodesk QTO supports automatic measurement of the entire BIM model. However, it is not a fully automated process on the first time using 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 previous element assignments and allow similar definition to be predictively applied in subsequent BIM projects.

3.2.2.4 Reliability of information production

As part of the Autodesk product family, it is claimed by Alexander (2010) that it provides 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, it is advisable to use alternative model checking tools in conjunction with Autodesk QTO to assess the quality of the BIM model before running the taking off process.

3.2.2.5 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 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.

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.

3.2.2.6 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.

3.2.2.7 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.

3.2.3 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) explains 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.

3.2.3.1 Model Information Exchange

CostX provides integration with Revit BIM model not only through 3D DWF and DWFx file; but also, IFC file format. 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.

3.2.3.2 Model Visualisation

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)
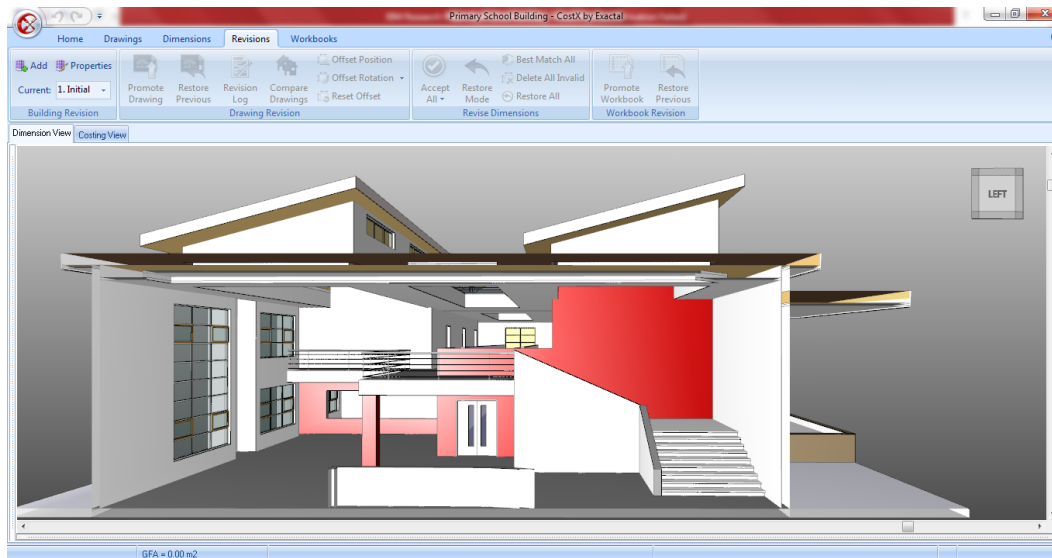

Fig. 8 CostX model visualisation

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.

3.2.3.3 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 9)
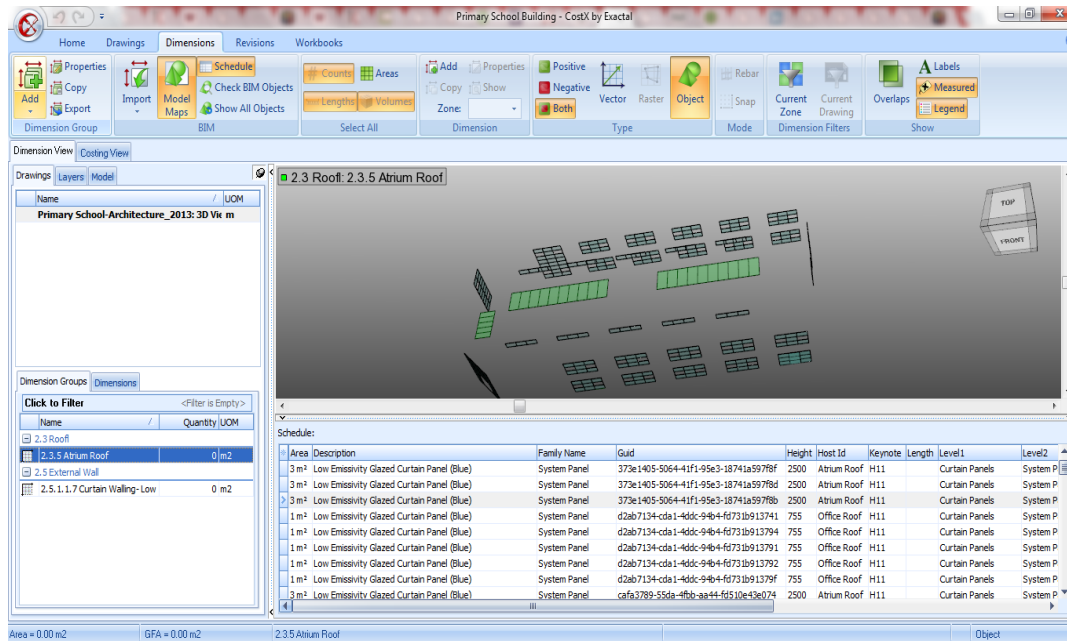
Fig. 9 CostX measurement schedule

CostX allows users to decide whether to quantify the model completely or partially, through manipulating the visibility of BIM objects within the dimension viewing tab. Users can make a selection of BIM objects and choose either to filter or hide them before running the dimension import. CostX will later only extract quantities from the selected visible objects. In other words, in order to take-off the model completely and accurately, it requires all BIM objects to be visible. Therefore, users have to be careful to make sure no objects are hidden during the take-off process.

CostX uses its dimension import tool to automate the extraction of all dimensions from BIM models. The automated quantity take-off process relies on a series of standard built-in BIM templates to capture and populate the object dimensions from information contained within the BIM model into the desired dimension groups. The BIM templates contain pre-defined grouping requirements to form the structure for the dimensional information extracted from BIM model.

3.2.3.4 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.

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.

3.2.3.5 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.

3.2.3.6 Report generation and export capabilities

All the measurements or quantities can be exported to Excel format easily in 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.

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.

3.2.3.7 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.
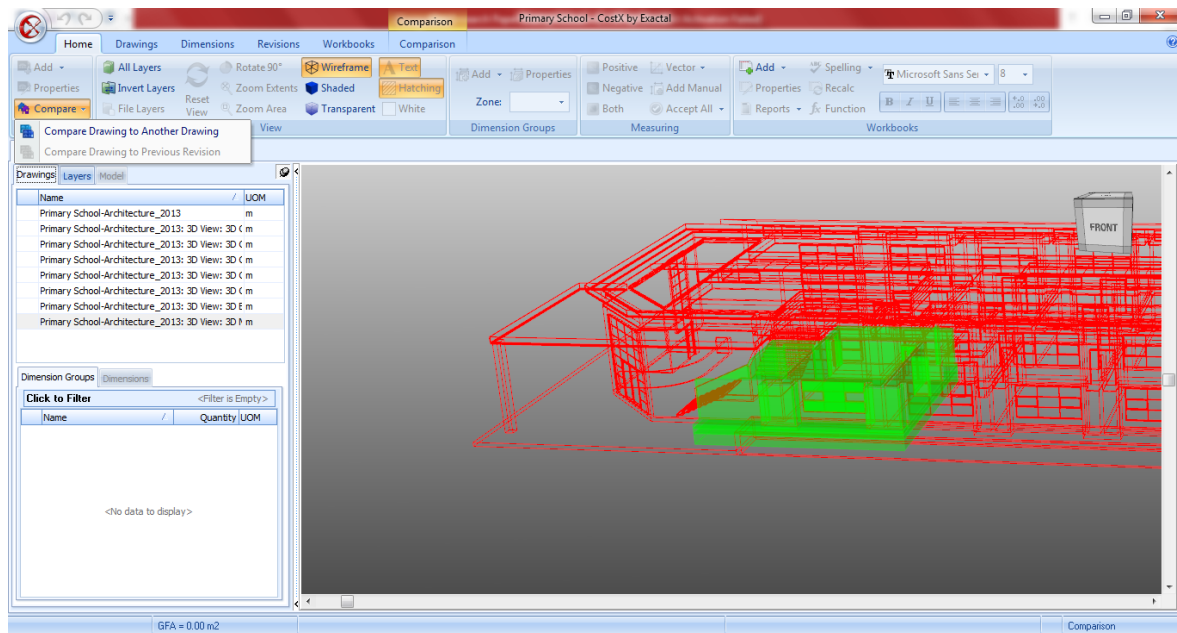
Fig. 10 CostX revision control

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.

3.2.4   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.

3.2.4.1   Model Information Exchange

BIMmeasure supports 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.

IFC file is also tested, opening IFC model took significant 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.

3.2.4.2 Model Visualisation

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 11)

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.
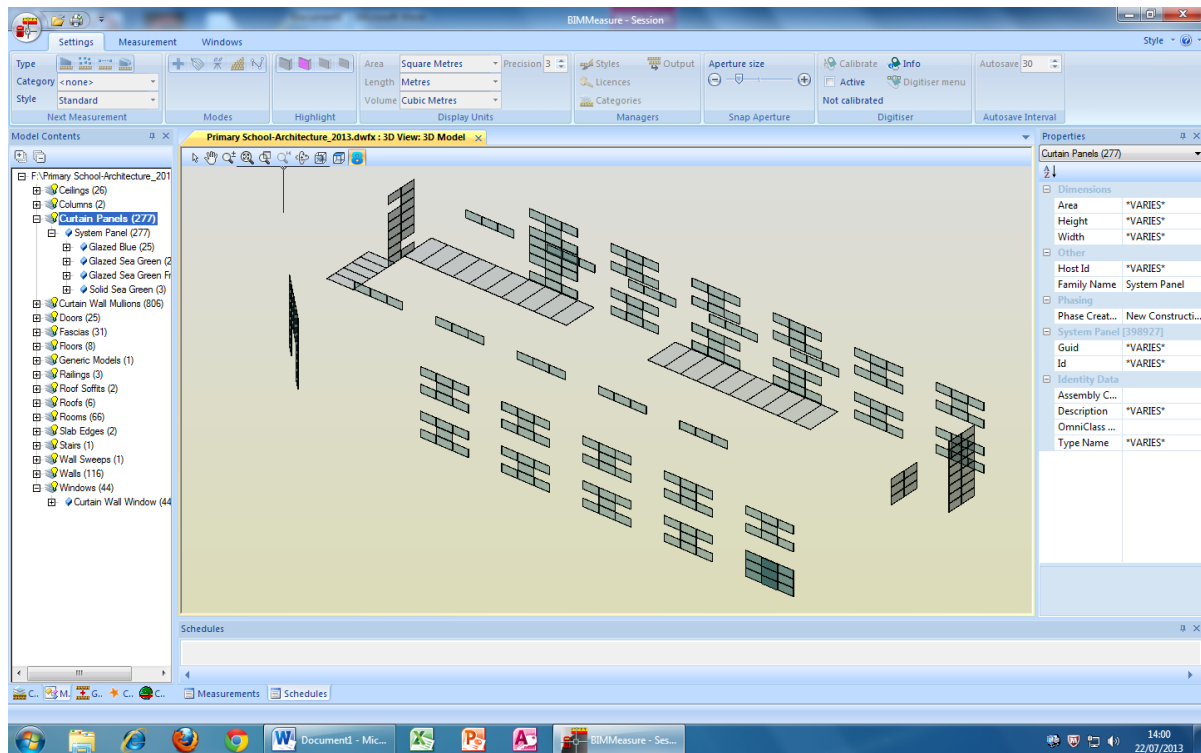

Fig. 11 BIMmeasure element view

3.2.4.3 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 12)

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.
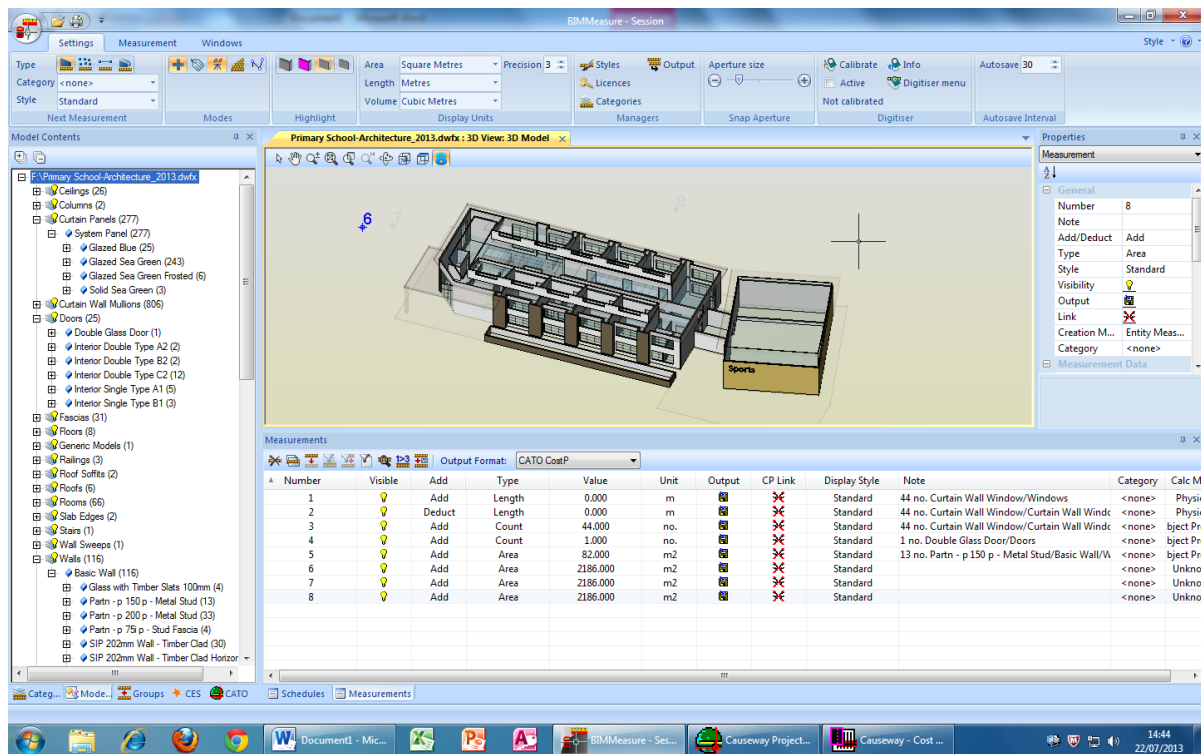
Fig. 12 BIMmeasure measurement schedules

3.2.4.4 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 user 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.

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

BIMmeassure 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 13) . NRM 1 and 2 are currently supported by the CATO suite as one of the built-in libraries.
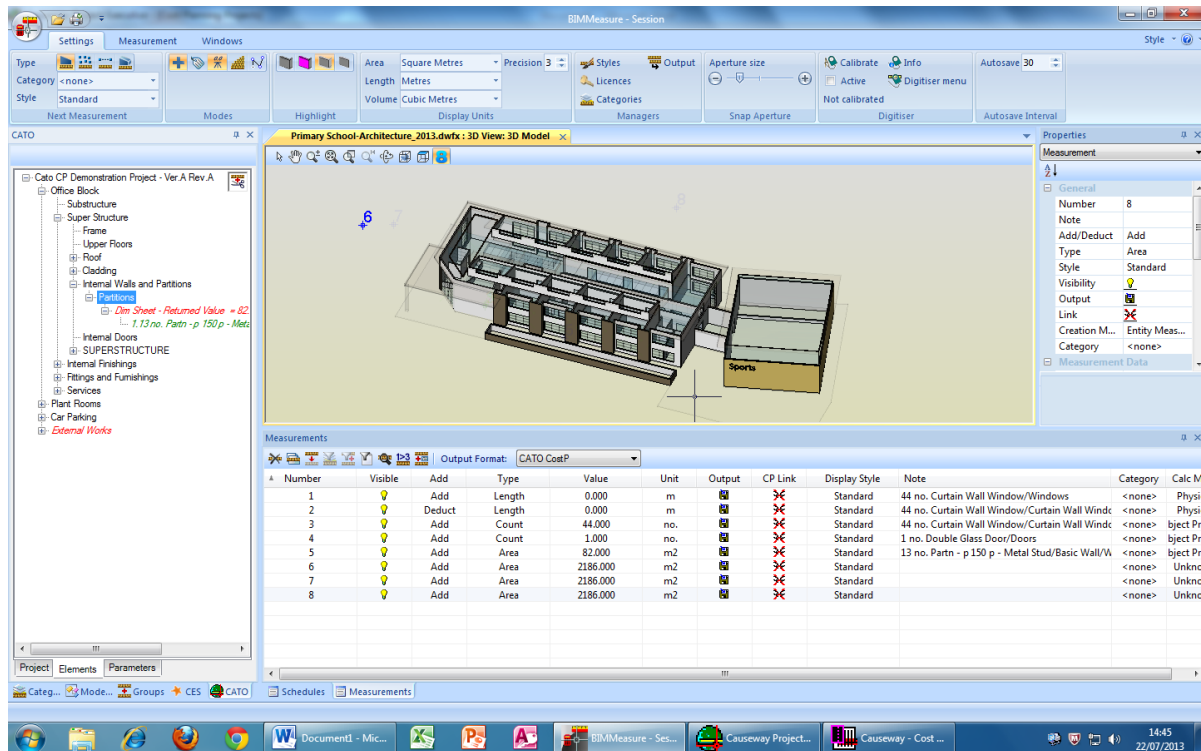
Fig. 13 BIMmeasure link to CATO cost plan

3.2.4.6 Report generation and export capabilities

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

3.2.4.7 Change management or revision control

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

4. CONCLUSION

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. From the Quantity Surveyor 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 digital building model and update them simultaneous to design changes.

However, 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 paper establishes the key approaches of BIM based cost estimating and planning, including exporting BIM quantities, linking BIM estimating with design tool and using specialised BIM measurement tool. It also 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. Furthermore, the design and development of the UK cost estimating and measurement standards is independent of the BIM development, gaps such as the interpretation of the measurement rules and

building modelling process, have to be addressed in order to accelerate the BIM adoption among the QS professions.

BIM estimating software tools are one of the important resources necessary for quantity surveyors to perform BIM based cost estimating. 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 BIMmeasure in order to provide a holistic picture based on a set of criteria, which are most relevant to the UK cost estimating and planning practice. The review results are summarised in the Table 2. It is quite clear from the review that majority of the tools with the exception of BIMmeasure do not support the UK practice automatically and additional works are required to use them in the UK projects. However, each tool has its own unique capability to assist the Quantity Surveyor to take advantage of the BIM technology, such as model checking in Solibri, model visualisation in CostX and CATO integration in BIMmeasure. It is the authors' intention to provide an overall view of the capabilities of the existing tools, which enables the Quantity Surveyors to make an informed decision to select the tools to suit their practice or projects.

5. ACKNOWLDEGEMENTS

6. REFERENCES

Alexander, C. (2010). A Quick Primer to Using Autodesk QTO for Model-Based Takeoff Retrieved 15th August, 2012, from http://www.aecbytes.com/tipsandtricks/2010/issue51-autodeskQTO.html

Alexander, C. (2010). A Quick Primer to Using Autodesk QTO for Model-Based Takeoff Retrieved 15th May, 2013, from http://www.aecbytes.com/tipsandtricks/2010/issue51-autodeskQTO.html

Aranda-Mena, G., Crawford, J., Chevez, A., & Froese, T. (2008). Building Information Modelling Demystified: Does It Make Business Sense to Adopt BIM? Paper presented at the International Conference on Information Technology in Construction, Santiago, Chile.

Ashworth, A. (2004). Cost Studies of Building (4th Edition ed.). Essex: Pearson Education Limited.

Ashworth, A., & Hogg, K. (2007). Willis's Practice and Procedure for the Quantity Surveyor (12th ed.). Oxford: Blackwell Publishing Ltd.

Autodesk. (2007). BIM and Cost Estimating. Retrieved from http://www.consortech.com/bim2/documents/BIM_cost_estimating_EN.pdf

Autodesk. (2008). Autodesk Quantity Takeoff 2009.

Autodesk. (2012). Autodesk Quantity Takeoff Retrieved 15th August, 2012, from http://usa.autodesk.com/adsk/servlet/pc/index?id=10354648&siteID=123112

BCIS. (2009). The SFCA and the NRM. Retrieved from http://www.bcis.co.uk/downloads/SFCA-NRM_Complete_15-10-09.pdf

BCIS. (2011). RICS 2011 Building Information Modelling Survey Report. Retrieved from http://www.bcis.co.uk/downloads/RICS_2011_BIM_Survey_Report.pdf

Brisk, S. (2008). Autodesk Quantity Takeoff 2009 Product. Retrieved from http://revitmep.blogspot.co.uk/2008/06/autodesk-quantity-takeoff-2009-product.html

Eastman, C (1999) Building Product Models: Computer Environments, Supporting Design and Construction, CRC Press

Cartlidge, D. (2009). Quantity Surveyor's Pocket Book. Oxford: Butterworth-Heinemann.

Cartlidge, D. (2011). New Aspects of Quantity Surveying Practice. Oxon: Spon Press.

Corke, G. (2013,). AEC Magazine: Solibri Model Checker V8. Retrieved December 23, 2012, from AEC Magazine: http://aecmag.com/index.php?option=content&task=view&id=527

Day, M. (2008). Exactal CostX Retrieved 5th June, 2013, from http://aecmag.com/index.php?option=com_content&task=view&id=249&Itemid=32

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2008). Managing BIM Technology in the Building Industry Retrieved 21st July, 2012, from http://aecbytes.com/viewpoint/2008/issue_35.html

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM Handbook: A Guide to Building Information Modeling. New Jersey: John Wiley & Sons.

Eos Group. (2008). Building Information Modeling: A Cost Estimating Perspective. Retrieved from http://www.eosgroup.com/product_pdfs/BIM_White_Paper_6-08-no_contact.pdf

Exactal. (2010). CostX Whitepaper, retrieved http://www.exactal.co.uk/sites/default/files/pdf/CostX-White-Paper_v3.20.pdf

Hardin, B. (2009). BIM and Construction Management: Proven Tools, Methods, and Workflows. Indianapolis: Wiley Publishing Inc.

Jellings, J., & Baldwin, M. (2009a). BIM Based Quantity Surveying. BIM Journal - Improving the Construction Process, 1(11), 82-87.

Jellings, J., & Baldwin, M. (2009b). Model Based Estimating. BIM Journal - Improving the Construction Process, 1(4), 32-35.

Jiang, X. (2011). Developments in Cost Estimating and Scheduling in BIM Technology. Northeastern University.

Khemlani, L. (2009). AECbytes Product Review: Solibri Model Checker. Retrieved December 22nd, 2012, from AECbytes: http://www.aecbytes.com/review/2009/SolibriModelChecker.html

Khemlani, L. (2011). AECbytes Product Review: Solibri Model Checker v7. Retrieved December 22nd, 2012, from AECbytes: http://www.aecbytes.com/review/2011/SolibriModelCheckerv7.html

Khemlani, L. (2011). Solibri Model Checker v7 Retrieved 17th August, 2012, from http://www.aecbytes.com/review/2011/SolibriModelCheckerv7.html

Kirkham, R. (2007). Ferry and Brandon's Cost Planning of Buildings (8th ed.). Oxford: Blackwell Publishing Ltd.

Kiviniemi, A., Rekola, M., Belloni, K., Kojima, J., Koppinen, T., Makelainen, T., . . . Heitanen, J. (2007). Senate Properties: BIM Requirements 2007 Quantity Take-Off (Vol. 7). Finland: Senate Properties.

Kulusjarvi, H., Widney, J., & Jauhiainen, J. (2010a). Introduction to Information Takeoff. Retrieved from

Kulusjarvi, H., Widney, J., & Jauhiainen, J. (2010b). Mining the Model, Solibri Introduces Information Takeoff (ITO). Solibri Magazine, 17-19.

Kymmell, W. (2008). Building Information Modeling: Planning and Managing Construction Projects with 4D CAD and Simulations. New York: McGraw Hill Companies.

Lee, G. (2011). What Information Can or Cannot be Exchanged? Journal of Computing in Civil Engineering, 25(1), 1-9.

Lee, S., & Smith, A. (2010). New Rules of Measurement - Order of Cost Estimating and Elemental Cost Planning. Retrieved from http://www.rics.org/site/download_feed.aspx?fileID=7074&fileExtension=PDF

Lee, S., Trench, W., & Willis, A. (2011). Willis's Elements of Quantity Surveying. Chichester: John Wiley & Sons Ltd.

Lovegrove, S. (2011). BIM and Cost Estimating. Retrieved from http://www.rism.org.my/ISMDoc/SEASC2011/1-CD%20SEASC/PAPER/TS1D/TS1D_PAPER_3.pdf

Ma, H., Ha, K. M. E., Chung, C. K. J., & Amor, R. (2006, 14-16 June). Testing Semantic Interoperability. Paper presented at the Proceedings of the Joint International Conference on Computing and Decision Making in Civil and Building Engineering, Montreal, Canada.

Matipa, W. M., Cunningham, P., & Naik, B. (2010, 6-8 September). Assessing the Impact of New Rules of Cost Planning on Building Information Model (BIM) Pertinent to Quantity Surveying Practice. Paper presented at the 26th Annual ARCOM Conference, Leeds, UK.

Matipa, W. M., Kelliher, D., & Keane, M. (2008). How a Quantity Surveyor Can Ease Cost Management at the Design Stage Using A Building Product Model. Construction Innovation, 8(3), 164-181.

Matthews, D. (2011a). De-coding BIM Retrieved 15th June, 2012, from http://www.building.co.uk/buildings/technical/de-coding-bim/5018618.article

Matthews, D. (2011b). Rise of the Machines: BIM and QSs Retrieved 15th June, 2012, from www.building.co.uk/news/qs/rise-of-the-machines-bim-and-qss/5019945.article?sm=5019945

McCuen, T. (2009). Cost Estimating in BIM: The Fifth Dimension Retrieved 18th June, 2012, from http://constructionadvisortoday.com/2009/11/cost-estimating-in-bim-the-fifth-dimension.html

McGraw Hill Construction. (2010). The Business Value of BIM in Europe: Getting Building Information Modelling to the Bottom Line in the United Kingdom, France and Germany. Bedford: McGraw-Hill Construction.

NBS. (2012). National BIM Report 2012. Retrieved from http://www.thenbs.com/pdfs/NBS-NationalBIMReport12.pdf (Retrieved 15th June, 2013)

Odusami, K. T., & Onunwube, H. N. (2008). Factors Affecting The Accuracy of Pre-Tender Cost Estimate in Nigeria. Paper presented at the RICS Construction and Building Research Conference, Dublin Institute of Technology.

Olatunji, O. A., Sher, W. D., & Gu, N. (2010). Building Information Modelling and Quantity Surveying Practice. [Review Paper]. Emirates Journal for Engineering Research, 15(1), 67-70.

Olatunji, O. A., Sher, W. D., & Ogunsemi, D. R. (2010). The Impact of Building Information Modelling on Construction Cost Estimation. Paper presented at the 18th CIB World Building Congress Salford, UK.

PDS. (2009). Cost X - The Powerful Project Costing Tool Retrieved 15th June, 2013, from http://www.pdssb.com.my/index.php/products-solutions/exactal/costx.html

Pittard, S. (2012). What is BIM? Retrieved from http://fat.glam.ac.uk/media/files/documents/2012-03-16/What_is_BIM_1_.PDF

Raisbeck, P., & Aibinu, A. A. (2010, 6-8 September). Early Stage Cost Estimation and The Relationship of Architects to Quantity Surveyors. Paper presented at the Proceedings 26th Annual ARCOM Conference, Leeds, UK.

RICS (2011) Construction Procurement: New Rules of Measurement [Online] rics.org, Retreieved from: http://www.rics.org/site/scripts/documents_info.aspx?documentID=761 [Accessed on 5th October, 2011]

RICS, & CC. (1998). SMM7: Standard Method of Measurement of Building Works (7th ed.).

RICS, & Davis Langdon. (2007). Contracts in Use: A Survey of Building Contracts in Use during 2007.

RICS. (2012). RICS New Rules of Measurement 1: Order of Cost Estimating and Elemental Cost Planning. Coventry: Royal Institution of Chartered Surveyors (RICS).

Sabol, L. (2007). Technology, Change and the Building Industry. Real Estate Review, 36(3).

Sabol, L. (2008). Challenges in Cost Estimating with Building Information Modelling. Retrieved from http://www.dcstrategies.net/files/2_sabol_cost_estimating.pdf

SAGE. (2009). Integration with Autodesk Quantity Takeoff 2010. Retrieved from http://ftp.sagesoftwareuniversity.com/lms/cre/CRE411/QTO101/SageEstimatingIntegration_with_QTO.pdf

Samphaongoen, P. (2009). A Visual Approach to Construction Cost Estimating. Marquette University, Wisconsin.

Tocoman. (2010a). BIM Based Quantity Take-off, Estimating and Scheduling. Retrieved from http://www.tocoman.com/sites/default/files/webfm/user/WHITE%20PAPER%20-%20BIM%20based%20estimating%20and%20scheduling.pdf

Tocoman. (2010b). Tocoman iLink - BIM based Quantity Takeoff Retrieved 17th August, 2012, from http://www.tocoman.com/ilink

Yan, H., & Damian, P. (2008). Benefits and Barriers of Building Information Modelling. Paper presented at the 12th International Conference on Computing in Civil and Building Engineering, Beijing, China.

Zhiliang, M., Zhenhua, W., Wu, S., & Zhe, L. (2011). Application and Extension of the IFC standard in Construction Cost Estimating for Tendering in China. Automation in Construction, 20(2), 196-204.

Table 2: Summary of BIM based cost estimating tools review

Tools / Criteria	Exchange	Visualisation	Quantification	Reliability	Customisation	Change	Report
Solibri Model Checker 8	IFC for BIM model	3D navigation view	Automatic process with default structures, no UK library	Comprehensive Model checking ability	Flexible, No UK template but different library can be introduced	No automatic check and link with external applications	Limited built in template, but can be exported to Excel
QTO 2012	DWFX or DWF for BIM model	3D navigation view, adjust visibility and colour	Manual process required initially, no built-in UK library	No model checking ability	Flexible, No UK template but different library can be introduced	Compare feature and revision control	Flexible built in report tool
CostX 3.5	IFC, DWFX or DWF for BIM model	3D navigation view, adjust visibility and colour, section cut through and model walk through	Manual and automatic process, built in automatic BIM take off structure. No built in UK library	Model checking ability for unmeasured objects or duplicated objects	Flexible, No UK template but different library can be introduced	Change management and revision control	Flexible built in report tool
BIM Measure 16.4	DWF, DWFx, IFC and PDF for BIM model	3D navigation view	Manual and automatic process, built in automatic BIM take off structure.	No model checking ability	UK library included as part of the CATO suite	Included in the CATO suite	Included in the CATO suite