AUTOMATION OF BIM QUANTITY TAKE-OFF TO SUIT QS'S REQUIREMENTS

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ABSTRACT

Building Information Modelling (BIM) is a thriving technology which laid potential to address problems in conventional practices based on Computer-Aided Design (CAD) drawings. Sustainability and complexity of today's buildings are insist BIM technology and associated processes to develop for project delivery through sustainable procurement systems. Quantity Take-Off (QTO) is vitally important task in any building project since measurement practice applied to buildings has to be both accurate and consistent for auditing a building project from many different perspectives. However conventional QTO methods are tedious and error-prone. Major portion of Quantity Surveyor's time is spent for QTO. BIM QTO tools are task specific software applications delivering great promise to automate the extraction of quantities from BIM models. Visual building QTO improves productivity and accuracy that leads to sustainable QS practices. The time saving offered by these technologies will allow the Quantity Surveyor to focus more on other value adding services. However the automated outputs must suit the Quantity Surveyors' requirements in order to be effectively useful. Otherwise, the reliance on such technologies could result in such consequences, deviate from sustainability. This research is focused on "How far BIM QTO tools can automate QTO to suit QS's requirements?" The findings will contribute to the knowledge by establishing the status contribution of BIM for QTO being a primary function of Quantity Surveying within the overall sustainable procurement systems anticipated for the building industry.

Keywords: *Automation; Building Information Modelling (BIM); BIM Tools; New Rules of Measurement (NRM) Quantity Surveyor (QS); Quantity Take-Off (QTO).*

1. INTRODUCTION

Quantity Take-Off (QTO) is vitally important task in any construction project because of measurement practice applied to buildings has to be both accurate and consistent (Cartlidge, 2009). QTO is generally performed manually or using software packages from 2D or 3D Computer-Aided Design (CAD) drawings. BIM is gaining increasing acceptance in construction industry and utilisation of Building Information Modelling (BIM) make possible to considerably automate the QTO process using BIM QTO tools via model based quantity extraction techniques. There is a concern that BIM's capability to automate QTO will eliminate the need for Quantity Surveyor (QS) for this task. This paper presents a literature synthesis on "How far BIM QTO tools automate QTO to suit QS's requirements?"

2. BACKGROUND

Time, cost, and sustainability are of critical importance in today's construction market. In order to meet these constraints, designers require prompt feedback on the cost, schedule and environmental implications of their design decisions, and contractors need to find means to increase productivity on site. Current approaches that depend on 2D CAD drawings of a project are not adequate to meet these demands. The increasing complexity of buildings and requirement for more fast-track project delivery has made it more challenging to manage building information and deliver projects on time and under

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budget (Douglas, 2010). Building Information Modelling (BIM) is gaining popularity in the construction industry and holds great promise for addressing these challenges.

BIM is defined by the National BIM Standard (NBIMS) as "a digital representation of physical and functional characteristics of a facility" (National Institute of Building Sciences, 2007, p. 21). The concept of BIM is to build a building virtually, prior to building it physically, in order to work out problems, and simulate and analyse potential impacts. The heart of BIM is an authoritative BIM model (Smith, 2007).

Eastman, *et al.* (2011) defines BIM tool is a task-specific application that produces a specific outcome such as tools are those for model generation, drawing production, specification writing, cost estimation, clash and error detection, energy analysis, rendering, scheduling, and visualization. Tool output is often standalone, as reports, drawings, and so forth. In some cases, however, tool output is exported to other tool applications, such as QTO to cost estimation, and structural reactions fed to a connection-detailing application.

BIM QTO tools are QTO software applications that produce specific outcome for QTO by extracting necessary information from BIM models. All BIM QTO tools provide capabilities for extracting counts of components, area and volume of spaces and material quantities, from BIM models and to report these in various schedules (Eastman, *et al.*, 2011). Therefore there is a potential that total QTO can be automated by using BIM QTO tools.

QTO is one of the most critical tasks concerned by all participants in the Architecture, Engineering, Construction and Facilities Management (AEC/FM) industry throughout the lifecycle of a building project (Zhiliang, *et al.,* 2010). The development of information technology in the AEC/FM industry has resulted in the emergence of numerous software applications for QTO. These achievements have greatly improved QSs' working efficiency. However, in practice, when using the traditional two-dimensional representation of design, QSs still have to manually extract useful information from printed drawing sets or CAD drawings (Fortner, 2012). Due to the working complexity and comprehending deviation in these processes, QTO is still time-consuming and prone to error (Firat, *et al.,* 2010). Vico Software, Inc. (2013), Innovaya (2013), Tocoman (2013), Autodesk Inc. (2013), Buildsoft (2013), Nomitech (2013), Gala Construction Software (2013) and Digital Alchemy (2013) claims that the advent of BIM technology and their BIM QTO tools are potential solution for above problems.

High level of automation of QTO is possibly leads to no requirement of QS in QTO processes. Therefore dynamic and continuously updated BIM models itself may be enough to perform QTO automatically. However, if automated BIM QTO fails to fulfil the QS's requirements to carry out his primary tasks like tendering and estimating, then such outputs may become less useful or even aggregate the current problems. Manual technical input will be required, but for that, it will be necessary to know for which items the manual input is required. Therefore for both the cases, there is a potential to research on level of automation in QTO by using BIM QTO tools. BIM revolution leads to be assumed BIM can fully automate QTO (Jernigan, 2008) and if that is not true, there is a risk that the process will result in less accurate estimate.

3. QUANTITY INFORMATION EXTRACTION REQUIREMENTS

There are a number of situations that require a QS to measure and record dimensions (or quantities) from both drawings as well as on site, depending on the stage of the project. In order to standardise measurement rules and conventions, there are a number of standard codes and methods of measurement available (Cartlidge, 2009). Quantities should be extracted from BIM models to suit QS's requirements since extracted information serves wide scope applications such as pricing, cost modelling, estimating, and life cycle costing for various professionals like cost consultant's and contractor's QS.

Measuring construction works differently different parties was found to be a serious difficulty to contracting parties and a standing cause of disputes. For this reason a unification of the various systems at the technical level had been accepted as very desirable and wanting (Seeley, 1994). To cater this requirement Standard Methods of Measurement (SMMs) have been used such as Standard Methods of Measurement 7 (SMM7), Civil Engineering Standard Methods of Measurement 3 (CESMM3), New Rules of Measurement (NRM) and Sri Lanka Standard 573 (SLS573). SMMs provide a uniform basis for the measuring of works and embody the essentials of good practice, but more detailed information than is required by the standard shall be given where necessary in order to define the precise nature and extent of the required work (Wainwright & Whitrod, 1985).

SMMs were developed also to provide more consistency through providing guidelines on how the Bill of Quantities should be structured, which items should be measured, how they should be measured and what units should be used (Robin & Selwyn, 2012).

Further when doing QTO it is very important to measure the objects in the same way otherwise it will be difficult for other persons to get involved in the work or take over the tasks with the quantities. If for example the area of a wall has been calculated, it is essential to know whether the area includes door openings or not. Clear rules and norms are therefore essential (Eastman, *et al.*, 2011). In this case SMMs vitality is experienced.

New Rules of Measurement - Detailed measurement for building works (NRM2) is the current SMM from Royal Institute of Chartered Surveyors (RICS) and effective from 1st January 2013. NRM2 provides a uniform basis for measuring and describing building works and embodies the essentials of good practice and replaces SMM7. Usage of each SMM is differs on scope of work and territories. For example, NRM2 and CESMM3 are used in United Kingdom (UK) for building works and civil works respectively and NRM2 and SLS573 are used for building works in UK and Sri Lanka respectively. In this research NRM2 is considered as definite requirement to quantity information extraction.

According to Tweeds (1995), Quantity Extraction falls into four continuous activities namely taking off, squaring, abstracting and billing. Quantity information extraction from BIM model is the first activity (i.e. take-off). Latter three activities can be found as derivation of the results of take-off since this research is targeted on how far quantity information can be automatically extracted from BIM models.

There are several rules set out in NRM2. For example for unit of measurement, common brick wall can be measured in m^2 but concrete wall can be measured in m^3. There are measurement rules, coverage rules, definition rules are governing requirements for QTO to suit NRM2 requirements. According to NRM2 there are three method of QTO are elemental, work section and work package (Royal Institute of Chartered Surveyors, 2013). According to organization preference any of the method is adopted. Anyhow traditional method is popular one. All these requirements eventually govern the standard and definite requirements to QTO.

4. BIM MODELS

Digital files are generated by all types of CAD systems. The older CAD applications employed only graphical information such as vectors, line-types to describe a building object. These systems where then developed to allow for more information to be added such as blocks of data and text. When 3D modelling begun to gain more popularity even more information could be added with complex surfacing and advanced definition tools (Eastman, *et al.*, 2011).

With this development towards more information based drawings the focus changed from solely drawing and images towards the data itself. Today's BIM tools are object-based meaning that they show multiple views of the model in 2D and 3D as well as allows for properties to be stored within every single object. According to Eastman, *et al.* (2011), BIM is defined as:

> *"A modelling technology and associated set of processes to produce, communicate, and analyse building models."*

A building model is then characterized by:

- *Building components* - Represented by objects that "know" what they are and can be linked with data attributes, graphic and parametric rules. In this way a door will "know" that it is a door and that it can for example only be attached to a wall and not to a roof,
- *Consistent and non-redundant data* - a change made in one view will be represented in all other views as well,
- *Components* - include data that describe how they behave, for analyses and work processes, e.g. specifications, quantity take-offs and energy simulations,
- *Coordinated data* - all views will be represented in a coordinated way.

The main building product data model is the Industry Foundation Classes (IFC), for building planning, design, construction and management. IFC is the effort of building SMART whose goal is to specify a common language for technology to improve the communication, productivity, delivery time, cost, and quality throughout the design, construction and maintenance life cycle of buildings. Each specification (called a 'class') is used to describe a range of things that have common characteristics. These IFC-based objects aim to allow AEC/FM professionals to share a project model, while allowing each profession to define its own view of the objects contained within the model. The newer version of IFC is IFC4 published in 2013 as ISO 16739 (buildingSMART International Ltd., 2013).

The IFC is organized into sections that address different core areas and domain areas. These sections are organized into four layers, as shown in Figure 1 (buildingSMART International Ltd., 2013).

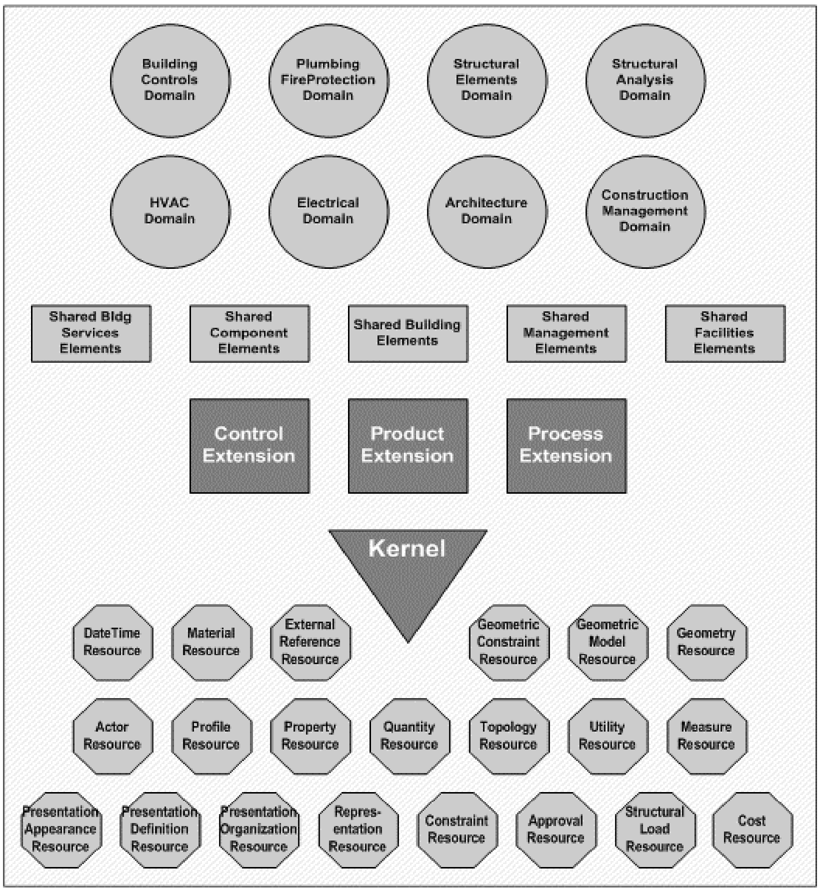

Figure 1: IFC4 Layered Structure (buildingSMART International Ltd., 2013)

The Resource Layer provides common resources used in defining the properties used by the upper layers. It includes Utility, Properties, Geometry, Measure and Property Type Resources. These provide geometric properties, units of measurement, cost units, time units and so forth. Those are standalone information required to information extraction.

Core Layer includes a Product Extension, Process Extension, Document Extension, Modelling Aid Extension and Kernel. The Product Extension supplies the majority of object classes making up the physical description of a building, defined at an abstract level. It includes generalizations for walls, floors and spaces, for example.

The Process Extension provides definitions of classes needed to represent the processes used to design and construct a building. The Modelling Aid Extension provides those abstract elements used in developing a building design, such as grids, modules and centrelines.

The Document Extension provides means to present project data in a particular format, useful for different needs in the building lifecycle. Future Core Extensions are planned for Controls and Resources.

The Kernel schema defines the most abstract part of the IFC architecture. It defines general constructs that are basic to object orientation, such as object and relationship. These are then specialized into constructs like product and process, which form the entry points of the next level, the Core Extension layer. The Kernel also handles some basic functionality, such as relative location of products in space, sequences of processes in time, or general-purpose grouping mechanisms which are important to QS.

The Interoperability Layer defines objects those are shared by more than one application. These objects specialize the Core Layer objects and elaborate them for use by applications. Currently the Interoperability Layer objects are primarily building elements and building service elements. Later, they are expected to include Distribution Elements (ducts and piping), Furniture, Electrical Appliance, and Building Codes.

The domain-specific application layer supports the applications used by QS. This layered architecture identifies the different resources and incremental abstractions needed forth definition of objects that carry data in a building product model (buildingSMART International Ltd., 2013).

5. BIM QUANTITY INFORMATION EXTRACTION METHODOLOGIES

The object model of the BIM is the logical data model that defines all entities, attributes and relationships in the BIM. The object model is physically implemented in the form of schemas. The model data is created by an application and stored in physical files or databases. The model data must be consistent with the object model of the BIM. The Standard for the Exchange of Product model data (STEP) covers the exchange of product model data. A STEP implementation is an application that uses this standard to exchange product information, or makes it possible for quantity information extraction applications to do so.

According to ISO 10303, STEP has four different implementation levels presented as (International Organization for Standardization, 2002):

1. *File exchange level*: Standard data modelling language for product data (EXPRESS)-defined product data is passed between applications using flat files. The STEP File part 21 and The STEP XML (Extensible Markup Language) Part 28 are the formats has been defined for this purpose and at this level for an application to simply read and write files. An application may read the EXPRESS-defined data file using a dedicated parser and immediately convert the instance data into some other data structure. Further XML files are capable of exchange through web based systems.
2. *Working form level*: The software in working form level has all features of level one in addition to the ability to manipulate data. When an application in this level reads the data into its memory the data should be made available to the code, in a form organised and described by the EXPRESS model. Standard Data Access Interface (SDAI) is developed as a standard API for level two. The SDAI functions allow the product data to be manipulated.

3. *Database level*: This level has all features of level two along with the ability to work with the data stored in a database.
4. *Knowledgebase level*: Implementations of this level will have all features of level three and should be able to reason about the contents of the database. This level has never been implemented.

It is possible to share and ex-change BIMs by using three implementation levels of STEP, if the model is defined by using STEP description methods. If not, then the BIM will possibly be defined and populated as a model in a relational or object database, and the data sharing will be realised by using the database interfaces. On the other hand, as the IFCXML implementation points out, the structure of the physical file will most probably be defined by using an XSD schema and the physical file will be exchanged as an XML file. There are five different methods for storage and exchange of BIMs (given in Figure 2– 6) that were identified through literature synthesis from various sources (buildingSMART International Ltd., 2012; Isikdag, *et al.*, 2007; Eastman, *et al.*, 2011; Eastman, *et al.*, 2012; Dimyadi, *et al.*, 2012; Kymmell, 2008).

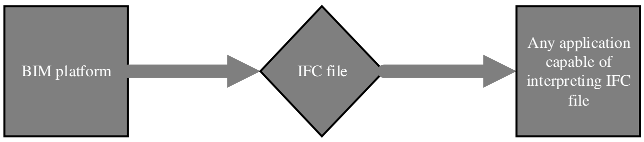

Figure 2: Data Exchange by Using Physical Files

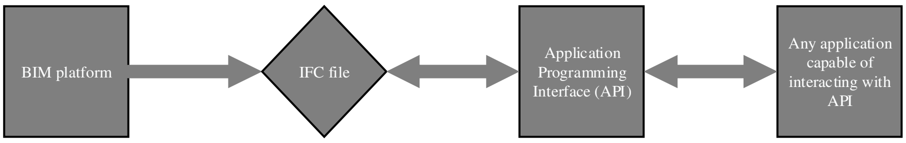

Figure 3: Data Sharing through Application Programming Interfaces

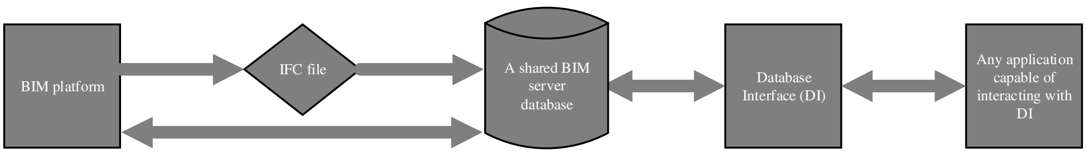

Figure 4: Data Sharing through Central Project Database

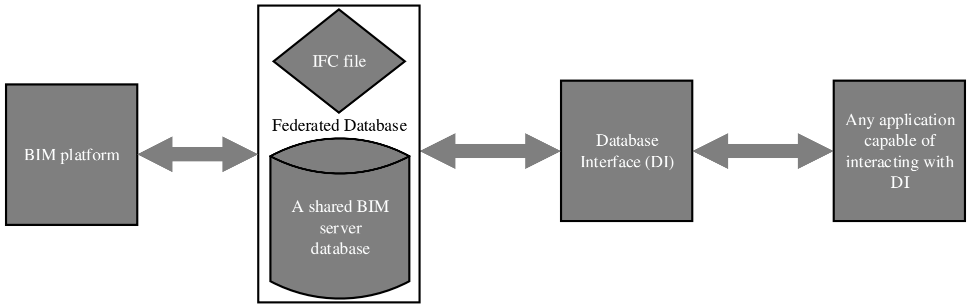

Figure 5: Data Sharing through Federated Project Database

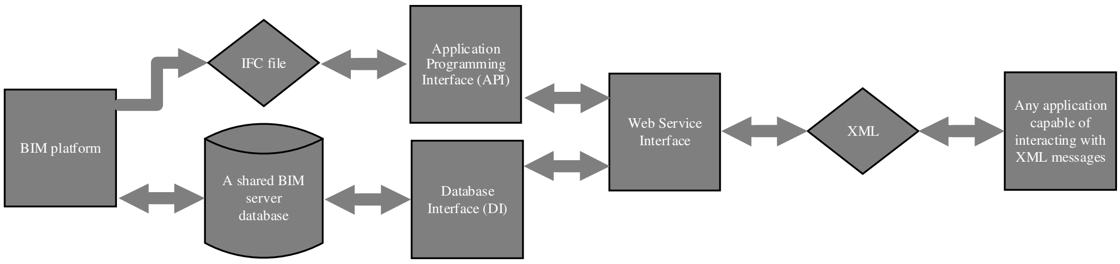

Figure 6: Data Sharing by Web Services

6. BIM QTO TOOLS

There are various open and proprietary BIM QTO tools available in the market. Most of them are intended to be capable of handle IFC files. IFC is supported by about 150 software applications worldwide to enable better work flows for the AEC industry (buildingSMART International Ltd., 2013). BIM QTO tools have the ability to extract required information from BIM platform like Revit and manipulate them within their API or derive information from BIM platform to them. Following are the notable BIM QTO tools:

- Innovaya Visual Quantity Takeoff
- Vico 3D BIM Quantity Takeoff
- Tocoman iLink
- Autodesk Quantity Takeoff
- CostX Takeoff
- Interactive Cost Estimating
- Buildsoft Takeoff 2
- CostOS BIM Estimating
- Gala Estimating
- IFC Takeoff for Microsoft Excel
- Smart BIM QTO
- ITALSOFT

Innovaya (Innovaya, LLC., 2013), Tocoman (TocoSoft Oy., 2010) and Vico (Vico Software, Inc., 2013) employ API to extract quantity information (Autodesk, Inc., 2006). This approach uses a direct link between the costing system and BIM platform like Revit. From within Revit, a user exports the building model using the QTO program’s data format and sends it to the QS, who then opens it with the QTO solution to begin the QTO process.

CostX (Exactal Technologies Pty Ltd., 2010) and ITALSOFT use Open DataBase Connectivity (ODBC) connection (Autodesk, Inc., 2006). ODBC is a tried and true standard, useful for integrating data-centric applications like specification management and QTO with building information modelling. This approach typically uses the ODBC database to access the attribute information in the building model, and then uses exported 2D or 3D CAD files to access the dimensional data.

Quantity information extraction can be done within BIM platform like Revit and can be exported Output to Microsoft Excel (MS Excel). QTO can be done within Revit and output to a MS Excel program may seem lacklustre, but the simplicity and control is perfectly suited to some costing workflows. For instance, many firms just create material take-offs in Revit, output the data to a spreadsheet, and then hand it off to the cost estimator.

Vico 3D BIM Quantity Takeoff examines the BIM model geometry, applies special algorithms, and produces construction-calibre quantities (Vico Software, Inc., 2013). For example, Volume of the slab can be identified as a closed geometry with number of nodes within Vico environment. Surface area of slab can be identified from continuous loops of the faces that are identified from closed planes. When a slab is considered, edge surface area and plane surface area should be separately identified as per QS requirements. So different unique proprietary algorithms used by Vico to attain such (Vico Software, Inc., 2013).

Each QTO tool uses different extraction mechanisms; it is difficult to ascertain correct or wrong mechanisms (Autodesk, Inc., 2006).

7. CHALLENGES IN BIM QUANTITY INFORMATION EXTRACTION

As expected, attempting to automate the QTO process leads to some insights in the nature of the data itself .There are different components of quantity information need to be extracted from models as requirement of SMMs (Royal Institute of Chartered Surveyors, 2013). Those are:

- Items (counts),
- Linear (length),
- Surface (area),
- Mass (volume)
- Weight (in tonnes).

There are three kind of quantity information when we do QTO from the model. The rules that have been developed need to deal with kind of quantity information. The three types are (Bylund & Magnusson, 2012):

- Explicitly represented in the model,
- Components that are not explicitly represented but can be inferred,
- Components that are not represented in the model and cannot be inferred.

These obviously present a problem that cannot be resolved in taking models purely from BIM. The components that are represented explicitly need to be processed in two ways. Some components, such as doors and windows, just need to be counted. This requires simple query against the database. Other components need to be identified, have the length, area or volume determined, and then aggregated to the output. Discrete solid components, such as skirtings, floor finishes and concrete walls all fit in this group. NRM2 requires that the length of some components (e.g. precast units, Steel) to be included in the item description. For example manufacturer’s code, tonnage per meter or unit length should be included in description for structural steel. In this case, the presented quantity is in tones. The weight per meter of the member is required by QS. Eventually knowledge of the manufacturer’s products is required. This means item descriptions can be generated from following four stages - identify the relevant components, extract the required quantity, generate the item description and count the number of occurrences.

Vico claims that, With Vico Office, the QTO unique algorithm looks at each piece of geometry within the 3D BIM, calculates their properties (such as surface area, volume, etc.). The model geometry analysis algorithms can even determine the sides of the elements (for example "top of slab") and use the boundaries to calculate quantities such as "net surface area". This type of analysis is much more intuitive than simply counting windows and doors, floors, ceilings, and walls, and produces a much more detailed QTO. However, Vico deduced that "There Is No "Easy Button" for QTO in BIM" (Vico Software, Inc., 2013).

Sunny Choi claims that one of the challenges in extracting quantities is the requirement to follow the measurement rules SMMs and another challenge is different methods of building up BIM models will give out different quantities (Autodesk Inc., 2012). When different BIM applications are used in the project, not all software measures quantities in the same way. For example the length of a wall might be measured from the centreline or the outside resulting in a somewhat different area when calculated. Furthermore some applications gives the user the flexibility of modelling objects in different ways though quantification does not work with all of them. An example of this is when modelling openings using Revit. Openings could be modelled using an "opening tool", an "edit profile tool", an "opening family tool" or a "void extrusion". However the only way the opening gets quantified is if they are modelled using the opening tool or opening family tool (Tiwari, *et al.,* 2009).

8. BIM BASED QTO IN SRI LANKAN CONTEXT

BIM is still not implemented in Sri Lanka. Hence it's the big challenge to use BIM based QTO. There are several challenges for implementing BIM as well as using BIM based QTO. Shifting from CAD based current Sri Lankan construction industry to BIM based system need to lot of prerequisite like hardware, software and liveware alterations. Hardware includes system requirements to implement BIM and software includes the BIM platforms and other BIM tools and liveware includes construction industry professionals who need to have knowledge on BIM tools in their respective practices.

Still after implementing, interoperability and IFC supported BIM platform and BIM tools selection will only lead to successful quantity extraction. Except the challenges in implementing BIM, with in BIM based QTO, competency of professionals like QS are ultimate requirement to success.

9. CONCLUSIONS

Conclusions are derived on the basis of current literature synthesis since this is an ongoing research. QSs requirements are vital in QTO process in any scope of work or in any country. Quantity information must be extracted to suit QS requirements if BIM make any good to basic QS practices. Different components of quantity information should be able to be extracted by BIM QTO tools. Since identifying of objects counts is straight forward automated QTO will not be a problem for those items. Area measurement is likely to be most challenging and difficult to extract. Interoperability and retrieval mechanisms play vital role in QTO process and consistency in BIM modelling will ensure the reliability of QTO output. Ability to provide dynamic links within BIM data and BIM QTO tools will improve the reliability of QTO output. Bidirectional data retrieval methods will ensure consistency of the model with extracted quantities. Current developments in the BIM QTO automation are impressive, but there is no enough evidence concludes they can satisfy the needs of QSs QTO requirement. For QSs to receive true benefits from the developments in BIM, it is essential to clearly identify the QTO automation capabilities brought with them.

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