ARTICLE IN PRESS

Engineering Science and Technology, an International Journal xxx (2017) xxx–xxx

HOSTED BY

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: www.elsevier.com/locate/jestch

Full Length Article

BIM – New rules of measurement ontology for construction cost estimation

F.H. Abanda [a,*], B. Kamsu-Foguem [b], J.H.M. Tah [a]

[a] Oxford Institute for Sustainable Development, School of the Built Environment, Faculty of Technology, Design and Environment, Oxford Brookes University, Oxford OX3 0BP, UK
[b] Laboratoire Génie de Production, Ecole Nationale d'Ingénieurs de Tarbes 47, Avenue Azereix, BP 1629, F-65016 Tarbes Cedex, France

ARTICLE INFO

Article history:
Received 14 September 2016
Revised 21 December 2016
Accepted 25 January 2017
Available online xxxx

Keywords:
Building Information Modelling
Construction projects
Cost estimation
New Rules of Measurement
Ontology

ABSTRACT

For generations, the process of cost estimation has been manual, time-consuming and error-prone. Emerging Building Information Modelling (BIM) can exploit standard measurement methods to automate cost estimation process and improve inaccuracies. Structuring standard measurement methods in an ontologically and machine readable format for a BIM software can greatly facilitate the process of improving inaccuracies in cost estimation. This study explores the development of an ontology based on New Rules of Measurement (NRM) for cost estimation during the tendering stages. The methodology adopted is methontology, one of the most widely used ontology engineering methodologies. To ensure the ontology is fit for purpose, cost estimation experts are employed to check the semantics, descriptive logic-based reasoners are used to syntactically check the ontology and a leading 4D BIM modelling software is used on a case study building to test/validate the proposed ontology.

1. Introduction

Emerging Building Information Modelling (BIM) is one of the leading technologies being used in different construction applications such as energy simulation [1], sustainability [3,5], facilities management [25], risk management [36,35] and cost estimation [12]. BIM has been used in cost estimation; with research revealing it is more efficient than the manual cost estimation and leads to project cost reduction [2,12]. In Finland, BIM adoption in housing projects has led to the following benefits: increased profit margins of 45%, waste reduction of 45%, on-site accident reduction of 5% [20]. In the UK, the Ministry of Justice (MoJ) adopted BIM in delivering the Cookham Wood project (value of £20 million), which yielded a 20% cost saving [49].

Detailed cost estimates consist of two parts. These are products/procurement quantities (PPQ) which are physical quantities of design components and process quantities (PQ) which are related to specific construction processes [45]. Examples of PPQ include volume of concrete columns and areas of windows. Examples of PQ include labour hours for hanging drywall and extracting quantities of earthwork. Data such as labour hours are intangible compared to volume of concrete that is obtained from a tangible geometric model. Most intangible data are non-geometric in nature. The beauty about emerging BIM is the fact that non-geometric data can be embedded into a BIM model (see Section 2). The importance of data or information embedded into a BIM model is the kernel of BIM and encapsulated in the "I" of BIM. Without loss of generality, this study will focus on PPQ. The benefits of BIM in cost estimating discussed in the preceding paragraph has been achieved partly due to the use of various BIM software packages that enabled accurate modelling of projects thus leading to precise quantity takeoffs (QTO). Some leading software in the field are Navisworks, Autodesk QTO, CostX, Innovaya, iTWO, d-profiler, Vico, ProjectWise Navigator, Bentley ConstrucSim, Balfour Technologies, etc. The process of cost estimation using these software packages can be modelled in Fig. 1.

The current cost estimating process as depicted in Fig. 1 has four major short comings.

Firstly, some of the cost estimating software do not contain a measurement standard that can be used in cost estimating. This means, potentially there could be lack of consistency in cost estimates produced with BIM software that do not contain measurement standard. A consequence of this, is the fact that two or more cost estimates cannot be easily compared. Secondly, the extraction of building components is still a manual and time consuming process. Building components and their respective quantities are generated from a BIM software, and then manually edited into a pre-prepared standard measurement template. Given, the list of components and respective quantities are not in the same order as the structured template, time is spent aligning

* Corresponding author.
E-mail address: fabanda@brookes.ac.uk (F.H. Abanda).

Peer review under responsibility of Karabuk University.

http://dx.doi.org/10.1016/j.jestch.2017.01.007
2215-0986/© 2017 Karabuk University. Publishing services by Elsevier B.V.

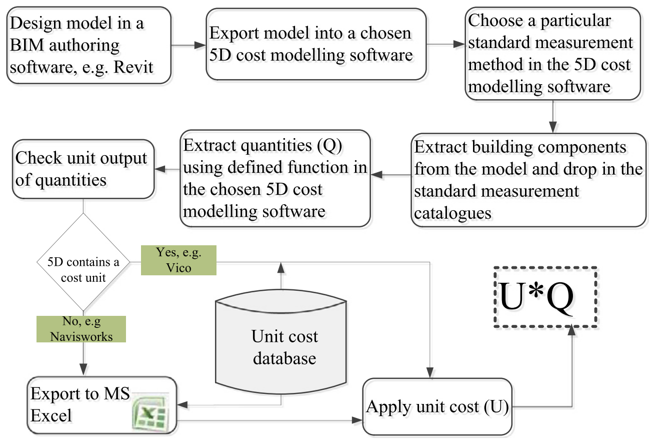

Fig. 1. Cost estimating process in a BIM-based cost estimating software.

components to the different concepts in the structured template. This is time-consuming and error-prone. Thirdly, where the software contains a measurement standard, it is likely to be that of the country where the software was manufactured. For example, most Autodesk cost estimating products generally have American and North American measurement standards and not NRM. Consequently, in countries where NRM is in common use, e.g., the UK, the need for an electronic NRM is imperative so as to be integrated in the chosen Autodesk product during cost estimation. Fourthly, for the few software that contains a standard measurement catalogue, it is embedded into the software and/or included in the installation folder, hence cannot easily be re-used by other software or professionals for any knowledge acquisition activity. An NRM ontology that is not software-dependent will be of great use to the academic as well as professional community. Previous efforts (e.g., [7,38]) aimed at addressing these challenges revealed a potential in integrating BIM and Semantic Web for improving many construction activities including cost estimation. Key to the Semantic Web, is the ontology used to formally represent knowledge and rules of a particular domain for the purposes of facilitating computer processing, reasoning, knowledge sharing and re-use.

The aim of this study is to investigate how an ontology based on NRM can be used for construction QTOs/cost estimation (In this paper, emphases will be laid on QTOs. This is because, once QTOs have been obtained, only unit cost is required to obtain the total component cost as illustrated in the formula in Fig. 1). To achieve this aim, the following objectives will be accomplished.

a. Investigate the different concepts in the NRM that can aid in (QTOs)/ and hence cost estimation;
b. Develop an ontology that model knowledge about construction QTOs/cost estimation;
c. Investigate how best to deal with constraints in NRM in the developed ontology;
d. Demonstrate the use of the ontologies in performing QTOs and hence cost estimation;
e. Evaluate the ontology whether it is fit for the intended purpose in standard BIM software systems.

To facilitate understanding the rest of this manuscript is divided into 11 sections. This study is mostly about an application of BIM for cost estimation. It falls under what is often called nD modelling. Hence, to gain insights and identify how cost estimation fits with nD modelling, the next section will be about nD modelling with focus on cost estimation (also known as 5D modelling). In Section 3, an overview of the research methods adopted for this study will be examined. An overview of BIM-based construction cost estimation is presented in Section 4. Furthermore, in Section 5, the link between BIM-based cost estimation and standard rules of measurement is examined. Section 6 is about the development of the ontology while the implementation of the developed ontology in Protégé-OWL, a popular ontology editor is discussed in Section 7. The practical applications of the ontology are illustrated in Section 8, while its validation is undertaken in Section 9. The challenges encountered during the ontology development are reported in Section 10. In Section 11, how the research aim and objectives have been attained are discussed. The study ends by a way of summary of what has been covered in this paper in the conclusion Section 12.

2. nD modelling

A model in BIM should be "a means to an end, not an end in itself". While not underminding the importance of 3D models, the information attached to a model for different applications is quite important. The importance of the "I" of BIM cannot be underestimated as strongly emphasised in Abanda et al. [3]. An nD model is an extension of a building information model that incorporates multi-aspects of design information required at each stage of the lifecycle of a building facility [30]. In other words nD modelling brings in the n^{th} number of design perspectives [10], $n \in N^{+} = \{1, 2, 3, \ldots\}$. The design perspectives varies in each phase of a construction life cycle and include scheduling, cost estimation, accessibility, crime or forensic analysis, sustainability, maintainability, acoustics, energy simulation, code reviews, conflict interference and conflict detection [10,13]. While the term nD (n-dimensions) has been used in Mathematics and Physics for generations, its usage in the construction industry is fairly recent. Although, it is unclear who and when the term was first used in construction, around 2005 researchers in the University of Salford-UK popularised the term in its Special Issue call in the Journal of Information Technology in Construction [10]. The special issue call led to the publications of six articles about nD modelling [26,15,21,50,19,24]. It is important to note the nD as used in Mathematics and Physics generally refers to the minimum number of coordinates needed to specify any point in space. In construction research and practice, 3D stands for the geometric model, 4D stands for scheduling and 5D for cost estimation. However, there is a lack of concensus about other D's where $n > 5$. The use of nD for $n > 5$ are in some cases conflicting. In Bryde et al. [16] and Kamardeen [27], 6D BIM is considered to be a facilities management information while the same 6D BIM is considered by Yung and Wang [56] to mean sustainability information. To further illustrate the degree of ambiguity, sustainability is considered as the 7D BIM in Kamardeen [27].

Although this area is still emerging, there are already few peer-reviewed literature about intelligent cost estimation techniques. Staub-French et al. [47,46] developed an ontology to support construction cost estimation. Abanda et al. [4] developed an ontology for estimating the cost of labour in construction projects. Cheung et al. [17] developed a BIM-based plug-in for SketchUp for simultaneously determining embodied energy and carbon, cost, construction waste and time. Lee et al. [31] developed a BIM and ontology-based approach for building cost estimation. Ma and Liu [33] developed a BIM-based intelligent system for cost estimation of building projects, which however did not exploit the concepts of ontologies. Lawrence et al. [29] proposed a generic approach for creating and maintaining a cost estimate using flexible mappings between a building model and a cost estimate. Wu et al. [54] examined cost estimating practice and procedure in the UK and the impact of the use of BIM. Choi et al. [18] proposed a methodology that connects BIM data (volume and area) with unit cost and developed a quantity takeoff prototype system.

From the studies cited in the preceding paragraph, Lee et al. [31] and Cheung et al. [17] considered the Chinese standard method of