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Towards an Intelligent Ontology Construction Cost Estimation System: Using BIM and New Rules of Measurement Techniques

F. H. Abanda, B. Kamsu-Foguem, J. H. M. Tah

Abstract**—**Construction cost estimation is one of the most important aspects of construction project design. For generations, the process of cost estimating has been manual, time-consuming and error-prone. This has partly led to most cost estimates to be unclear and riddled with inaccuracies that at times lead to over- or under-estimation of construction cost. The development of standard set of measurement rules that are understandable by all those involved in a construction project, have not totally solved the challenges. Emerging Building Information Modelling (BIM) technologies can exploit standard measurement methods to automate cost estimation process and improve accuracies. This requires standard measurement methods to be structured in ontological and machine readable format; so that BIM software packages can easily read them. Most standard measurement methods are still text-based in textbooks and require manual editing into tables or Spreadsheet during cost estimation. The aim of this study is to explore the development of an ontology based on New Rules of Measurement (NRM) commonly used in the UK for cost estimation. The methodology adopted is Methontology, one of the most widely used ontology engineering methodologies. The challenges in this exploratory study are also reported and recommendations for future studies proposed.

Keywords**—**BIM, Construction projects, Cost estimation, NRM, Ontology.

I. INTRODUCTION

THE UK construction industry has been concerned about levels of productivity in delivering projects. As a result, it has been under challenge from various departments to improve practices. The recent UK government construction strategy requires 33% reduction in construction cost and 50% in reduction of delivery time by 2025 [1]. Although achieving these targets is a huge challenge, innovative practices supported by emerging BIM provide opportunities to attend them; especially given that BIM will be mandatory on all government procured projects by 2016 [2].

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 [3]. This has been as a result of many BIM software packages that can enable accurate modelling of projects thus leading to precise quantity takeoffs. Some leading software packages in the field are Navisworks, Autodesk QTO, Synchro, Vico, CostX, etc. The process of cost estimation using these software packages can be modelled in Fig. 1.

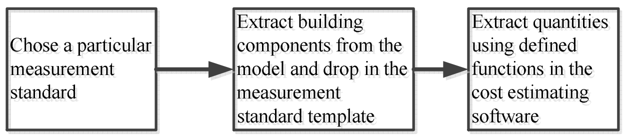

Fig. 1 Cost estimating process in a BIM-based cost estimating software package

The current cost estimating process as depicted in Fig. 1 has four major short comings. Firstly, the extraction of building components is still a manual and time consuming process. Secondly, the cost estimating software should contain a measurement standard that can be used in cost estimating or should be able to read an electronic measurement standard. Thirdly, based on the second weakness, most of the software packages available in the market do not contain NRM. Fourthly, when the software contains a given standard, it is not clear whether the different measurement rules and constraints have been considered. In a previous study by [4], the potential of integrating BIM and Semantic Web in performing many construction activities including cost estimation revealed the possibility of overcoming some of the aforementioned challenges. 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. Given that this area is still emerging, there are very few peer-reviewed literature about cost estimation and ontology. Staub-French et al. [5], [6] developed an ontology to support construction cost estimation. Abanda et al. [7] developed an ontology for estimating the cost of labour in construction projects. Niknam and Karshenas [8] developed a Semantic Web service approach for use in construction cost estimating. Lee et al. [9] developed a BIM and ontology-based approach for building cost estimation. Other than [9] that considered the Chinese standard method of measurement most of the cost estimating ontologies do not consider the UK standard rules of measurements. A recent study by [10] funded by the Royal Institution of Chartered Surveyors developed information requirements for building information model to support the NRM order of cost estimating and elemental cost planning.

F.H. Abanda and J.H.M Tah are with the Oxford Institute for Sustainable Development, Department of Real Estate and Construction, Faculty of Technology, Design and Environment, Oxford Brookes University, Oxford, OX3 0BP, UK (e-mail: fabanda@ brookes.ac.uk, jtah@brookes.ac.uk)
B Kamsu-Foguem is with the Laboratoire Génie de Production, Ecole Nationale d'Ingénieurs de Tarbes 47, Avenue Azereix, BP 1629, F-65016 Tarbes Cedex, France (e-mail: bernard.kamsu-foguem@enit.fr).

The aim of this study is to investigate the possible development of an ontology based on NRM for cost estimation in the UK construction industry. To achieve this aim, a literature review was undertaken to establish current BIM-based cost estimation practices in the UK construction industry. Based on this review, an ontology engineering methodology was pursued to develop an ontology that could potentially be used in BIM environment for construction cost estimation. As this is still work in progress, the ontology was validated using Web Ontology Language (OWL)-based reasoners for technical consistencies while validation for fitness of purpose will be conducted later.

To facilitate understanding the rest of this manuscript consists of six sections. Section II is about an overview of BIM-based construction cost estimation methods. In Section III, the link between BIM-based cost estimation software packages and standard measurement methods are examined. In Section IV, a brief discussion on the development of key concepts of the BIM-based cost estimation ontology is presented. The implementation of the proposed ontology is presented in Section V. A preliminary validation discussion is presented in Section VI. In Section VII, the challenges and lessons learnt in the ontology development process are discussed. The conclusion of the paper is discussed in Section VIII.

II. Overview of BIM-Based Construction Cost Estimation

Based on Fig. 1, it can be inferred that BIM-based construction cost estimation requires at least a BIM authoring software and a specialised cost estimating software. The two software needs to communicate, at least unidirectional where the latter can read files from the former. The communication requires interoperability standards such as Industry Foundation Classes (IFC). Key to understanding construction cost estimation is the understanding of IFC and rules of measurements and how both can be related. IFC is an open and neutral data format for openBIM developed and maintained by buildingSMART International. Since the first IFC initiative was launched in 1994, different versions have been developed. The most widely used version integrated in most BIM software is IFC 2X3. Proceeding IFC2x3, the latest version IFC4 was released in March 2013 which incorporates numerous improvements and enhancements over the predecessor. However, given that IFC4 is still relatively new, and not incorporated in most software packages, the discussion in this study will focus on IFC2x3. IFC2x3 covers nine domains in building construction, namely Building Controls, Plumbing Fire Protection, Structural Elements, Structural Analysis, HVAC, Electrical, Architecture, Construction Management and Facilities Management. For clarity purposes, some selected IFC nomenclatures of building components are presented in Table I.

TABLE I
Correspondence between IFC Entities and Building Products

IFC entity	Building product
ifcBeam	beam
ifcColumn	column
ifcDoor	door
ifcWindow	window
ifcPile	pile
ifcStair	stair
ifcRoof	roof
ifcFooting	foundation
ifcRamp	ramp
ifcSlab	slab
ifcAlarm	alarm
ifcLamp	Lamp or artificial light
ifcBoiler	boiler
ifcFan	fan

The NRM provides a standard set of measurement rules that are understandable by all those involved in a construction project, including the employer; thereby aiding communication between project teams and the employer [11]. Furthermore, it assists the quantity surveyor/cost manager in providing effective and accurate cost advice to employer and the project/design team. NRM is comprised of three volumes NRM1, NRM2 and NRM3. NRM1 was first published in February 2009 (as NRM Order of cost estimating and elemental cost planning). Now in its second edition, it provides guidance on the quantification of building works in order to prepare order of cost estimates and cost plans as well as approximate estimates. The second edition has been renamed to better distinguish between capital building works and building maintenance works, and the arrangement of elements has been revised. It became operative on 1 January 2013. NRM2 was published in April 2012. It became operative on 1 January 2013 and replaced the Standard Method of Measurement, seventh edition (SMM7) on 1 July 2013. NRM2 establishes detailed measurement rules allowing the preparation of bills of quantities, quantified schedules of works and schedules of rates in order to obtain tender prices. Guidance is also provided on the content, structure and format of bills of quantities. NRM3 was published in March 2014. It allows the quantification and description of maintenance works. It can be used for initial order of cost estimates, general cost plans and asset-specific cost plans. It also provides guidance on procurement and cost control.

The NRM1 breaks building works into 15 group elements, numbered from 0 to 14. The most important group elements are 0-8 ([11], pp.24). The different group elements are Group 0: Facilitating Works; Group 1: Substructure; Group 2: Superstructure; Group 3: Internal Finishes; Group 4: Fittings, Furnishes and Equipment; Group 5: Services; Group 6: Prefabricated Buildings and Building Units; Group 7: Work to Existing Buildings and Group 8: External Works. Each of these groups is further broken down into elements. For example, Group 3: Internal Finishes is broken down into 3, namely, Wall Finishes, Floor Finishes and Ceiling Finishes.

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III. The Link between BIM-Based Cost Estimation Software and Rules of Measurement

To understand the extent to which standard rules of measurement are being used in BIM cost estimation packages, an extensive review was conducted on most popular BIM cost estimating software. These are Navisworks, AutoDesk QTO, Synchro, Vico and CostX. Navisworks is an Autodesk product used for 4D and 5D modelling. It comes with CSI-16, CSI-48 and Uniformat catalogues for Quantity takeoffs. These catalogues are in Extensible Markup Language (XML) format. Also, Autodesk QTO has the same catalogues as Navisworks. CSI-16 refers to 16 divisions of construction, as defined by the Construction Specifications Institute (CSI)'s MasterFormat. MasterFormat is a standard for organizing specifications and other written information for commercial and institutional building projects in the U.S. and Canada. Similarly CSI-48 contains 48 divisions, although there are now up to 50 divisions. Synchro has no inbuilt work break-down structure or standard methods of measurement, although any can be imported if developed in XML format. Vico contains a work break-down structure based on Uniformat. CostX contains NRM1, NRM2, Standard Method of of Measurement 7 (SMM7), Hong Kong SMM (HKSMM), Australian Standard Method of Measurement 5 (ASMM5) libraries although the author uses phaseology as its terminology referring to library or catalogue. To facilitate understanding, an illustration of a BIM-based construction cost estimation in Navisworks is presented in Fig. 2.

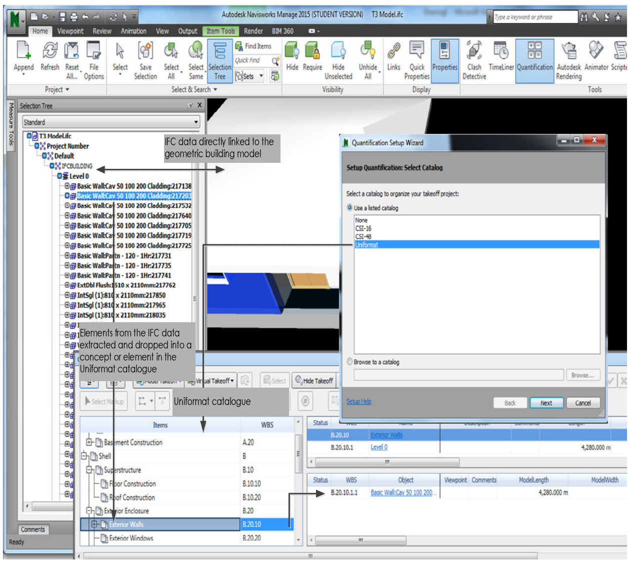

Fig. 2 BIM based cost estimation in Navisworks

Although, most software packages already have libraries of standard method of measurement, these libraries are not free. Also, most of the library are software dependent and cannot easily be exchanged or used in other BIM software packages. Furthermore, most BIM-based cost estimating software packages do not fully adopt UK practices and standards of measurement. A recent report by [10] identified this as a key reason for limited usage of BIM in quantity surveying practice in the UK. There is an urgent need of a catalogue (i.e. library or phraseology) that is software independent and that is free for use by interested users. In this study, an ontology based library is proposed. Although our proposed ontology will focused on the UK NRM, it can be used by other countries especially those using NRM for their practices.

IV. Development of Ontology Based On UK NRM

The development of any ontology requires a description of use of a specific methodology (or have modified an existing one), tools used, lessons learned, any modelling and language issues, wider context of practical usage, experiences compared with other ontology development projects, etc.

An extensive review of ontology engineering techniques including methodologies, modelling languages and software, and examples of ontologies have been examined in [12], [13]. These efforts will not be duplicated. Nonetheless, to facilitate understanding, emphases will be placed on justifications of choices or decisions, lessons learned, any modelling and language issues, wider context of practical usage, experiences compared with other ontology development projects vis-à-vis methodology, tools, and languages.

In the plethora of ontology methodologies, some issues are common to them. The main issues to be considered are fivefold. The reasons why an ontology is to be developed for, the main concepts or classes, properties of concepts, instances or individuals of concepts. Lastly depending on the purpose of the ontology rules may be included to enhance reasoning.

First, the purpose of the NRM ontology is to facilitate and automate construction cost estimation in the UK. Hence the ontology should capture concepts relevant and understandable to professionals in the UK, although the ontology can still be re-used by other professionals who are familiar with the UK NRM. Second, the ontology concepts were developed from the work break-down structure examined in the NRM book [11]. Only the most important groups were considered. These are Group 0: Facilitating Works; Group 1: Substructure; Group 2: Superstructure; Group 3: Internal Finishes; Group 4: Fittings, Furnishes and Equipment; Group 5: Services; Group 6: Prefabricated Buildings and Building Units; Group 7: Work to Existing Buildings and Group 8: External Works. In all, concepts were categorised into four and five levels. The top (first) level concepts adopted are Substructure; Superstructure; Internal Finishes; Fittings, Furnishes and Equipment; Services; Prefabricated Buildings and Building Units; Work to Existing Buildings and External Works. The second level concepts were obtained from the immediate break-down of first level concepts as in the NRM. The third and fourth concepts were obtained from the first and second columns respectively from the tables under each second level concept. To facilitate understanding the screenshot showing some of the different concepts, using Superstructure as an example will be examined in Figs. 3 (a), (b).

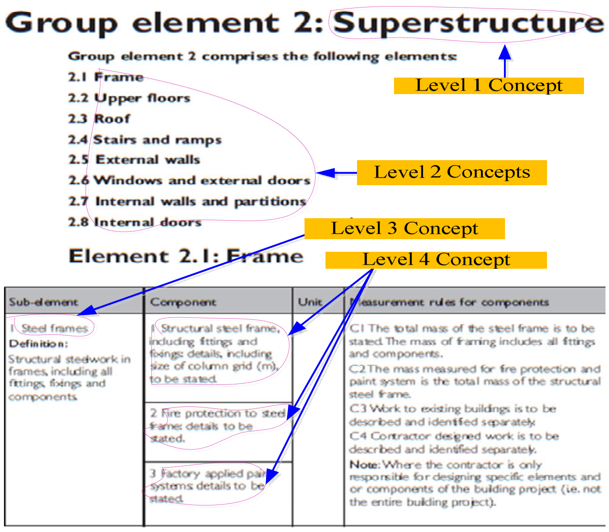

Fig. 3 (a) Manual abstraction of concepts from NRM

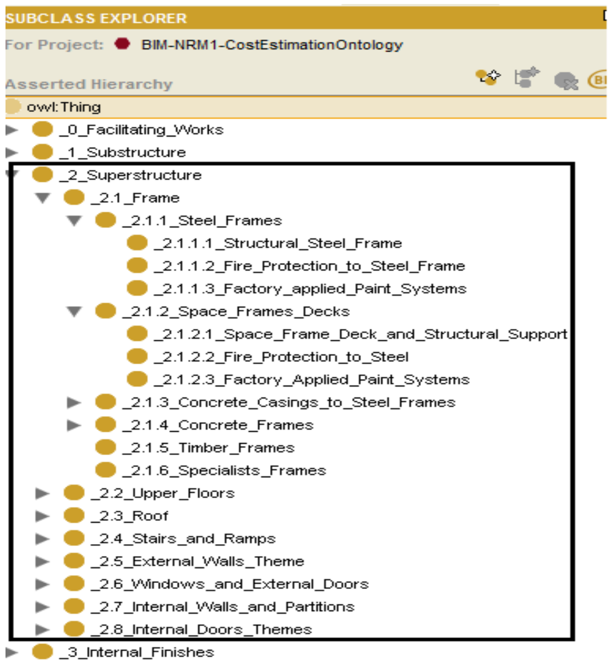

Fig. 3 (b) Modeled concepts in an ontology editor

Thirdly, properties of concepts were defined. The three common data types are object, data and annotation properties. In defining properties a reflection of how, professionals output results in construction cost estimation in practice was considered. In bill of quantities, numbers are usually next to concepts or Item description. For example, Superstructure will be 2 Superstructure. All other sub-concepts will be 2.1 Frame, 2.1.1 Steel Frames, 2.1.1.1 Structural Steel Frames, 2.2 Upper Floors, etc. To facilitate identification, the pre-fixed numbers were also modelled as datatype properties with property name hasCode. Other data types include hasUnits, hasUnitCost, hasTotalCost, hasQuantity, etc. Annotation properties were used to clarify some concepts, especially those whose longer names had been shorten. For example, in the fourth level concepts <<Structural steel frame, including fittings and fixings: details, including size of column grid (m) to be stated>>, the concept name adopted was "Structural steel frame" while <… including fittings and fixings: details, including size of column grid (m) to be stated>> was used as part of the annotation properties. Furthermore, annotation properties were used to clarify other ambiguities and inconsistences found in the NRM. Fourthly, instances of the ontology should be developed. This activity depends on whether an ontology engineering software will be used (or not) in modelling the ontology. In the case of this study, Protégé-OWL 3.5 will be used. This software allows placeholders for instances to be automatically added later on. Therefore, instances were generated after the ontology had been implemented (see Section V). Fifthly, depending on the purpose of the ontology, rules can be included. Given, this ontology will be used for construction cost estimation, rules were more appropriate to facilitate this. Although, OWL allows for reasoning to be performed in ontologies, such reasoning is not sophisticated enough to deal with some real life situations. One way of enhancing reasoning in ontologies is to include rules. The rules were based on the constraint often related to the rules of measurement in the NRM. Several different queries and rules were included in the ontology. The queries enabled the abstraction of information such as quantity and unit cost of a given building component; while rules enabled the abstraction of more complex concepts. For instance, an example of a rule is to search for components with a certain toxicity level that has exceeded a given threshold and classify them for detoxification or removal from the building. The SWRL like syntax for modelling the queries and rules will be discussed in Section V.

V. Implementation in an Ontology Engineering Editor

Based on the review of the different ontology editors [12], Protégé-OWL 3.5 was adopted for this study. One major reason is its stability and popularity in the ontology and Semantic Web community. Another reason is its compatibility with other plug-ins required for other purposes. For example, in the case of this study, Jambalaya, SWRLTab and JessTab were required. Jambalaya is a plugin for visualising the ontology in graphical format. SWRLTab is used in modelling rules in the ontology. JessTab is a plug-in for Protégé that allows you to use Jess and Protégé together. Rule-based reasoners, like Jess, allow for more general reasoning than the OWL-based reasoners typically found in Protégé.

An OWL ontology in the abstract syntax contains a sequence of axioms and facts. Axioms may be of various kinds, e.g., subClass axioms and equivalentClass axioms. It is advised to extend this with rule axioms. A rule axiom consists of an antecedent (body) and a consequent (head), each of which consists of a (possibly empty) set of atoms. A rule axiom can also be assigned a URI reference, which could serve to identify the rule. Atoms can be of the form C(x), P(x,y), sameAs(x,y) differentFrom(x,y), or builtIn(r,x,...)

where C is an OWL description or data range, P is an OWL property, r is a built-in relation, x and y are either variables, OWL individuals or OWL data values, as appropriate. In the context of OWL Lite, descriptions in atoms of the form C(x) may be restricted to class names.

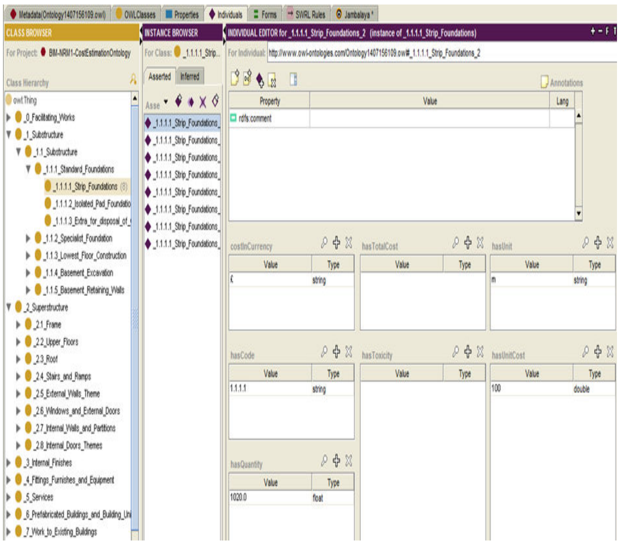

Fig. 4 The construction estimation ontology based on UK NRM

The SWRL language syntax used are the conjunction symbol, the implication symbol, the rule variables, the individual syntax, class atomic syntax, individual property atoms syntax, data valued property atoms. The conjunction syntax is denoted as Λ and the implication symbol as →. The rule variables are represented by the interrogation identifier?, e.g ?x. The class atoms are constructed from an OWL named "class", followed by one variable or individual name in parenthesis, e.g _1.1.1.1 Strip_Foundations (?x). The individual property atoms are constructed from an OWL object property name followed by two arguments in the parenthesis, e.g undertakeTreatmentOfGroundMaterialOn (?x, ?y). Similarly, the data valued property atoms are represented in the same way as individual property atoms, e.g. hasUnitCost(?x, ?y).

Using this syntax, an example of a query in the ontology is:

$$\begin{aligned}&\_1.1.1\_Standard\_Foundations(?x) \wedge hasUnit(?x, ?z) \wedge \\ &hasQuantity(?x, ?y) \wedge hasUnitCost(?x, ?a) \\ &\rightarrow sqrl: select(?x, ?a)\end{aligned} \quad (1)$$

Query 1 selects different standard foundations and output their respective quantities and unit costs.

Similarly a rule is included to identify components of superstructure that has been intoxicated and classifies them as components to be detoxified (rule 2)

$$\begin{aligned}&\_2\_Superstructure(?x) \wedge hasToxicity(?x, ?y) \wedge \\ &swrlb: greaterThan(?x, ?z) \wedge Actors(?a) \wedge \\ &undertakeDetoxification(?a, ?x) \rightarrow \\ &DetoxComponents(?x)\end{aligned} \quad (2)$$

Based on rule 2, the intoxicated components are selected using the query 3.

$$DetoxComponents(?x) \rightarrow sqrl: select(?x) \quad (3)$$

VI. Validation of the Developed Ontology

Evaluation of ontology is a mandatory activity [12]. During the development of the ontology, Pellet 1.5.2-an OWL-based reasoner in Protégé-OWL was regularly used to check technical inconsistencies. As part of future study, it is anticipated that through a workshop, quantity surveyors will be invited to validate the ontology. This type of validation is crucial as it establishes or verifies if the purpose for which the ontology was developed for has been achieved.

VII. Challenges and Lessons Learned in the Modelling Process

In the development of this ontology, four main challenges were encountered. Firstly, given that spaces are not allowed in concepts or names in Protégé-OWL, it was not possible capturing names of concepts as they appear exactly in NRM. For example, in practice the concept "Fittings, Furnishes and Equipment" will appear as so, but in protégé-OWL, commas (,) and spaces are not allowed. Underscores (_) were therefore used to separate words, such that this concept now becomes "Fittings_ Furnishes_ and_ Equipment". Also, hyphens (-) were used to add additional meanings, when required to avoid confusion. Second, some concepts' names were too long to be edited into Protégé-OWL. Although there is no restriction on length of names in Protégé-OWL, the first few words of the concepts were used as names of concepts and the remaining parts were captured as part of annotation properties. Third, in some cases, there were repetitions in same concepts appearing at different hierarchies. For example, 1 Substructure and 1.1 Substructure appearing as level 1 and 2 concepts respectively. Given that in the NRM book, the term "Details" have been used in specifying further details or information about concepts, "Details" was used on the lower concepts to distinguish from the higher concepts. For example, 1 Substructure stays the same while and 1.1 Substructure becomes 1.1 Substructure Details.

Fourthly, in some cases, some terms were included as major components before types of components included. For example, in Fig. 5, Piled Foundations and Underpinning have been included before sub-components or activities listed. These concepts, Piled Foundations and Underpinning were captured as concepts. This means in such circumstances there were five levels in the hierarchy.

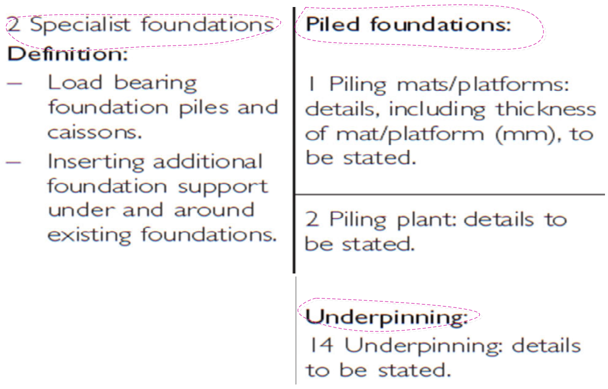

Fig. 5 Dealing with additional terminologies in NRM

VIII. Conclusion

In this study, the challenges facing construction cost estimators have been discussed. To address these challenges, an ontology based approach has been proposed. This approach builds on the UK standard method of measurement that already exists and commonly used in most construction industries.

The steps for the development of the ontology have been discussed and the challenges encountered highlighted. As part of future study, this ontology will be fully developed and uploaded into popular open ontology repositories such as the Protégé ontology library.

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