INCORPORATION OF EXPERT REASONING INTO THE BIM-BASED COST ESTIMATING PROCESS

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The analytical cost estimation is an efficient and robust data based approach. Yet, there are two key issues associated with analytical cost estimation; the need to make sure that practice standards are adhered to and the implementation of subjective recommendations. The degree of precise detail, and the intricacy of standards and expert insight is a hindrance to its computerisation, as a result of complicated software development schedules and increasing expenses. A rule based semantic method is utilised as a model and is demonstrated as a way to tackle these problems. The investigation of BIM-based cost estimation confirmed that industry foundation classes (IFC) can provide construction project semantics but incapable of relating domain semantics and pragmatics. Our model is founded upon the belief that three components are necessary to gain a full awareness of the domain which is being computerised; the information type which is to be assessed for compatibility (syntax), the definition for the pricing domain (semantics), and the precise implantation environment for the standards being taken into account (pragmatics). Moreover, organizational semiotics is employed to uncover the semantic components of cost estimation from a procedural standpoint and suggest an improved knowledge based system. This report outlines the way in which the proposed approach has been verified, by employing a selection of codes created by the prototype of the data based model. The standards of practice which have been establish are then verified, in accordance with actual building information gained from IFC. The utilisation of this approach has significantly advanced the procedure of automating professional costing practice within a BIM context. These pleasing outcomes demonstrate that, by implementing this model, the reasoning ability can be used by the BIM context and the restrictions around the application of BIM will be reduced.

Keywords: rule-based reasoning, semantic web ontology, organizational semiotics, industry foundation classes, quantity surveying.

INTRODUCTION

The guarantee of compatibility for analytical cost estimation is one of the most prominent issues for experts within the industry, particularly when it comes to ensuring compatibility against the standards of practice which regulate the sector (Beach *et al*. 2015). Whilst the employment of BIM to aid cost estimation has become a lot more regular, the efficient transformation of intricate and non-binary text based standards (created to be interpretable to specialists) into machine executable code continues to be a tricky process. Moreover, the subjective decisions of estimators also play an essential part (Cheng *et al*. 2009) and the level of access to historical information is similarly essential. Therefore, it is, by its very nature, a subjective

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process, and the utilisation of advanced problem solving is vital whether or not sophisticated pricing models or basic methods are employed. It is broadly utilised and perceived to be a solution for the oft-disregarded issue of cost estimation (Beltramo 1988; Stapel 2002).

This study aims to discuss the most prominent restrictions associated with the creation of BIM models for cost estimation functions. The use of a fresh and far reaching viewpoint is necessary, because it enables the use of reasoned capacity to address standards of practice, compatibility challenges, and issues relating to subjective choices. The intricate components of standards of practice and specialist insight means that a more complex software development framework is necessary. To be precise, this is needed to address the intricacies associated with explaining the objectives of industry specific standards to software experts and, equally, verifying the software resources created by domain specialists. The consequence of this model is that it tends to leave pricing systems restricted or fully closed.

The main objective of this research is to create, assess, and verify a generic rule based semantic expert cost estimating model. The authors predict that there will be two primary benefits for systems which employ our new model: (1) the capability of domain specialists to comprehend and upgrade the standards of practice and level of insight within an open software architecture, and (2) the expanded awareness of the fact that analytical cost estimating is equivalent to rule based reasoning. This enables verification of the system to be carried out with a much greater degree of accuracy.

STATE-OF-ART OF BIM-BASED COST ESTIMATION

There has been efforts in the past towards performing automatic cost estimation within BIM, thus an extensive exploration of intelligent solution for cost estimation is necessary (Abanda *et al*. 2011; Fidan *et al*. 2011; Lee *et al*. 2014; Ma and Wei 2012; Staub-french *et al*. 2003). It is also a good idea to point out that the filtered reports are founded upon a literature review of more than 100 papers. They were all discovered using key terms like semantics model, construction, design, building, built-environment, ontology, resource description framework, (RDF) semantic web ontology language (OWL), IFC, and more (all dated from 2002-2014).

The research of Staub-French *et al*. (2003) has already outlined an ontology of building characteristics which can help specialists to carry out accurate price predictions. The application approach can be outlined as creating the characteristics of the component, using demonstrations of building product models (such as IFC models), pinpointing the design specifics of the component, and applying the insights of specialists in a project-subjective manner, in order to evaluate or integrate actions for building components. Once this has been done, the expenses are adapted in accordance with the findings.

The work of Abanda *et al*. (2003) explores the work related expenses in Cameroon, where they are used to employing basic data engineering methods to construct UML models of work expenses, and then applies these in OWL. Then, utilising semantic web rule language (SWRL) for OWL enables various different task locations to be identified and a suitable work expense estimation can be chosen for the location in question.

A database system, founded upon an ontology of risk incident, was created by Fidan *et al*. (2011), in order to estimate the chance of expense overruns. The language has not been specified and the evaluation of expense overruns are beyond the reach of this study. This is because its primary aim is related to analytical cost estimation, even if expense overrun calculations are also a kind of estimation.

According to Ma and Wei (2012), it is useful to employ a system which moves IFC information to Owl. This transition means that it allows the reasoning capability to instantly categorise building construction resources into expense items and automatic amounts, before calculating the overall cost summary. Yet, the pricing phase is still not present, because (as Ma and Wei make clear), the expense items can always actively quote market prices, which negates the need for item pricing altogether. Then again, OWL is the application method, but the ontological/semantic method is founded upon IFC.

As explained by Lee *et al*. (2014), the searching procedure for the most suitable work related items associated with expense prediction can be identified with the use of OWL and SWRL. The given information is withdrawn from an IfcXML file position, so that semantic reasoning can be applied for the ontology of working conditions. These file types offer data about dimensions, thickness, technique, materials, width, size, and more, in order to clearly identify the work items needed for expense predictions.

On the other hand, commercial software for cost estimation, as is outlined by Eastman *et al*. (2011, p.220), *"There is no single BIM resource which can offer the same functions as a spreadsheet or a cost prediction service, so expert estimators are obligated to discover an approach which is suitable for their precise kind of prediction procedure."* The three key choices for cost estimation, founded upon BIM, are as follows; (1) move building object amounts to prediction software, (2) employ a BIM quantity take off resource, or (3) connect the BIM resource to the prediction software. These choices offer varying degrees of interoperability. For the first two choices, information is withdrawn from the model and transported using a format which can be easily interpreted by cost estimating programs. For instance, there are a number of programs which are compatible with cost estimation processes; CATO, CostX, and Nomitech are among them (Exactal 2013; Nomitech 2013).

The computerisation achievements of the construction sector are generally reliant upon the upcoming technologies of the next generation internet. This is commonly called the ontology/knowledge demonstration and it has the potential to usher in a great deal of innovation. One prominent characteristic of this ontology/knowledge based idiom is the need to be compatible with interoperability between software applications, inclusive of web based services and intelligent programs. If the construction sector is used as an example, it should be clear that the tools needed to introduce interoperability between software applications is the ISO-10303 Standard Exchange of Product Data (STEP). In fact, the IFC was designed to be a building information model for the construction sector and is founded upon tools created by STEP. The semantic heavy model is responsible for enhancing the condition of building data via the employment of semantic technologies. In other words, the aim is to expand upon the current building information using machine processable data and ontologies.

The reason that OWL is frequently recommend as the best knowledge representation language (particularly for aesthetic briefs) is because it is efficient, popular, and now broadly supported. It is worth noting that this situation does not speak of any system based issues with any of the other languages. However, it continues to be the case that the basic knowledge engineering procedure appears to be lacking in terms of an integration of semantics and pragmatics (Grzybek *et al*. 2014).

This chapter has explored subjects associated with the BIM-based cost estimation sector. It has proposed improved and more innovative methods, particularly when it comes to the ontology utilised within the construction industry. Yet, there is as yet no single study which has managed to integrate the suggested methods into an overarching model with the ability to take into account all relevant viewpoints. Whilst a number of the most important studies associated with costing emphasise a semantic foundation within the domain (Ma *et al*. 2013; Nepal *et al*. 2012), it is believed that a full account of all the relevant viewpoints has to incorporate an informational format which can be assessed for compatibility (syntax) the definition of the pricing domain (semantics), and the precise implementation environment for the standards which are being evaluated (pragmatics). This is particularly vital for the construction sector, because there is a developing popularity for reverse engineering the semantics of the domain from its main data storage type, which are the IFCs. It is also believed that this is not the best approach, as they IFCs were created to be a data storage function and cannot fully demonstrate the right series of semantics for the construction management sector. The assimilation of these three viewpoints is the most important advantage offered by our approach. It is hoped that it will continue to expand the reasoning capacity of the pricing models used alongside BIM, particularly in comparison to similar models outlined in this chapter, and that it will serve as an advanced progression. In our opinion, this new approach offers plenty of benefits to specialists who use BIM.

DEVELOPMENT OF A FRAMEWORK FOR BIM-BASED COST ESTIMATION

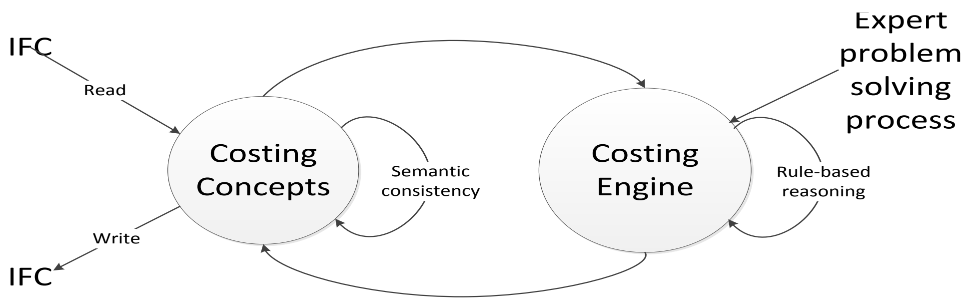

Figure 1 A proposed framework of costing professional services under BIM environment

According to Figure 1, the suggested model demonstrates a heterogeneous method to be used in an abstract context. It directs the way in which the designed model should be employed alongside a BIM scenario. The outlined model demonstrates the fact that IFC informational structures are deconstructed for building data and are expected to carry the outcomes of cost prediction. This is verified by our own semiotics system evaluation, carried out in line with IFC (BuildingSMART 2013; ISO 16739 2013) and cost estimation standards (The Royal Institution of Chartered Surveyors 2007), and which provides a semantic heavy model for building data, but does not have enough specialist reasoning (Venugopal 2012). Therefore, IFC is easily leveraged as the primary data collector for building construction tasks. Yet, domain ontology is used to demonstrate specialist insights.

From a theoretical perspective, knowledge representation is a concept based approach created to aid logical programing. At the heart of knowledge lies the trio of predicates, objects, and subjects. In terms of the OWL, it primarily subjects as categories, predicates as object characteristics, and objects as categories too. This report uses problem based briefs to source all the semantic components from standards (The Royal Institution of Chartered Surveyors 2007, 2011), but semantic evaluation emphasises the task components. This leads to an enhancement of the input and outtake of these tasks, because all of the tasks are linked, and can be used to create an ontological table of quantity surveying. The semantic evaluation strategies have been influenced by organisational semiotics (Liu 2000).

There are two key motivations for utilising organisational semiotics. The first relates to the fact that the varying ontological idioms can be tricky; it is thought that, without a knowledge assimilated process of expense prediction, this knowledge is considered 'lost in the system.' It can only be recovered and utilised with additional expense. The semiotic phases then are able to clearly demonstrate syntax, semantic, pragmatic, and cultural viewpoints. In fact, semantic evaluation can assimilate semantics and pragmatics using a series of complex methods (Stamper 1991). Thus, the basic guidelines can be made even simpler, so that they are able to aid expert tasks at a detail specific level. For instance, they can explain, outline, highlight, choose, and adapt information throughout the expert cost estimation phase. Secondly, due to the fast paced evolution and widespread use of computers, cost predictions now require a technology based upgrade approach to prediction. This methodology must include a degree of human input, which is they creators of this research argue that analysis experts should have to use suitable and methodical analytics strategies within information system engineering and related sectors. It should also be noted that this is not a claim that technology can be a substitute for human specialists, but rather that technology can be integrated into enterprises.

Within a practical context, not all of the building characteristics can be assessed alongside a modelling idiom. This further emphasises the value of using reasoning capacity for domain specialists, particularly if they are trying to handle complex scenarios by employing standards and deductions. Moreover, normative evaluation verifies the guidelines which regulate the actions of a cost estimator as they are carrying out analytical cost estimation. The advanced problem solving strategy is provided by normative withdrawal from domain standards and the ontological renewal of earlier studies.

DEPLOYMENT AND IMPLEMENTATION OF METHODOLOGY

To apply our model and allow for its verification within the selected scenario, a prototype of application was created to provide accurate expense predication outcomes. The employment of our model was carried out in three key phases: (1) withdrawal of meta-data from standards of practice reports (The Royal Institution of Chartered Surveyors 2011), (2) identifying semantic mappings, and (3) the application of specific strategies.

Semantic Evaluation – to conduct this phase of the model, the Order of Cost Estimation (The Royal Institution of Chartered Surveyors 2007), and the best practices associated with cost prediction (Evans and Peck 2008; Isakowitz 2002; Schinnerer 2007; Sinclair *et al*. 2002; Tan and Makwasha 2010) have been analysed. There are a total of 123 meta-data components which have been withdrawn.

Semantic Mapping – to conduct this phase of the model, the mapping between the key terms utilised for standards of practice and the idiom of the IFCs has been implemented. The outcomes of the mapping are outlined in Table 9.

Table 1 Semantic units mapping

Documents	Total IFC entity	Number of attributes	Number of relationships
Order of Cost Estimation	22	27	8
New Rules of Measurement	42	59	22

Application of Strategies – the following phase of the model is based on the application of strategies already highlight by the semantic evaluation. These strategies form the precise steps which must be carried out by specialists and they are all linked with a different kind of data. Moreover, in order to verify these strategies (a total of 13), a question based survey has been created to enquire about specialist reasoning directives.

The next phase of system building takes the form of a confirmation procedure for pricing insights. Thus, officially identified ontologies can be confirmed via the use of reasoning tools. The Protégé offers this function via the use of inbuilt reasoners like FACT++, Hermit, and Pellet (Bechhofer 2004; Shearer *et al*. 2008; Sirin *et al*. 2007). The accuracy of all the tools has been evaluated and an unpredictable insight was offered and highlighted by the reasoner.

The final aspect of our research focuses on the confirmation of guidelines which have been developed for the study. This is achieved via the transformation of norms within a logical program. The engine has been given an extra level of precision, so as to be as accurate as possible and to be compatible with many different kinds of standards of practice. The abilities of this engine include the following; the capability to question and upgrade the semantic framework, the capability to deduct non-existent building components, and the capability to entreat pricing predictions in line with the given reasoning directives and phases.

To verify the results of the cost estimation model, it will be tested alongside an active construction task. To make this happen, the model will be linked with a predefined modification of IFC. For the purposes of this research, an IFC parser will be applied. This is because it can interpret entities within the IFC physical file positions 2 and 3 and transform RDF file formats – refer to Figure 2 for an example of a transformed IFC physical file.

```
<!-- #ifcwall_15478 -->
  <owl:NamedIndividual rdf:about="&untitled-ontology-12;ifcwall_15478">
    <has_id rdf:datatype="&xsd;string">15478</has_id>
    <ace_lexicon:PN_sg rdf:datatype="&xsd;string">IfcWall_SW-007</ace_lexicon:PN_sg>
    <has_type rdf:datatype="&xsd;string">external wall</has_type>
    <name rdf:datatype="&xsd;string">sw-007</name>
    <has_constructionworkresult rdf:resource="&untitled-ontology-12;brick1"/>
    <has_quantity rdf:resource="&untitled-ontology-12;ifcquantityarea_33501"/>
    <has_quantity rdf:resource="&untitled-ontology-12;ifcquantitylength_33505"/>
    <has_quantity rdf:resource="&untitled-ontology-12;ifcquantitylength_33506"/>
    <has_quantity rdf:resource="&untitled-ontology-12;ifcquantitylength_33507"/>
    <has_quantity rdf:resource="&untitled-ontology-12;ifcquantityvolume_33499"/>
    <has_spacefunction rdf:resource="&untitled-ontology-12;ifcspace_1234568"/>
  </owl:NamedIndividual>
```

Figure 2 IFC Entity represented by Web Ontology

RESULTS

Once the construction of the pricing model was finished, it was tested alongside an active building task. It is important to note than an IFC model of development for a residential venture was employed within this study. For the purposes of this research, a two floor villa type building is the central focus. The basic strategy followed pertains to that of shadowing and closely watching the relevant building costing estimations. In other words, whenever a costing system was utilised for the task in question, the model was also brought into play to provide an alternative set of results. This is how this research are able to compare and contrast two sets out outcomes from one construction scenario.

Table 2 Result summary

Procedure	Rule	Manual result	Automatic result
Decomposing	Boundary work to voids is only measured where the void exceeds 1.00m2, and is measured by length (The Royal Institution of Chartered Surveyors 2011 p. 152).	New item will be created	√
Selecting	Measured by length (The Royal Institution of Chartered Surveyors 2011 p. 152)	Certain measuring unit will be selected	√
Establishing	Boundary work; location and method of forming described (The Royal Institution of Chartered Surveyors 2011 p. 152)	Description of items is associated	√

The number of new rules of measurement (NRM) total over 350, but for the aim of outlining the phases of this analysis, they will be restricted to those associated with wall coverings, as an example. In Table 2 Result summary, the key guidelines for deducting non-existent building characteristics on walls and their consequent outcomes are demonstrated.

Figure 3 presents the engine which has been created. From this resource, it is clear to see how standards of practice (after being transformed into guidelines via normative evaluation) are demonstrated in line with the relevant procedures. This enables a variety of rules to be quickly assessed using the same steps. It also enables much more efficient verification. These outcomes and their comparative results, from the manual predictions, are presented in Table 2.

Figure 3 Rules developed

DISCUSSION AND CONCLUSION

This report has discussed our work on the creation of a rule-based semantic approach to cost estimation; the proposed model has been assessed using NRM. Furthermore, a suitable scenario has been used to show how our model enables domain specialists to pinpoint and employ a reliable cost estimation framework, based on their precise needs. The cost estimation framework that has been created as a result of our research was seen to efficiently, reliably, and successfully, carry out quantity surveying on building information, as confirmed by NRM.

In taking on this scenario, the procedures whereby which construction costing specialists employ the strategies outlined have been suitably verified. It is also clear now that they are compatible with BIM resources, being able to help them with (1) highlighting standards of practice without needing advanced software, and (2) pinpointing expert reasoning directives for individual employment. This method of upgrading standards of practice and reasoning directives is easily conducted by enhancing the semantic evaluation and semantic mapping tools developed when the system was first implemented. Moreover, the implementation of semiotic framework to evaluate BIM-based cost estimation verifies the theory that the IFC schema suffers from a deficit of reasoning capacity; this is something which is essential for advanced cost estimations. It has also allowed us to better locate additional informational items which add value to the IFC specifications, by providing increased assistance for the expense prediction procedures.

These attributes enable the functionality of the standards of practice for the framework to be altered quickly and without notice of the following; (1) sector information file formats, or (2) how the basic implementation of the guidelines function. The strategy that used involves the breakdown of specification guidelines, which made sure that the information formats and the processes relevant to a methodical strategy were a true success. Additional enhancement of the system can take the form of either (1) assimilating plug ins with the primary BIM system (for example, in the case of Benley Microstation and ArchiCAD BIMx), in order to virtualize the costing documents, (2) utilising an interface of precise processes and guidelines, or (3) developing automatic ontology from semantic evaluations.

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