Applying Organizational Semiotics for Developing Knowledge-Based Cost Estimation of Construction Project

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Abstract. Cost estimation is a dynamic and knowledge intensive process. Current practice of construction cost estimation is a process with fragmented knowledge. In order to have an integrated process, semantic should be modelled in respect to pragmatic. The investigation of BIM-based cost estimation confirmed that IFC can provide construction project semantics but incapable of relating domain semantics and pragmatics. In order to overcome this gap, we adopt organizational semiotics to fully reveal semantic units of cost estimation from a process perspective. Pilot study confirms feasibility of this approach. Future research will be a case study to collect all the instances for semantic units. Then semantic consistency and pragmatic implementation should be realized by the applications. This research highlights the importance of alignment between semantic (domain ontology) and pragmatic (meaning in use), it contributes also to identify a new approach of knowledge engineering for construction professional services under BIM environment.

Keywords: analytical cost estimation, knowledge representation, information system development, industry foundation classes, quantity surveying.

1 Introduction

An exploration and analysis of various BIM-5D applications confirmed observations in the literature that model-based construction cost estimation need a new method that could meet the need to core cost estimating workflows [1–3]. Because in addition to material quantities, product features, such as openings and repetition, also affect construction costs [4]. Previously such factors are being considered by expert into the adjustment of estimation [5]. This approach is often difficult to integrate into current computing practices because it is a ‘black box’ and difficult for computer to understand [6]. Therefore, existing software tools do not explicitly capture quantity surveyors' rationale for how the component properties and product features affect the cost information and cost estimation requires contextual information and current support is insufficient for this requirement [4]. Meanwhile, conventional programming language is insufficient to deal with certain estimating activities for example comply with standard, which is an essential requirement for costing practitioner.

Existing knowledge engineering process produces ontology, in the form of classification systems and product data models, lacks effective modelling of concept semantics and related pragmatics: a fundamental requirement for human-based exchange of knowledge [7]. Being investigated into human reasoning processing, more specific, the cost estimating process consists of locating objective information, recognizing it in the immediate situation or in the past, evaluating the objective information, combining the information together, and then implementing it as a certain value of estimation. With the development of information technology, locating objective information is helped by using a search engine, recognizing objective information in the immediate situation or in the past is facilitated by cost database (cost index). However, by lacking a knowledge model of cost estimation which integrates domain semantic and pragmatics, the issues remain the same, firstly time is insufficient for doing cost estimation [8], secondly we are hardly able to find the valuable information [5], thirdly, cost estimation requires contextual information [4].

Furthermore the general idea is that data and services are semantically described with respect to knowledge representation language, which are formal specifications of a domain of interest, and can thus be shared and reused in a way such that the shared meaning specified remains formally the same across different parties and applications. Then a business process is being modelled with norms in order to capture the application logic. Finally a special purpose reasoning engine could be employed, based on logic programming that operates on the above two structures in an integrated way. The paper has been structured as follows: we firstly study the advantage of applying the framework, in which corresponding to the knowledge capturing problem in quantity surveying organization. Then the results of pilot study have been demonstrated to show feasibility of introduced approach. Finally conclusion and future research is presented.

2 Semiotics in Construction Domain

While the development of information technology, many software applications, for instance Sage Timberline [16], Innovaya Visual Estimating [17], CostX [18], and Nomitech [19], have been developed and applied in the construction cost estimation. However, based on case studies of the software using in cost estimation process, for instance BIM cases [1–3,20], and quantity surveyor cases [21–27], estimators still have to read and extract useful information from the model or manully rebuild a three dimentional model specific for cost estimation then conduct measuring by strictly complying with specifications such as SMM [28] or Professional Practice Guides [29] then applying unit price intuitively. Because of working complexity and comprehending deviation during the process, analytical cost estimation is both time-consuming and error-prone [30].

To improve the communication efficiency of BIM, Hartmann (2012) introduces semiotics to analyse BIM systems. This semiotic framework is focusing on technical perspective [10], according to Liu (2000)'s semiotics ladder, it focuses on IT-platform, however, to author's best of knowledge, the communication problem is an inherent issue due to the nature of construction industry [12]. The analysis solo focuses on the technology part cannot solve the inherent problem of construction industry. High level requirements are not technical, but mainly social and organizational. Therefore, the success of information systems implementation depends more on how well an organization is prepared and organizational aspects are integrated rather than the pure technical systems itself [13].

Eastman [14] reveals that there are two major perspectives that influence the form of information technologies in the building information modelling: the organizational perspective, the technical perspectives, which includes software technology, the system architecture perspective, and the modelling technology perspective.

Organizational perspective depicts the structure of organization will influence information exchange and integration requirements. For example, traditional construction team, which is a virtual team with dispersed members working for a single project will have different requirements in contrast to an international building company that have various divisions, such as design, costing, and construction divisions [15]. Organizational requirements will guide the information techniques of the construction industry. Technical perspectives describe contribution from software technology, for instance new programming languages, function libraries, and exchange standard; the system architecture perspective, for instance different implementation methods, service oriented architecture (SOA) and P2P networks etc.; and the modelling technology perspective depict different modelling languages which focus on interoperability issues.

2.1 Current Ontology Application in BIM-based Cost Estimation

Based on our literature reviews, current BIM-based cost estimation is a fragmented process with knowledge. Along the cost estimation process, IFC model provides the information of a building, IDM verifies the information exchanged between IFC model and the cost estimation, says quantity take off [31]. And the IFD supply the detailed components information contained in the general IFC model, however supports to cost estimation is not facilitated. Thus we need further improvement to BIM-based cost estimation.

Table 1. Comparison between estimation methods

Estimation method	**General Cost Estimation Process** Cost Item Quantification	 Unit Price Determine
Conventional Cost Estimation	Manual	Manual
BIM based Cost Estimation	Automatic*	Automatic*
Ontology Improved BIM and language used	1: Describe cost item comply with standard; IFC-based ontology. 2: Identify working condition to select cost item; OWL	3: Identify project location to select labour cost; UML+OWL. 4: Identify construction condition to adjust unit price; ontology language not specified

Note: BIM based QTO and price identification doesn't comply with standard
1: [32]; 2: [33]; 3: [34]; 4: [35]

In table 1 these researches highlight that highlight the gap of BIM-based cost estimation which it doesn't satisfy the needs of domain users. The different ontology languages used concerns us, we argue that without a process for integrating knowledge of cost estimation, such kind of knowledge is still lost by the system and mainly maintained by individual cost expertise. Furthermore we also believe that the general process can be further breakdown to support professional activities in detail, for example describe, identify, select, and adjust etc. can be employed to describe professional cost estimation process. We believe that without a new stance to review cost estimation as a human intervention process and without a comprehensive framework to provide a foundation of interaction between IT platform and human function, professional works cannot be further improved.

The greatest challenge however is that of engaging in the development of knowledge representation in BIM-based model which is a knowledge representation language as well. This requires a fully "a cost estimator mind" with high software modelling knowledge that can model the processes of developing a cost estimation. Thus it represents two major problems that the complexity of knowledge language (industry foundation classes and ontology language) can hardly be understood by the domain user meanwhile knowledge engineer doesn't understand cost estimation in a good picture which could break cost estimation process into piece. Thus it is essential to have a knowledge capturing process could facilitate an integrated estimation process for estimating domain or at least could capture semantics and pragmatics.

2.2 Advantage of Applying Semiotics Framework to Cost Estimation

The adaption of the new approach needs a strong justification as it is essential for us to question about why stand from an organizational perspective for cost estimation. Capturing the rationale and identifying the knowledge intensive processes is not a trivial task. It is difficult for experts to explain what it is that they know. To data, the only thing we know is that the expert in the quantity surveying organization needs to make assumptions about future cost resulting from: different locations, fluctuation of labour productivity and changes in the market conditions [36,37]. Corresponding to our two problems of cost estimation, which are quantification and pricing. In software, the main stream is quantification which start with building drawings. Firstly expertise will extracting a set of building elements from drawings, then decomposing them into cost items. Once these cost items are complied with standard, they often make comparisons and references to historical projects respectively in order to predict the cost of the new project [38].

Together with the concerning of the development of information system, we adopt organizational semiotics which trying to understand cost estimation from an estimating process perspective. By capturing knowledge, the reasoning and inference steps can be delivered to the development of information system. We incorporate a suite of semiotics tools: semantic analysis and norm analysis [11]. Firstly, it identifies concepts of interest and the ontological dependency between semantic units, having established the ontology chart; it will then ascertain the semantic relations. Hence, formalising these relationships to model the behaviour of organisational systems design [39]. In our research, the main focus addressed in engineering aspect has been put onto knowledge representation and information analysis to provide pragmatic and semantic support to quantification and pricing for cost estimation. This engineering perspective is related to information system engineering, which studies information system design and development. There are two major reasons why the engineering aspect is important to the automatic cost estimation:

- Adopting a proper information system engineering perspective helps grasping quickly the importance of information analysis and knowledge representation for cost estimation. The knowledge and information have to semantically represented, and reasoning engine can be supplied to enable estimator to leave tedious works as much as possible to system, in other words, to enable the system to automatic or semi-automatic perform cost estimation;
- On the other hand, with the rapid development and heavy use of IT, cost estimation needs a technology-led updated estimating approach. This approach should incorporating human inference, and we argue that the analyst should use compatible and systematic analytical methods as used in information system engineering or the related disciplines. Gaining a clear understanding of the state-of-the-art approach to information system could nourish the ideas for up-to-date studies of cost estimation and receives the payoff from information system for cost estimation;
- The semiotic approach takes one a step further. It will stress the distinctions as well as the interdependent links between the organization, the business process and the IT system. The notion of human responsibility and possibility of delegation of functions to an IT system is clarified.

Therefore, the authors' approach to 'expertise-based' cost estimating, is first to examine the current practice via a well-established framework, which links the physical world and social world through the information mechanisms expertise use in the organization. Secondly we employ semantic analysis in order to understand and capture the procedure knowledge used by experts when perform surveying, moreover standard investigation and observation have been conducted. By understanding these issues, it becomes possible to model the expert behaviour and further developing model in the sense of computability. Furthermore integrating such knowledge in a BIM system which enabling a knowledge-based approach to professional services. It is interesting to notice that some researchers are tagging IFC model as a semantic rich model [40–42], but others are claiming that IFC has insufficient semantic contained in the entity and relationships [43–45]. This conflict has been addressed by our framework.

3 Pilot Study and Results Discussion

An investigation of BIM-based cost estimation through organizational semiotics ladders has been conducted, from the physical token to social norms, six aspects of signs in the semiotics ladder of IFC-based cost estimation summarized the findings in the analysis, due to page constraints, and detailed results are not presented in this paper. At technical perspective, in the physical level, STEP file and API usage is sufficient for establishing software integration and database exchange, however there is no implementation in knowledge base. In the empirical level, the emphasize is focused on IDM, which provides a mechanism to reduce the information uncertainty, however it is still highly in the initial phase and did not address the semantic, pragmatic and social problem derived from organizations. In the syntactic level, IFC provides a powerful schema that transmit construction information for all stakeholders but the redundancy and complexity of schema is barrier for the implementation. Moreover, regarding the domain practice, in other words the professional service provided by the participants, is requiring new entities that should be defined in the schema, especially the standards and professional activities.

IFC lacks the formal specifications to relate the entities and relationships to reasoning mechanisms from the human reasoning process perspective. As we discussed previously without an integrated process of cost estimation and a systematic framework, in the semantic and pragmatic level, the pattern of behaviour is not fully recognized and defined. For instance, in the current detailed cost estimation process, Comply with standard is a description of this behaviour, but the activities are not recognized nor computer supported. Other examples like forming behaviour which should before adjust behaviour has not been recognized either. These unrecognized behaviour patterns on the one hand are providing the flexibilities to do cost estimation but also is a time consuming process for cost estimation as expertise are mostly dealing with various software packages and attempting to link all these behaviours together to deliver cost estimation via quantity surveying approach.

After producing ontology chart of QS organization, the above three ladders, which are semantic, pragmatic and social, can be covered from an organizational perspective. Semantic analysis reveals professional activities that expertise are acting to accomplish their tasks. Norm analysis shows the pattern of expert problem solving and the logic behind the process. Briefly, professional activities and norms can be defined in the semantic. The affordances revealed in the semantic analysis can be formed as information requirements in empirical level. In figure 2, due to page limitation, we represent the stage of preparation (it can also be called classifcation stage), there are four actions we need to focus. They are dissemble, decompose, selects and synthesis. Figure 2 represents the semantic units translated into semantic web ontology (OWL), which is a knowledge representation language. The language has been widely accepted and used in the construction domain. All the categories can be related with professional activities, e.g. quantity surveying in the object property. It is important to notice that the most important aspect of OWL is their emphasis on tractability of inference. Furthermore a problem instance is solved by describing it and then asking if it is subsumed by one of several possible solution categories. By revealing professional activities and showing the dependency between semantic units as well as employ a special purpose reasoning engine, for example rule-based reasoning in logic programming, we could get a step further to implement the knowledge-based system, see figure 3.

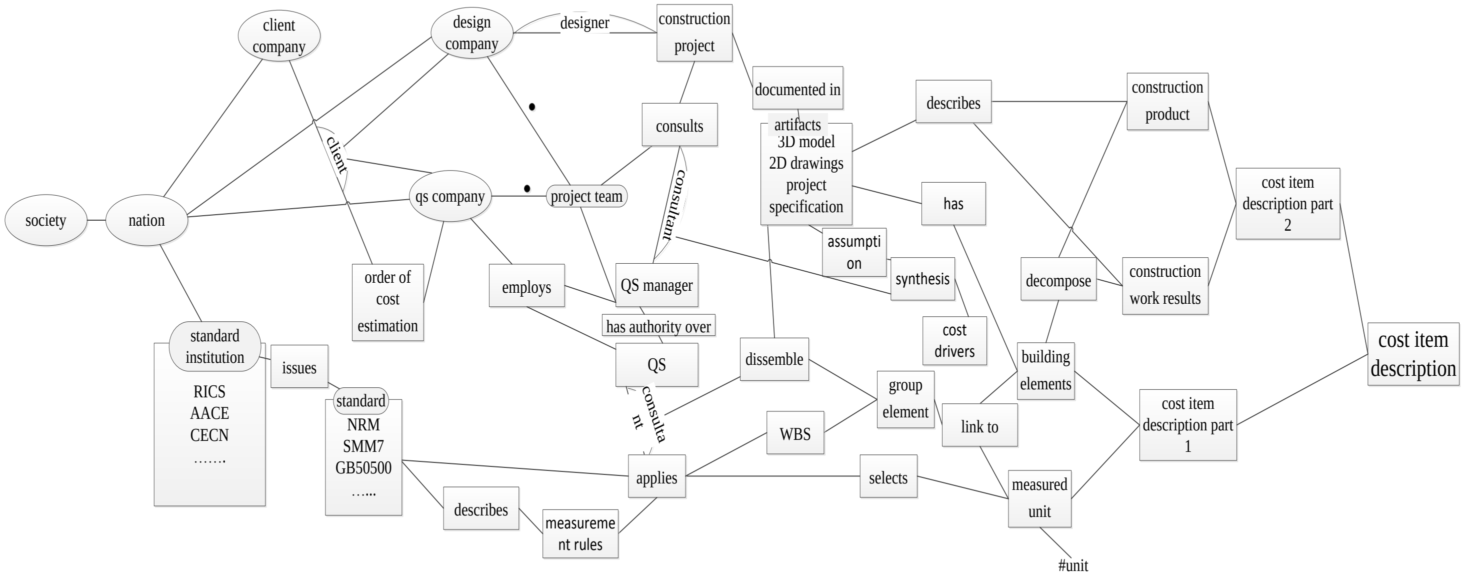

Fig. 1. Ontology Chart: Preparation of cost item

Prepare stage: According to [46], the estimators first receive the order of cost estimation request from client. And the estimators will receive information about the new project in various forms. They *receive* a request to do the work, and data such as 3D models, drawings and project documents. From this information, the estimator deepens their understanding of what it is that needs to be estimated by *synthesising* all the data and information. The estimator needs to analyse the requirements, *decompose* the project and classify the type of product. A Work Breakdown Structure (WBS) is employed and used as the framework to cost the new product [28]. During the decomposing of project, the expert may need to obtain more data to clarify the product of the project. They also need to understand the constraints in terms of time and resources. Once they understand what is required, they establish and document any ground rules and assumptions and identify the main cost drivers of the project.

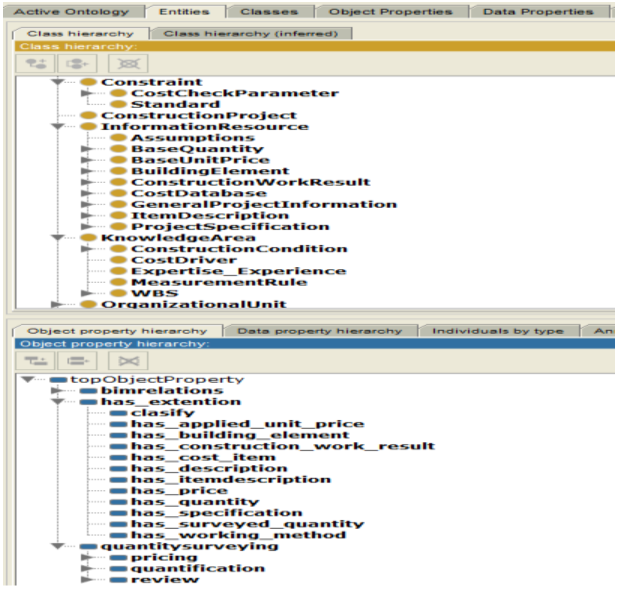

Fig. 2. Knowledge Representation of Analytical Cost Estimation in BIM

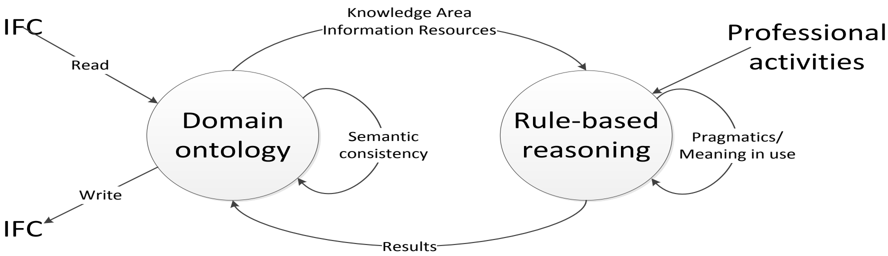

Fig. 3. Semantic and Pragmatic Implementation Map

Table 2 discusses select in detail for an illustration. Norm analysis specify the rules used during the process, which has been illustrated in the logic programming language, see figure 4, when expert perform professional activity of select units in order to measure wall1 and wall2, the condition has been specified according to the standard and successfully differentiate two units for two walls. It presents feasibility of realizing quantity surveying in a logic programming environment.

Table 2. Semantic Unit Analysis: select

Semantic Unit: selects		
Input:	Action description:	Output:
Conditions; Potential measured units	Expertise strict applies measurement rules, the process can be depicted like that whenever certain condition meets, a particular measured unit will be selected, and the same as construction product, and construction work results.	1. measured unit
Example:		
1. Masonry, width of damp-proof is 500mm 2. Potential measured units: length in meter, area in square meter.	Together with the building section 14: Masonry, if the width of damp-proof is larger than 300mm, then it should be measured in square meter	Measured unit: square meter
Knowledge: Memory of the conditions for example 500mm width.		

Fig. 4. Results from a Logical Programming Environment

4 Conclusion and Future Research

In a summary, IFC is a powerful modelling language and is viewed as a semantic rich data model. More specific, it presents the project components and it's constructing processes, and how they related to each other, especially for its geometry representation. However semantic contained in the IFC is mainly focused on the components and constructing process information. Regarding the new framework introduced to BIM-based cost estimation, IFC lacks of semantic, pragmatic and social from a human reasoning perspective in which there are two aspects of knowledge, they are 'know-what' (could be mostly stored in the IFC) and 'know-how'. As we can see the domain knowledge which in terms of norms is generally manipulating the components' information derived from IFC models. Thus the professional activities are of most interesting in this research.

Organizational semiotics has the capacity to reveal full semantic units for expert reasoning process and provide the alignment between semantic and pragmatic. The semantic units are modelled by organizational semiotics ontological chart, the ontological dependency fully describes the organization structures, inputs (semantic), professional activities (pragmatics), and results (intended semantics). By a simple mapping between OS semantic model and OWL semantic model, the revealed semantic units can be converted to OWL ontology in order to establish a common vocabulary of quantity surveying under a BIM environment.

This research highlights the importance of alignment between semantic (domain ontology) and pragmatic (meaning in use), it contributes also to identify a new approach of knowledge engineering for construction professional services under BIM environment. The roadmap and government report of BIM development confirm that BIM is toward a centre database of construction project. We believe that an integrated approach of semantic and pragmatic could promote BIM into a knowledge-based system, which currently hasn't been realized. Therefore the benefits can be identified from several perspectives, which are industry, domain user and research. From an industry perspective, a knowledge-based system which not only store descriptive knowledge but also procedure knowledge is essential for industry development. From a domain user perspective, implementing new techniques should truly benefits to the domain in terms of efficiency and effectiveness that aligned with human reasoning process. From a research perspective, semantic information exchange is the main stream of researches however the leverage of ontology implementation is still at the first stage which is the classification reasoning. Introduced new approach of knowledge engineering could facilitate discussions on the suitableness of general knowledge engineer process in the BIM environment and implementing the ontology in an innovative approach.

However the limitations are that revealed semantic units of organizational units and agents have not been used and there is no explicit contribution to pragmatic and semantic consistency although they are extreme important to the structure of BIM environment. On the other hand, virtualisation of this representation for domain user is quite difficult as there are many concepts and relations integrated and result in a human unreadable diagram. Future research will be focusing on find all the instances for the semantic units based on a case study, virtualisation of ontology need also being investigated that could be easily understood by domain user and redundancy of semantic units could be reduced in order to provide a precise semantic model of BIM-based cost estimation.

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