Developing An Ontology-Based Representation Framework for Establishing Cost Analysis Knowledge Base for Construction Work Items

Han-Hsiang Wang[a], Shao-Wei Weng[b], Abdoul Aziz Gansonre[b] and Wei-Chih Wang[b]

[a]Graduate Institute of Construction Engineering and Management, National Central University, No.300, Jhongda Rd., Jhongli City, Taoyuan County, Taiwan
[b]Department of Civil Engineering, National Chiao Tung University, 1001, University Rd., Hsinchu, Taiwan.
E-mail: hhwang@ncu.edu.tw, m09716005@chu.edu.tw, ernos0508@hotmail.fr, weichih@mail.nctu.edu.tw

Abstract -

Successful implementation of construction projects depends on accurate cost estimation. Cost analysis of construction work items is essential to a cost estimating process for contractors. However, current cost analysis tasks cannot be implemented effectively in practices. Therefore, this study proposes an ontology-based representation framework that aims to address such practical problems. The framework can be used to establish a cost analysis knowledge base which can benefit the modeling and application of cost analysis knowledge and hence, improve the accuracy of cost analysis and estimation. This framework is developed by using the ontological modeling technique with which key cost items of cost analysis and relationships among these cost items can be modeled and subsequently be examined. Actual cost analysis information of eight cases were collected and used to demonstrate and validate the framework. The case study results show that the proposed representation framework can effectively model and store cost analysis knowledge from both historical data as well as current professional work. Furthermore, the modeled cost analysis knowledge can be reused in new cost analysis tasks, and the accuracy and efficiency of cost analysis and estimates can be improved by eliminating the possibility of leaving out necessary cost breakdown items. Future research is suggested on improving the framework by developing a reasoning mechanism that can automate cost analysis processes of reusing existing cost analysis knowledge.

Keywords -

Construction Management; Cost Analysis; Cost Estimation; Ontological Modeling; Ontology

1 Introduction

Accurate cost estimation of construction projects enables successful project implementation. Construction project cost commonly has three levels of estimates: project summary level, cost item level and unit price level [1]. Project summary level summarizes various cost categorizes; cost item level subdivides each category into smaller cost items; and unit price level calculates the cost required to complete a unit of work for a cost item (the cost item level and unit price level are respectively referred to as work item level and cost breakdown level in the herein study). Therefore, to accurately estimate construction project costs, cost estimators should have practical experience and knowledge to determine the cost of every work item by performing cost analysis in which the cost breakdown items (i.e., sub-work items and resource items) of a work item are specified and their costs (unit prices) are determined. The overall project cost can then be calculated by summing up the work item costs.

Cost analysis of construction work items is essential to a cost estimating process for contractors for two reasons. First, it specifies the necessary sub-work items and resource items and their respective costs. Second, cost analysis generates cost analysis sheets for major work items that usually become a part of a contract; therefore, work item costs presented in these sheets become the basis for the application for payment of a contractor and for determining the cost of newly added work items during the construction stage.

Although commercial cost estimating software is available, they mainly support cost estimation on work item level instead of cost breakdown level. In practice, cost estimators usually use spreadsheet software to perform cost breakdown because using spreadsheets makes performing cost breakdown more flexible especially when the cost items of a construction project are plentiful and diverse. However, the major drawback of using spreadsheet is that estimators' cost analysis knowledge is not well-organized and hence cannot be easily reutilized in future cost analysis tasks.

In recent years, Taiwan has encountered difficulties in establishing an accurate estimation of construction costs, further causing disputes. One of the reasons for such a problem is that cost analysis for work items is not effectively implemented. According to practitioners and professionals in the construction industry, three causes hindering the effective implementation of cost analysis were identified. First, time frame for a construction project is tight. Limited time is allotted to the planning, design and bid preparation phase; as a result, cost estimation tends to be inaccurate. Second, cost analysis generally relies on cost estimators' practical experience and knowledge of various disciplines; however, there is a lack of such competent personnel. Finally, cost analysis knowledge of experienced cost estimators is not structurally organized and stored. The inability to resolve these limitations makes it nearly impossible to fully exploit the knowledge of experienced cost estimators to initiate a new cost analysis task or conduct educational training on cost analysis for inexperienced estimators. Thereby, the herein proposed ontology-based representation framework aims to model and store cost analysis knowledge based on the work of contemporary cost estimators and historical cost analysis data. Moreover, in addition to facilitating the utilization of this stored knowledge in new cost analysis-related tasks or educational training, the proposed framework further aims to improve the accuracy of cost analysis and estimation by eliminating the possibility of leaving out necessary sub-work items or resource items of work items.

This paper is organized as follows. Section 2 reviews the essential literature of ontology and ontology language. Section 3 discusses the proposed representation framework and how to deploy the framework to establish a cost analysis knowledge base as a cost analysis ontology. Section 4 presents a case study that tests and validates the feasibility and application of the framework. The final section summarizes the findings of this study and future research directions.

2 Related work

2.1 Ontology and ontological modeling

Ontology was first defined by Bunge in 1977 as "the basic characteristics of the real world." [2] Ontology originated from the philosophy domain and was commonly defined as "an explicit and formal specification of a conceptualization" [3]. Noy and McGuinness [4] further pointed out that the goal of ontology is to share common understanding of the structure of information among people or software agents in order to enable the reuse of knowledge in a field. In short, Ontology is a normative model, which represents concepts of a knowledge domain and the relationship between the concepts. Ontological modelling, therefore, can be viewed as a systematic approach for modelling concepts and relationships into ontologies [5].

Ontological modeling is widely used in fields such as knowledge management and organization, semantic web, web commerce, database design, natural language processing, agent-based systems, and software engineering [6]. In the field of construction engineering and management, ontological modeling has progressively been applied to different research areas, such as construction safety knowledge representation, reasoning and retrieval [5] [7] [8].

The basic elements of ontology include classes, attributes, relationships, and instances, each of which is introduced as follows [4]:

1. Class: A class is a category representing an entity of a certain domain, using one word or a combination of words to allow users or computer systems to understand the meaning of the category. A class can be subdivided into many subclasses with more detailed descriptions. For example, a class "Concrete Worker" can be defined as a subclass of the class "Concrete Labor."
2. Attribute: Attributes are descriptions of the characteristics and features of each class in an ontology. Ontological information framework can be built and useful data can be provided through attribute definitions. For instance, an attribute "unit price" can be defined for the cost breakdown class "Concrete Worker," representing the daily wage of a concrete worker.
3. Relationship: Relationships are semantic connections between classes, including association, generalization, equivalence and disjointedness. In the present study, relationships are defined to connect work item classes to their cost breakdown item classes. For instance, the work item *concrete* has sub-work items, such as *concrete curing*, and multiple resource items, such as *concrete labor*, *140kgf/cm^2 Type I concrete*, and *concrete pumps*. Association relationships exist between the work item *concrete* and its sub-work item and resource items.
4. Instance: Instances are implementation of classes, similar to objects in object-oriented modeling. Therefore, an instance resulting from a class has specific values for all the attributes of the class. For example, the instance of a concrete labor class shall have a unit price of US$60. In other words, instances are implemented to more clearly express a class.

2.2 Ontology Language

An ontology requires a standard language to express domain knowledge. Therefore, different ontology languages were developed and used to create ontological models so that a computer system can understand a model by interpreting the ontology language for the model. Many ontology languages have been developed in recent years. These ontology languages began with Extensible Markup Language (XML) syntax as the basis for ontology development (Figure 1). Other important ontology languages include RDF (Resource Description Framework) and RDFS (RDF Schema), DAML+OIL (Darpa Agent Markup Language + Ontology Interchange Language) and OWL (Web Ontology Language). Among these languages OWL has stronger reasoning capabilities over others and is the most popular one in recent years for developing ontologies. Therefore, this study adopts OWL as the ontology language for establishing cost analysis knowledge base.

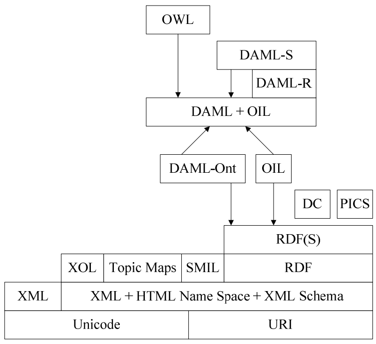

Figure 1. Ontology Language Stack [9]

3 Cost analysis ontology establishment

In this study, the representation framework is designed for the main structural work items of building construction (i.e., reinforce bar, formwork, and concrete). Figure 2 provides an overview of the representation framework. The representation framework provides a structure of an ontological knowledge base for storing cost estimators' cost analysis knowledge and historical cost analysis data. Figure 2 also shows a knowledge base, which simply signifies archived historical data from actual project cases and knowledge of cost estimators. The following sections explain the framework and knowledge base respectively with examples.

3.1 Representation Framework

The purpose of the representation framework is to provide a structure for storing cost analysis knowledge and historical data as a cost analysis ontology. That is, the cost analysis information of past projects can be properly classified and stored through the representation framework. To achieve this purpose, three aspects should be considered in the framework: classification of work items and cost breakdown items, associations between these items, and attributes of cost breakdown items.

In this study, the representation framework consists of two major classes: "Bill of Quantity Items" and "Cost Breakdown Items" (as shown in Figure 2).

1. The class "Bill of Quantity Items" collects the main structural work items and categorizes them into three subclasses: "Steel", "Form" and "Concrete". For example, a work item *140kgf/cm^2 concrete using type I Portland cement* is represented as a class "Structural Concrete Ready Mixed 140kgf/cm^2 Type I Cement" in the representation framework, and this new class is defined as a subclass of the class "Steel". Furthermore, two new classes "Common Forms" and "Natural Forms" are defined as subclasses of the class "Form" in the representation framework to respectively represent two work items, *common forms* and *natural forms*.
2. The class "Cost Breakdown Items" collects cost breakdown items of bill of quantity items and categorizes these breakdown items into two subclasses: "Sub-Work Items" and "Resource Items". The class "Sub-Work Items" represents the work performed in a work item whereas the class "Resource Items" indicates the resources used in a work item. Four classes, "Labor," "Equipment," "Material," and "Miscellaneous Work" are defined as subclasses of the class "Resource Items" to respectively represent labors, equipment, materials and miscellaneous items used in a work item. In addition, each of these classes is then specialized by defining its three new subclasses that can further specify a resource item for steel, form or concrete work. For instance, a class "Concrete Labor" is defined to represent labor resources for concrete work while "Form Labor" is defined to represent material resources for formwork. Both classes are subclasses of the class "Labor."

All the defined classes under the major class "Cost Breakdown Items" form a classification that can represent cost analysis information of bill of quantity work items. For example, for the work item, *140kgf/cm^2 concrete using type I Portland cement*, its cost breakdown includes a sub-work item, i.e., *concrete curing*, and resource items, i.e., *concrete operating worker* (labor), *concrete vibrator* (equipment), *140kgf/cm2 Type I concrete* (material) and *tool loss* (miscellaneous work). New classes representing these sub-work item and resource items then can be defined as classes in the representation framework. For instance, a class "Concrete Vibrator" is defined as a subclass of the class "Concrete Equipment" and represents the equipment used in the work item *140kgf/cm^2 concrete using type I Portland cement*.

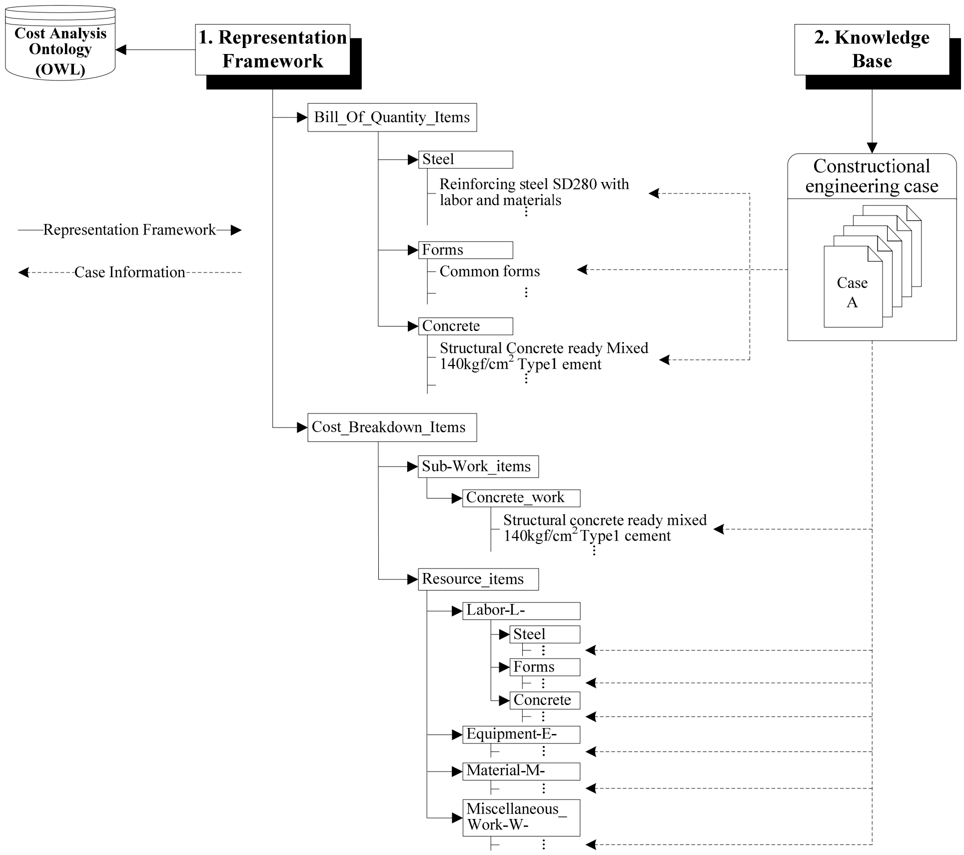

Figure 2. Overview of the proposed representation framework

In addition to the two major classes, five association relationships are also required in order to represent the connections between a bill of quantity work item and its cost breakdown items. Therefore, five association relationships, “hasSub-Work,” “hasLabor,” “hasEquipment,” “hasMaterial,” and “hasMiscellaneous,” are defined as object properties in the representation framework, which can be used to link a work item to its sub-work items and resource items.

Lastly, cost breakdown items own attribute information of unit, quantity, and unit price. Therefore, three attributes “unit,” “amount,” and “unit price” are defined as data type properties for the class “Cost Breakdown Items” in the representation framework to allow instances created from the class to take values on these attributes.

This representation framework provides a formal structure for categorizing concepts identified from actual project cases. Section 3.2 illustrates the steps of establishing a cost analysis knowledge base, i.e. cost analysis ontology, using the representation framework.

3.2 Knowledge base

This study collected cost analysis data from eight historical cases, seven of which were used to establish the knowledge base while the other case was used to test and validate the proposed framework. The work item *concrete ready mixed 140kgf/cm^2 type I cement* is used as an illustrative item (referred to as Case 1 in this study) to demonstrate the steps of establishing a cost analysis knowledge base. This study uses Protégé, an ontology editor developed by Stanford University [10], to establish the knowledge base.

1. <u>Create classes and instances for work items and their cost breakdown items</u>: Classes are first created in the representation framework for work items and their cost breakdown items. For example, a class “Concrete Ready Mixed 140kgf/cm^2 Type I Cement” is defined for the illustrative work item in Case 1 (Figure 3). Then, instances are created from the classes, and actual attribute values are assigned to the instances. For example, an instance “Concrete operating worker-Case1” is created from the class “Concrete Operating Workers” to represent that a labor item *concrete operating worker* is included in the work item *concrete ready mixed 140kgf/cm^2 type I cement* in Case 1. Furthermore, this instance have actual attribute values as follows: “labor” for the unit attribute,

"0.02" for the amount attribute, and "NT$2,500 (2,500 New Taiwan Dollars)" for the unit price attribute (Figure 3).

2. Connect classes with association relationships: Each of the bill of quantity items is connected to its cost breakdown items using the five association relationships. For example, the bill of quantity item class "Concrete Ready Mixed 140kgf/cm^2 Type I Cement" is connected to two equipment item classes "Concrete Vibrator" and "Concrete Handling Equipment" with the association relationship "hasEquipment" (Figure 4). The purpose of this step is to represent the semantic relations between bill of quantity items and their corresponding cost breakdown items; then, the instances of cost breakdown items of past cases can be retrieved by specifying the bill of quantity item which is of interest to cost estimators.

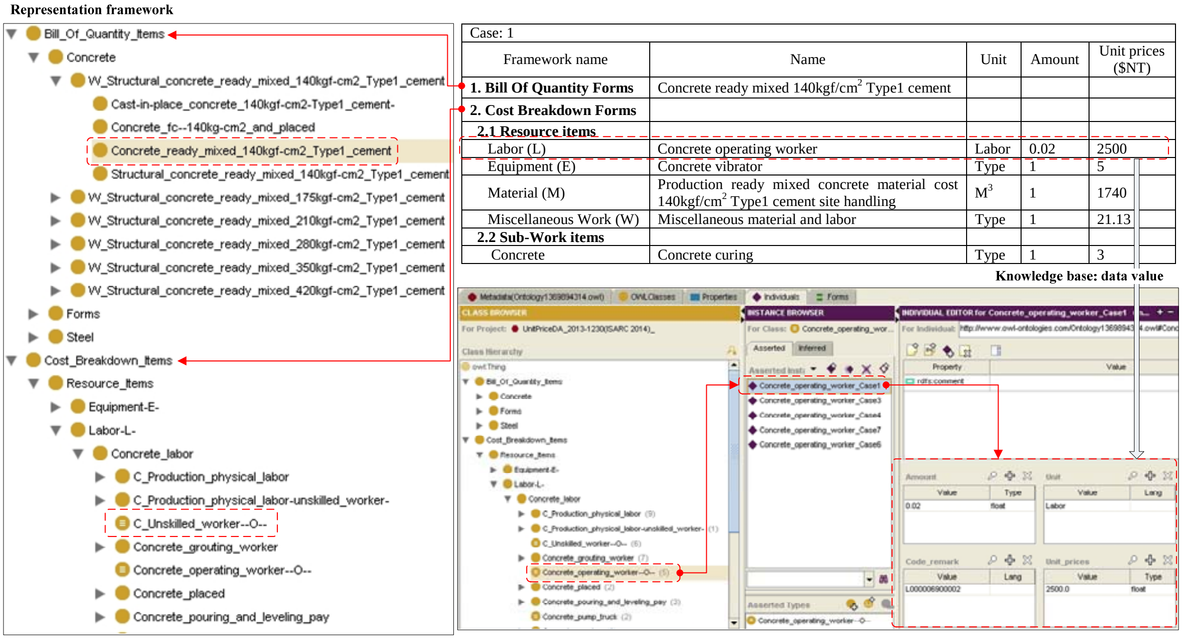

Figure 3. Create classes and individuals for Case 1

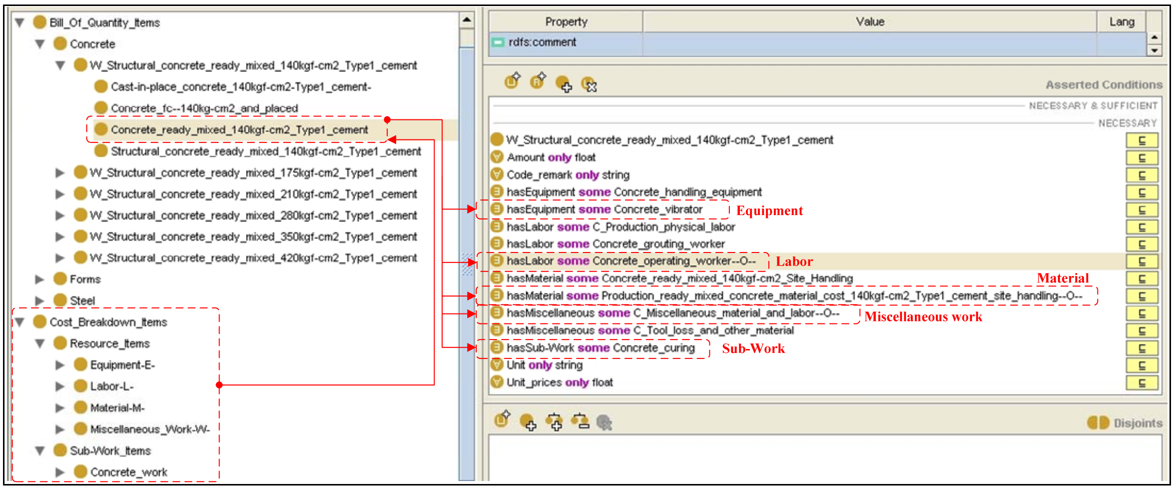

Figure 4. Connect classes with association relationships

3. Define equivalent classes: Classes which have the same semantic meaning are set equivalent (Figure 5). For example, two labor item classes "Production Physical Labor" and "Unskilled Worker" are used interchangeably in cost analysis process and therefore are defined equivalent to each other. Through the definition of equivalent

classes, cost breakdown items which have the same semantics can be formally represented and therefore, cost estimators will not ignore those cost breakdown items with the same meaning but in different texts when performing cost estimation.

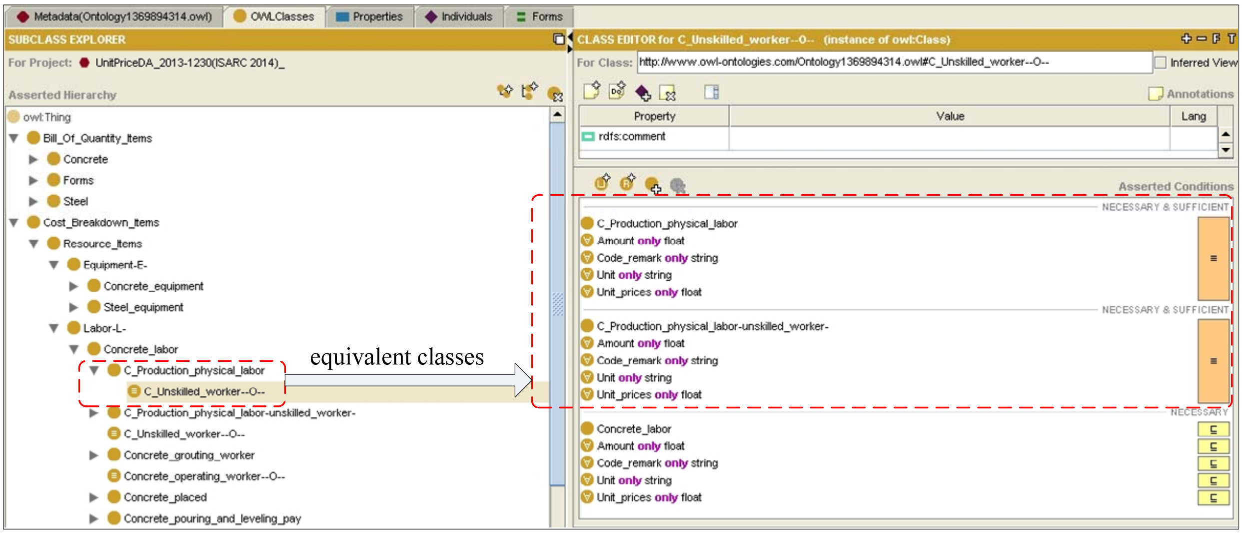

Figure 5. Define equivalent classes

4 Case Study

This case study illustrates the use of an established cost analysis knowledge base, i.e. cost analysis ontology, and also validates the capability of the proposed representation framework. A work item class "Common Forms" is taken as an example to demonstrate how to use the knowledge base to perform a cost analysis task for the work item. Figure 6 shows the contextual scheme of the case study.

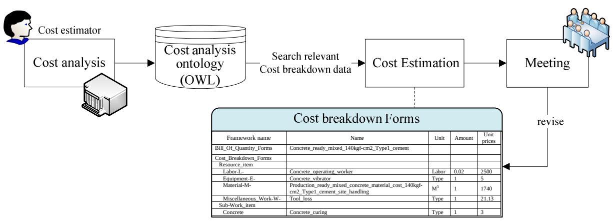

Figure 6. Scheme for performing a cost analysis with a cost analysis ontology

1. Start cost analysis: A cost estimator initiates a cost analysis and first decides to analyze the work item *common forms*.
2. Navigate the cost analysis ontology: The cost estimator can identify the class "Common Forms" for the work item *common forms* from the "Bill of Quantity Items" class hierarchy in the cost analysis ontology. The ontology displays those sub-work items and resource items used in the past projects as shown in Figure 7, allowing the ontology user to examine and evaluate the cost of those work items. For example, cost estimators can identify *carpenters* and *unskilled workers* as two labor items of the work item *common forms* because the cost analysis ontology shows that the classes "Carpenter" and "Unskilled Workers" are connected to the class "Common Forms".
3. Estimate a work item cost: Cost estimators then assess what cost breakdown items, i.e., sub-work items and resource items, should be selected for the work item. In addition, the historical cost data of all the instances for the selected cost breakdown items can be examined; estimators can refer to and use these cost (unit price) information in the new cost analysis. For instance, two instances are found for the resource item class "Carpenter", i.e., "Carpenter case6" and "Carpenter case8" (Figure 8). If estimators adopt the cost information for carpenters of the Case 8, the unit price for carpenters in this cost analysis is NT$2,400.
4. Meeting: After estimators use cost analysis ontology to perform cost estimation, they can list out the cost breakdown items and complete the cost breakdown form, as shown in Table 1, which includes all the cost breakdown items identified from the cost analysis ontology and their unit prices retrieved from the ontology. This can be used as a reference during the cost assessment meetings for project team members to evaluate

whether any cost breakdown item is missed or unit prices for these items are reasonable.

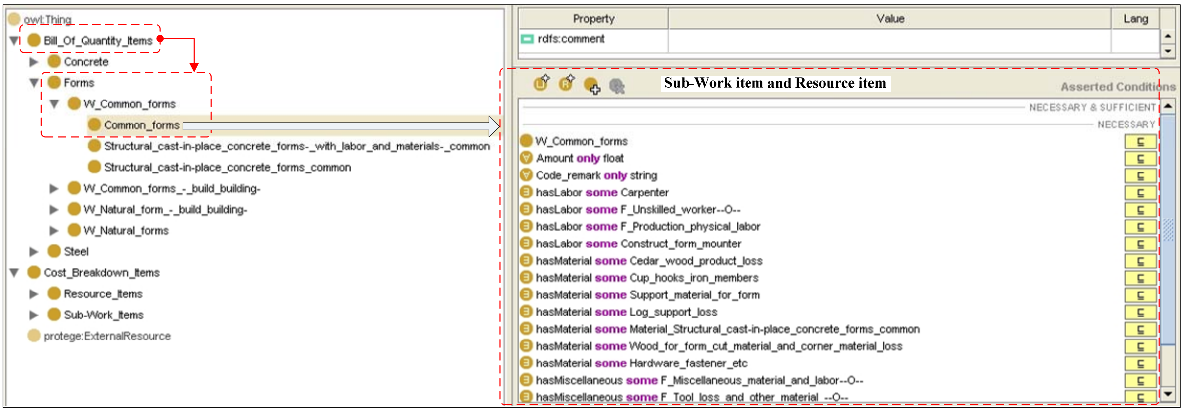

Figure 7. Identify cost breakdown items for the work item

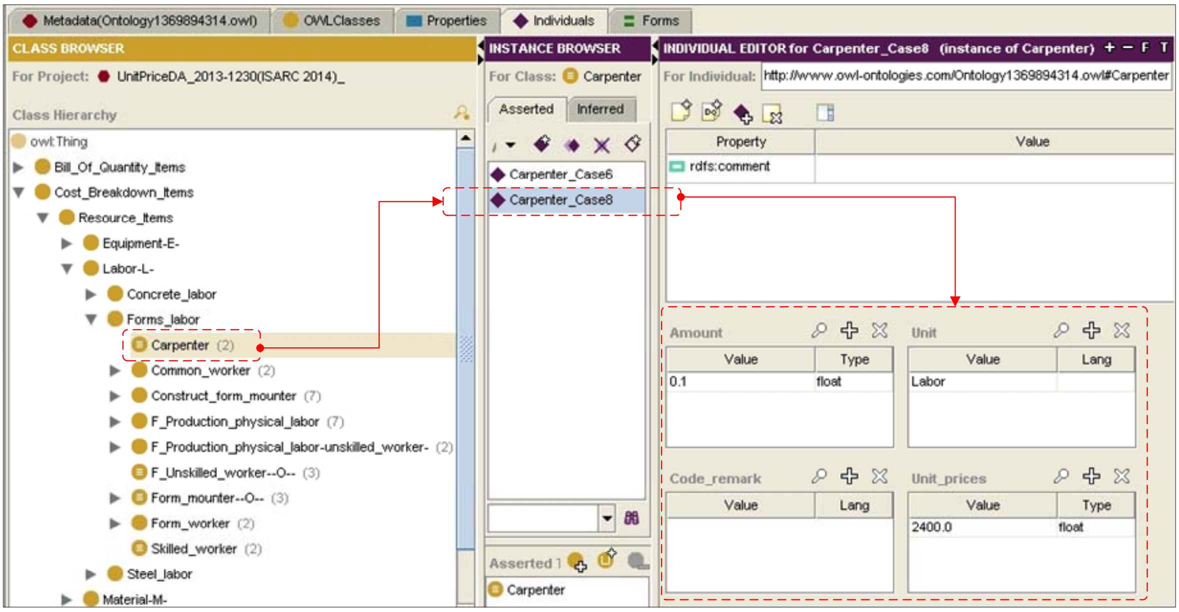

Figure 8. Retrieve the unit price of the instances of a cost breakdown item for the work item

Table 1. Cost breakdown form for estimating the work item cost

Work items：Common forms			Unit：M^2	
Cost Breakdown Items	Unit	Amount	Unit prices	Item cost
Sheet materials loss for form	M^2	1.000	56.34	56.34
Cut material loss for form (contain support)	M^2	1.000	52.82	52.82
Cup hooks iron members	M^2	1.000	17.61	17.61
Carpenter	Labor	0.100	2,400.00	240.00
Miscellaneous material and labor	Lump Sum	1.000	14.09	14.09
Total (New Taiwan Dollars)	M^2	1.000	380.86	380.86

5 Conclusion

This study proposes an ontology-based representation framework for establishing cost analysis knowledge base for work items. This ontology-based framework can store cost analysis experiences and knowledge of cost estimators from previous cases. It can also store historical cost analysis information of main structural work items. Additionally, this study utilizes the characteristics of an ontology, such as establishing association relationships between classes and defining equivalent classes, to establish the framework for cost analysis. The study result show that cost estimators can identify the cost breakdown items of a work item and retrieve their unit prices when performing cost analysis through the representation framework and steps demonstrated in this study to establish a cost analysis ontology.

The proposed representation framework and the steps of developing a cost analysis knowledge base is part of an ongoing research, which aims to integrate an ontology-based cost analysis knowledge base and building information modeling to assist in selecting construction methods. This study still has some limitations to be improved in the future research. First, this study only considers cost analysis components for structural construction in the framework. The framework should be expanded to consider other work item types, such as temporary work and demolition and decoration constructions, to establish a comprehensive cost analysis ontology. Second, the herein proposed framework does not support automated identification of and reasoning about cost breakdown items. Such goals can be achieved by developing an automated reasoning mechanism in future research using ontology reasoning languages, such as SWRL (Semantic Web Rule Language) or programming language, such as Java. The reasoning mechanism shall be able to facilitate cost analysis process and therefore shorten the time for estimating construction project costs.

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