Employing Ontology and BIM to Facilitate the Information for Subcontractor's Payment Requests and Ledger Generation

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Abstract –

General contractors usually need to handle subcontractor's payment requests periodically according to the progress of the construction project. The documents required for payment requests are related to various types of information generated from construction work items. Consequently, construction company needs to spend a lot of efforts to verify and approve the submitted documents in order to record accounts on the ledger.

Building Information Modeling (BIM) has been used to derive the information for various operations within the construction project. One of the important functions provided by BIM is quantity takeoff. With this capability, BIM can serve as an information platform to provide the information regarding various aggregated amounts of work required to be performed by subcontractors. However, detail information required to process payment requests is still hard to be obtained from the BIM model if no proper development specifications have been established.

This study employs ontology and BIM to facilitate the information required to process payment requests and ledger. First, various work items performed by subcontractors are analyzed to identify the information required to process payment requests. Then the relationships between work items and BIM elements are determined through the ontology developed according to the required information identified. Next, a variety of Dynamo modules are applied to develop the BIM model that can provide various types of measurements required by work items. Finally, a database that can help construction managers to facilitate information for payment requests and ledger is developed for future uses.

Keywords –

BIM; Ontology; Dynamo; Payment Request; Ledger Generation;

1 Introduction

There are two parts of construction company's ledger: (1) The payment requests to the owner (in cash flow). (2) The payment requests from subcontractors (out cash flow).

The payment requests from the construction company to the owner are based on the quantity of work items and the unit price of the budget, such as concrete grouting. The payment requests from the subcontractors to construction company are based on the unit price in the contract and the actual amount of work items applied on site, such as concrete pumping and concrete grouting.

The ledger records payments received from the owner and payments to the subcontractors, but the work items are based on the different basis. The payment to the subcontractors is based on the subcontracting type, such as labor only, material only, labor with material, and lump-sum. As a result, the work items are different between payment requests to the owner and payment requests from subcontractors. For example, the payment-request work item concrete grouting to the owner, after subcontracting, it will be divided into concrete pumping, concrete grouting, concrete material, etc., different work items for payment requests from subcontractors. The required information for subcontractor's payment requests has to consider the subcontracting type.

In order to obtain the actual amount of work items, such as applying area and working hours, as the basis of subcontractor's payment requests, engineers have to analyze the different subcontracting types and the measurement of actual progress identification according to their experiences.

In the construction industry, Building Information Modeling (BIM) has been used to produce specific information for various purposes, including cost estimation, visualization, quantity takeoff, etc.

However, all the required information of payment requests still hard to obtain from the BIM model if there are no proper development specifications. For example, the Level of Development (LOD) specification [1] developed by Association of General Contractor's (AGC) BIMForum group is a detail interpretation of LOD schema developed by American Institute of Architects (AIA) [2]. The LOD specification defines the model element's characteristics at different LOD, the categorization of model elements follow the CSI Uniformat 2010 [3].

For the waterproof work of the interior wall, the related LOD specification is the C2010 Wall Finishes, as shown in Table 1. The required information of the waterproof work item is the applying area of waterproof. However, there is no specification about building the waterproof. Even the model is built according to the highest LOD specification, the required information for payment requests can't be obtained. As a result, the proper development specification should be established.

Table 1. C2010 Wall Finishes LOD specification

LOD	Specification
100	Non-graphic information attached to model elements providing assumptions about proposed finish materials.
200	Generic materials other than sheet goods and coatings by type (e.g. tile or panelling), approximate thickness and scope in elevation.
300	Materials are modeled based on specific types (e.g. Tile typeCT-1). Thickness and scope of finishes other than sheet goods and are accurately modeled. Sheet goods and coatings may be specified in Part II related to interior partitions.
350	Additional non-graphic information to include: 1.Manufacturer 2.Model
400	1.Pattern layouts 2.Expansion/control joints 3.Edges

This study uses ontology and BIM to obtain the required information of payment requests and ledger. First, the work items performed by subcontractors are categorized, according to the subcontracting type and the characteristics of payment requests. The information required to process payment requests is identified through the interview. Then the ontology model and the semantic web rule language (SWRL) are built to clarify the relationship between work items and BIM elements, and is used to identify required information which is provided by BIM element's attributes. Next, the modeling rules for the elements are determined by LOD specification and the extra specification. In order to obtain the required information for payment requests, the Dynamo modules are developed according to the modeling rules developed to help build the BIM model. Therefore, various types of measurements required by work items can be intercepted from the model.

The rest of this research is organized as follows. Section 2 reviews the literature of ontology and the BIM and ontology related work. Section 3 proposes the framework of this research including: establish the payment request ontology and develop BIM modeling rules for obtaining the required information of payment request. Section 4 concludes and summarizes this study.

2 Literature Review

2.1 Ontology

Ontology is widely used in the information field. The definition of Ontology is "an explicit specification of a conceptualization" [4]. Ontology uses the text to conceptualize and standardize of knowledge and help the dissemination and sharing of knowledge so that the knowledge can be shared in different media. By defining the concept and the relevance of data, the computer can infer the information from different sources. Using classes, attributes and relationships describe the meaning of information, constraint and consistency. Ontology is mainly used to explicitly define a Domain (Classes, also known as concepts), the description of features and attributes between domains is known as Attribute, Relation, and Instance. [5]

The concepts of specific knowledge can be described by the class. Class consists of subclass, which is the detail classification of the knowledge. In order to describe the characteristics of the knowledge, the attribute is used to provide various information of the class and subclass. The relationship between class and attribute are performed by the relation. The relation connects the concept and the information of knowledge. The instance is the example of the class in reality. The characteristics can be shown by concrete example. For example, finishes work can be divided into plaster work, tiling work, etc. , the plaster and tiling work are subclasses of finished work. For plaster, the proportion of plaster is an attribute of plaster work. 1:3 Portland cement is an instance of plaster work, showing the characteristics of the plaster work in reality.

2.2 BIM and Ontology Related Work

The quantity takeoff of BIM is widely used in the construction industry. Quantity takeoff is one of the advantages provided by BIM for the cost estimation in the construction project. The many-to-many relationships between work items and BIM elements have to be considered when using BIM to calculate the quantity of work items. A work item may correspond to many elements. For example, the concrete grouting may be related to many elements, such as concrete columns, beams, walls. An element also may correspond to many work items. For example, the RC column may be related to many work items, such as steel reinforcement works, form works, and concrete works. It is necessary to clarify the many-to-many relationships between work items and elements, in order to facilitate the accurate calculation of work item's quantity.

Lee et al. [6] proposed a BIM-based project cost management model for bridge construction. First, the analysis of bridge BIM elements and the construction method of the bridge are done. Then identify the BIM elements and the related work items. The relationship between BIM elements and work items are defined and stored in the database of bridge element. Finally, the element quantity obtains from BIM combine with the database that records the related cost work items of bridge elements to generate the budget.

Niknam et al. [7] integrated the BIM model, work items, and material cost data, then presented in ontology for cost estimating. The relationships between BIM elements (classify by Uniformat II) and the work items (classify by MasterFormat [8]) are identified. Also, the relationships between work items and the related resource (material, equipment, and crew) are identified. The related work items of the element and the needed resource for the work items are inferred through ontology. Then the resource's unit price is considered for cost estimating, in order to reduce the human involvement and errors.

Chien et al. [9] proposed an ontology-based framework to develop intelligent BIM object for cost analysis. By integrating the semantic information of cost work items and the relationship between work items and BIM elements, the ontology model is developed. The construction process and the related cost work items are inferred according to BIM elements, in order to improve the efficiency of the current cost estimation process.

Lee et al. [10] combined BIM with ontology for building cost estimation. The ontology is used to infer the suitable work item, through identifying the work item's condition that is provided by BIM model. For the tiling work, work item conditions (e.g. Room usage, base type) are extracted from BIM model, then the work item information (e.g. Tilling method, Tilling material type) are inferred to obtain the accurate and consistent result of selecting work items.

2.3 Summary

According to those studies, current studies mainly use the BIM as a quantity takeoff tool for cost estimation. Some of the research used ontology to infer the related work items of BIM elements by clarifying the relationship between work items and elements, then combined the quantity of BIM elements and work items to estimate the cost. There are less concerns dealing with the relationship among the payment requests, general contractors, and subcontractors. The general contractors are still unable to obtain the required quantity information for subcontractor's payment requests from the BIM model.

3 The Framework and Result

The framework of this study is shown in Figure 1. First, the payment-request work items related to the ledger are identified according to the relationship among general contractors, the owner, and subcontractors. Then by analyzing the work items, including the basic information and the payment-request information, the relationship between BIM elements and work items are determined as well. The ontology model is further established to express the payment-request work item information and the relationship with BIM elements. Consequently, the required information that can be provided by BIM model are inferred through the ontology model. Finally, the modeling rules are established on the basis of the LOD Specification and the additional specification for developing the BIM model that can provide the required information for the payment requests.

3.1 Payment-Request Information Analysis

In order to build the ontology model, it is necessary to analyze the demands and information for constructing ontology. There are two parts of analyzing the information: (1) The basic information and payment-request information of work items. (2) The relationship analysis between work items and BIM elements. Through these two steps, the required information of payment requests that can be provided by BIM elements are identified. That information can be the basis of building the ontology model and SWRL.

3.1.1 Payment-Request Information of Work Items

The basis and the payment-request information about work items can be obtained from interviewing. First, we categorize the work items through payment-request frequency, base type, and base unit, as shown in Table 2. The payment-request frequency is usually based on time. From our interview case, the frequency is once or twice a month. There are two payment-request base types: Base on Quantity and Base on Spaces. Base on Quantity is that payment requests are based on the material or the element's quantity. For example, the work item quantity of concrete grouting (labor) is determined by the concrete material quantity.

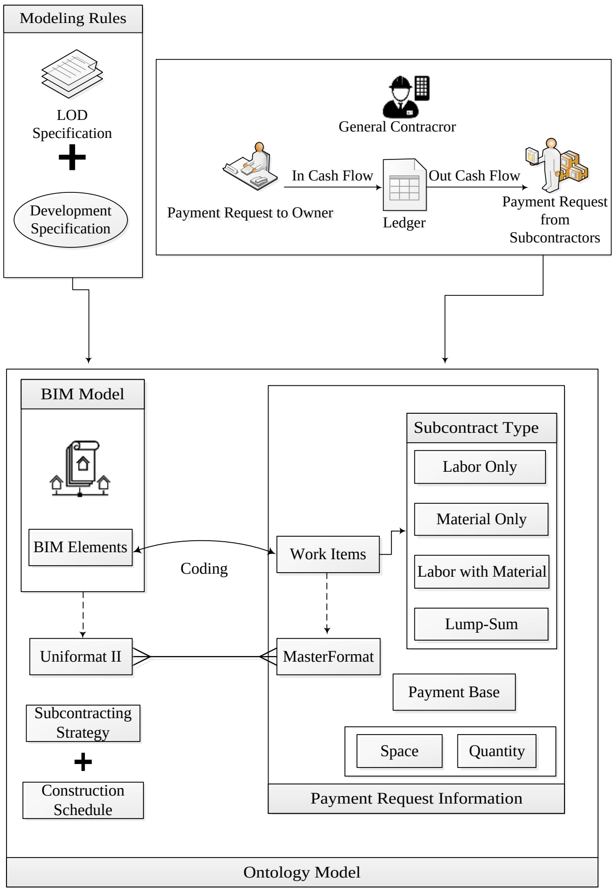

Figure 1. The framework of this study

Base on Spaces is that payment requests are associated with spaces, for example, the quantity of Tiling work (one type of Masonry work) is based on the space area (e.g., living room, bathroom). Table 3 is the further analysis of each work item, including payment-request base, subcontracting type and required information of payment requests. For example, when the Wall Plaster (Interior) is finished, the third party measurement measure the applying area of plaster as the base of payment requests for subcontractors.

3.1.2 Relationship between Work Items and BIM Elements

The relationships between work items and BIM elements are determined to identify the required information of payment requests that can be provided by BIM. There are three types of relationship between work items and BIM elements, including:

Table 2. Work items category

Request Frequency	Request Base Type	Request Base unit	Work Item	Subcontracting Type
Twice a month	Base on Quantity	Floors	Concrete	Labor Only
				Material Only
		Floors /Spaces	Form	Labor with Material
	Base on Spaces	Floors /Spaces	Masonry	Labor Only
				Material Only
Once a month	Base on Quantity	Floors	Silicone	Labor with Material
	Base on Spaces	Floors /Spaces	Waterproof	Labor with Material

Table 3. Further analysis of work item

Work Items	Masonry		
	Building Brick	Wall Plaster (Interior)	Wall Plaster (Exterior)
Subcontracting Type	Labor Only	Labor Only	Labor Only
Base	Third Party Measurement	Third Party Measurement	According to Drawing
Required Information	Applying Area	Applying Area	Applying Area

(1) Direct related: BIM elements directly provide the required quantity information. The required quantity can be obtained directly from the sum of BIM element's attributes, for instance, the concrete material volume of main structure can be directly obtained from the sum of the concrete columns, beams, walls and slabs volume in the BIM model. (2) Indirect related: BIM elements indirectly provide the required quantity information. The required quantity shall be indirectly obtained from BIM element's attributes with calculation or adjustment. For instance, the waterproof of window frame can be calculated from window circumference. The waterproof length is obtained from the sum of window element's length and width. (3) Non-related: The required quantity can't or doesn't need to be obtained from the BIM model, for instance, the tile sealant material use the invoice, which information don't need to be obtained from BIM elements, as the base for payment requests.

3.1.3 Identify the Required BIM Elements Data of Payment-Request Work Items

The required information about payment-request work items that can be obtained from the BIM model is identified. The information is identified by the relationship analysis of work items and BIM elements.

The payment-request work items are encoded in MasterFormat, then correspond to the Uniformat II according to the corresponding association table proposed by Charette [11]. The table is used to check if the corresponded BIM elements can provide the required information or not. If the required information can't be provided by the corresponded BIM elements, the elements have to be marked. For example, the MasterFormat coding of Wall Plaster (Interior) is 09220, which belongs to the division 09 Finishes. The corresponding Uniformat II is B2010 Exterior Walls and C30 Interior Finishes. After analyzing the required information of Wall Plaster, the required element data are wall plaster area and the column inside plaster area, whose Uniformat II code are C30 10 120 Wall Finishes-Coatings and C30 10 300 Column Finishes.

3.1.4 Encoding the Payment-Request Information

OmniClass Construction Classification System (known as OmniClass or OCCS) is used to encode the work items, elements, and location, as a unified code. OmniClass is a classification structure developed by the OCCS Development Committee for the construction industry. OmniClass integrated the MasterFormat, Uniformat II, and other extant systems currently in use. The classification of OmniClass is suitable for the BIM elements [12]. OmniClass consists of 15 hierarchical tables, including Spaces, Material, Work Result, Elements, etc. Most of the required information of payment requests is included in the OmniClass, as a result, the OmniClass is selected for encoding the payment-request information, such as Payment-Request Work Items Code, Model Elements Code, and the Space Code.

3.1.5 Organizing the Payment-Request Information

The payment-request information is collected as Table 4, including the basic information of work items, the payment-request information of work items, the relationship between work items and BIM elements, the required BIM data of payment requests and the OmniClass code. The form is convenient for querying the payment-request information through coding.

Table 4. Payment-Request Information (part)

Work Item	Portland Cement Plaster		Cement
Payment-Request Code	22-09 24 00 (Cement Plastering)		41-30 10 25 19 15 (Cement)
Space Code	13-15 13 00 (Interior Wall)	13-15 11 00 (Exterior Wall)	--
Subcontracting Type	Labor Only	Labor Only	Material Only
Required Information	Applying Area		Material Quantity
Base	Third Party Measurement		Invoice
Correlation with BIM	Direct Related	Direct Related	Non-Related
BIM Elements Data	The Wall Material Area	The Wall Material Area	--
Related Data	21-03 20 10 70 Wall Area	21-03 20 10 70 Wall Area	--
	21-03 20 10 71 Column (Inside)	21-03 20 10 72 Column (Outside)	--
Note	--	--	--

3.2 Payment-Request Ontology Model

The Ontology model is built to present the domain knowledge of payment-request information and BIM elements. The SWRL assists the engineers to infer the required information of payment requests. The development of the ontology model follows the following steps.

3.2.1 Building the Ontology Framework

The ontology framework is built on the basis of the analysis of the payment-request information, including classes, object properties, and data properties. The information can be categorized into four domain knowledge base according to the analysis of payment-request information and BIM elements: (1) Payment-Request Information Knowledge Base: including work items' basic information and the payment-request information. (2) BIM Knowledge Base: including model elements' classification and elements' data. (3) Construction Process: the further analysis of the budget work items, including the job steps and the used resources. (4) Budget Information: including budget work item's information. The framework is shown in Figure 2.

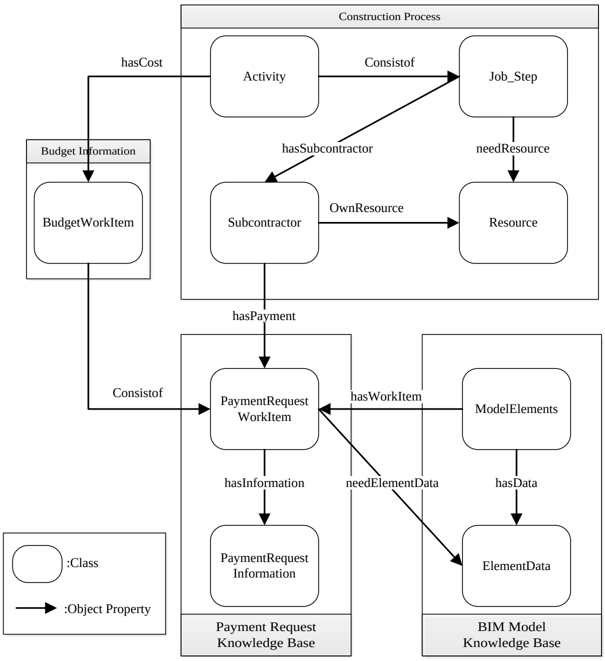

Figure 2. The framework of ontology

3.2.2 Introduction of the Ontology Framework

The concept of the ontology model is introduced in this section. The two domain knowledge bases are defined through the analysis of the payment-request information and BIM model. The Construction Process and the Budget Information are defined through the analysis of budget sheets, construction methods, and construction sequences.

In the Payment-Request Information Knowledge Base, the PaymentRequestWorkItem contains the work item's basic information, including four sub-classes: MaterialOnly, LaborOnly, LaborWithMaterial and Lump- sum, which are categorized by subcontracting type. The work items are built into each sub-classes according to subcontracting type. The location of work items and the payment-request code are described by data properties. PaymentRequestInformation consists of the payment-requests information, such as frequency, base, and base unit. The concept of Payment-Request Information Knowledge Base shows in Figure 3.

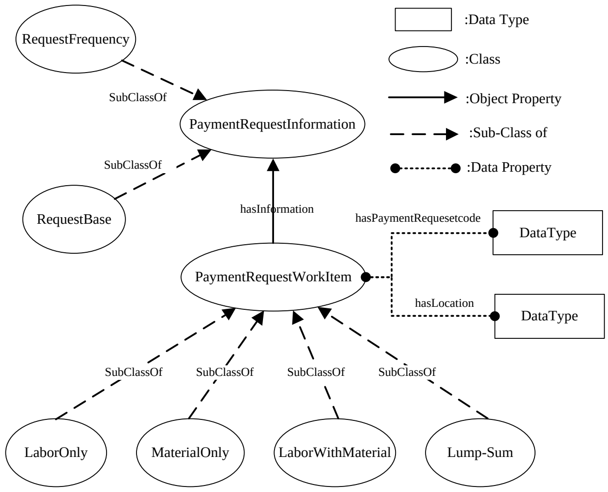

Figure 3. Payment Request Information Knowledge Base

In the BIM Model Knowledge Base, the ModelElements is the classification of BIM model elements, including the sub-classes: StructureSystem, Finishes, DoorsandWindows, HandrailAndRailings and Ceiling. The model elements are built into the sub-classes according to the classification. The properties such as location, object code, and object floor are described by data properties. The ElementData is the geometric attribute of BIM model elements, including Area, Length, Volume, etc. The concept of the BIM Model Knowledge Base shows in Figure 4.

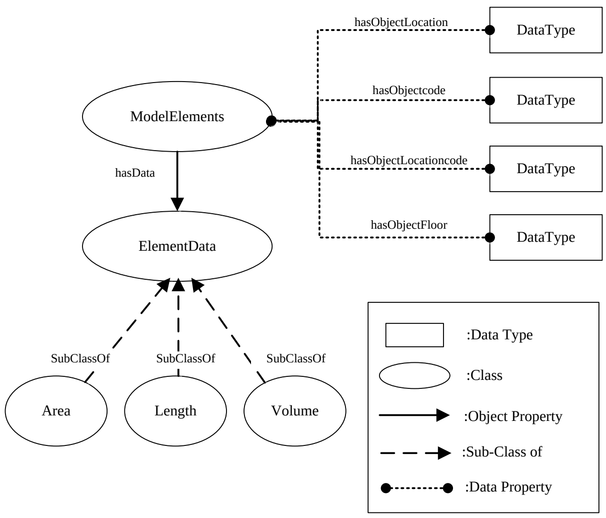

Figure 4. BIM Model Knowledge Base

In the Budget Information, the budget work item's information can be obtained from budget sheets, such as PCCES code. Budget work items represent the in cash flow of the construction company's ledger.

The Construction Process includes the Activity and Job_Step. The Activity is the task to describe budget work items. The Activity consists of different job steps, which are built in the Job_Step. Each job step has different subcontractors and the resources needed that are provided by subcontractors.

For example, the instance “Bathroom Finishes” in Activity is related to the “Bathroom Wall Ceramic Tiling 15*60” in BudgetWorkItem. This activity consists of two instances of Job_Step: ”1:2 Cement Plastering” and “Ceramic Tiling 15*60”. “Masonry Worker” in the Resource is one of the needed resources that is owned by the “Masonry subcontractor” in Subcontractor.

The payment-request work items of subcontractors represent the out cash flow of the construction company’s ledger. For example, the “Masonry subcontractor” has the payment-request work item ”1:2 Cement Plastering” and “Bathroom Wall Tiling”. The budget work item: “Bathroom Wall CeramicTiling 15*60” consists of those two payment-request work items.

Table 5 shows the example of the classes and the data properties. The PlasterWork is one of finish work and the subcontracting type is LaborOnly. It has the data property to describe the plaster proportion and the location. The wall finishes material is categorized as the WallFinishes, which has the data properties to describe the location and the code. The Area is one of element data, whose value is described by the data property: hasObjectArea.

3.2.3 SWRL Inference

The SWRL rules help to infer the required quantity information that can be obtained from BIM elements and the work item’s payment-request information. The knowledge bases provide the information of payment requests and the relationship between work items and BIM model elements. By SWRL rules, the required BIM element’s data (as the related data in Table 4.) and the related information for each work item can be inferred.

The SWRL rules are developed by following steps. First, according to the work item’s associated elements and the inference rule, the required element data are linked with work items through the object property: needElementData. After reasoning, the required quantity information that can be obtained from BIM model are shown in the ontology. Second, according to the work item’s associated elements and the work item's location, the request base of work items can be inferred. The example is shown in Table 6.

3.3 Model Development Specification for the Payment-Request Work Items Quantity Takeoff Model

In order to obtain the required information for payment requests from BIM model, the modeling specification has to be established.

Table 5. Example of classes and data properties

Class	Subclass			Data Property
BudgetWorkItem	B_FinishesWork	B_MasonryWork	--	hasPCCEScode
Activity	Finishes_Operation	--	--	Consistof
	_Tiling	--	--	hasCost
Job_Step	Finishes_Plastering	--	--	hasSubcontractor
		--	--	needResource
Resource	Labor	Masorny_Worker	--	--
Subcontractors	S_LaborOnly	--	--	OwnResource
		--	--	hasPayment
PaymentRequestWorkItem	P_LaborOnly	MasonryWork	PlasterWork	hasPlasterProprtion
				hasPaymentRequest _Code
				hasLocation
PaymentRequestInformation	RequestBase	--	--	--
ModelElements	Finishes	WallFinishes	--	hasData
			--	hasWorkitem
			--	hasLocationCode
			--	hasObjectCode
			--	hasObjectLocation
ElementData	Area	--	--	hasObjectArea

Table 6. Example of SWRL rules

SWRL Rules	Semantic
WallFinishes(?x) ^ hasWorkItem(?x, ?y) ^ PlasterWork(?y) ^ hasData(?x, ?y1) ^ Area(?y1) -> PlasterWork(?y) ^ needElementData(?y, ?y1) ^ Area(?y1)	When the model element: Wall Finishes has the Plaster work item, also has the element data: Area. Then the Plaster work links with the Wall Finished Area as the required data.
WallFinishes(?x) ^ hasWorkItem(?x, ?y) ^ PlasterWork(?y) ^ hasLocation(?y, "Exterior") -> PlasterWork(?y) ^ hasInformation(?y, AccordingToDrawing) ^ RequestBase(AccordingToDrawing)	When the model element: Wall Finishes has the Plaster work item, and the location of Plaster work is Exterior. Then the request base of Plaster work is according to drawing

3.3.1 Establish the Model Specification According to LOD Specification

According to the result of Ontology, the required BIM element's data for payment requests are identified. The related BIM elements correspond to the LOD specification by OmniClass. Then check if the BIM model built on the basis of the LOD specification can provide the quantity information or not. If not, the additional specification should be established.

3.3.2 Define the Space According to the Characteristics of Work Items

Space should be defined on the basis of the characteristics of work items in the model. Some work items repeatedly show in the same spaces at different zones or floors, as a result, the defined spaces can help to get the required quantity information for the work items whose request base type are Base on Spaces. The information of the space consist of space's name and code, for example, for the waterproof applies to the bathroom or the shower room's wall or floor, the bathroom and shower room should be defined in BIM model, in order to obtain the quantity information.

3.3.3 Develop the Dynamo Modules to Facilitate Model Development

The Dynamo modules are applied to develop the BIM model, in order to get the required information that is difficult or unable provided by BIM model of payment-request work items. For example, the height of the interior wall's waterproof may be different according to space. The payment request base unit of waterproof is Floors. In the BIM, the waterproof area is built by setting the wall material, which can't quickly obtain the applying area of each floor. Therefore, the Dynamo modules are developed to obtain the waterproof applying area by selecting floor, space and the setting of waterproof's height. First, the target floor, space, and the height of waterproof are selected according to user's demand. Then Dynamo calculates the perimeter of the selected space, and times the height to obtain the applying area. As shown in Figure 5. and Figure 6.

Figure 5. The waterproof of shower room (BIM model)

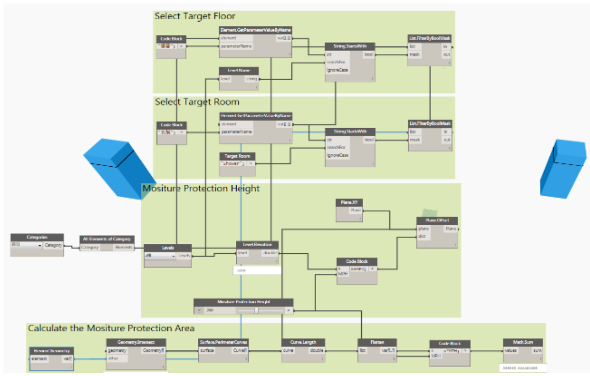

Figure 6. Calculation of applying area of Waterproof (Dynamo module)

3.3.4 Payment-Request Work Item's Quantity Information and Ledger Generation

The Microsoft Access is used to collect the payment-request work item's quantity and to generate the construction company's ledger. First, the relationship between work items and BIM elements (as shown in Table 4) are built into the database and combined with the BIM model that is established on the basis of the model development specification. The quantity of BIM elements from BIM model corresponds to the work items by OmniClass code. The required quantity information of payment-request work items can be obtained.

When the payments are requested by the subcontractor, the quantity of payment-request work items for each subcontractor can be obtained according to the payment-request base unit (Floors or Spaces). After the quantity combines with the unit price in the contract, the total amount of the payment requests can be obtained from the database. As shown in Figure 7.

When the ledger is generated by the construction company, the cost of the construction company is composed of the payments to the subcontractors. The ledger records the cost on the basis of the subcontracting type, including materials (Material Only), wages (Labor Only), and outsourcing (Labor With Material and Lump-Sum). The out cash flow of the construction company's ledger is the sum of each subcontracting type's payment that can be monthly produced from the database.

The income of the construction company is composed of the payments to the owner according to the budget work items. According to the analysis of ontology, the budget work items consist of the payment-request work items. The total amount of the payment-request work items in each budget work item is calculated by the database. The payment requests to the owner and the in cash flow of ledger for construction company are recorded on the basis of the amount of each budget work item.

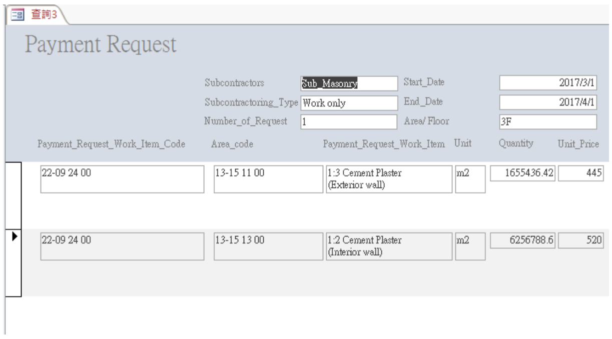

Figure 7. Total amount of payment-request work items

4 Conclusion

The required information of payment and the ledger can be obtained from the BIM model that is established on the basis of the modeling specification. The Dynamo modules are also developed to assist the model development. The work item's information and the payment-request information are analyzed. The relationship between BIM elements and the work items are expressed through the ontology model. The required quantity information and the related BIM model elements are inferred by SWRL rules. The model development specifications are established according to the LOD specification and the additional specification. The Dynamo modules are applied to develop payment-requests work item quantity takeoff model. The quantity information provided by BIM model can facilitate construction manager to obtain payment-request information and generate ledger.

5 Acknowledgment

The authors would like to thank Ministry of Science and Technology, R.O.C. program 105-2221-E-006-047-MY2.

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