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AN ONTOLOGY-DRIVEN BUILDING CONSTRUCTION LABOUR COST ESTIMATION IN CAMEROON

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EDITOR: Turk Ž.

F. H. Abanda
Research Assistant, Oxford Institute of Sustainable Development, Oxford Brookes University, UK
fhabanda@brookes.ac.uk

J.H.M. Tah
Professor, Oxford Institute of Sustainable Development, Oxford Brookes University, UK
jtah@brookes.ac.uk

C. Pettang
Professor, Ecole Nationale Supérieure Polytechnique, L'Université de Yaoundé I
cpettang@yahoo.fr

M. B. Manjia
Researcher, Ecole Nationale Supérieure Polytechnique, L'Université de Yaoundé I
mbmanza@yahoo.fr

SUMMARY: *Building construction is a very important development activity of any country. In addition to its basic role of providing shelter, the sub-sector contributes significantly to the Gross Domestic Product of both developing and developed countries, and plays an equally important role in the creation of employment. Unfortunately, the way building projects are managed in developing countries has often led to the under- or non-exploitation of the potential of these projects. Many factors, including inaccurate estimation techniques, poor and the challenge in predicting building construction labour cost, contribute to the poor management of building construction projects. Thus labour costing has become a key parameter for use in building construction projects. This article aims to investigate the use of an ontology-based technology in modelling information about labour costs in order to facilitate decision-making among building developers. This is achieved by pursuing two objectives. Firstly, a domain ontology that captures knowledge about labour costing practices in developing countries in general and Cameroon in particular is developed. Secondly, an ontology rule-based application is developed to facilitate decision-making and computation of labour cost in building construction projects. Three exemplary case scenarios are presented to illustrate how a construction decision-maker can intuitively query the labour cost ontology and navigate the results.*

KEYWORDS: *decision-making, building construction, ontology, labour cost*

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1. INTRODUCTION

The construction industry has been identified as one of the sectors key to sustainable development. However, the sector is at the same time hit with a multitude of problems. For instance, the completion rates and costs of most projects, particularly those executed in developing countries, often exceed their schedules and their costs are alarmingly above the bill of quantities figures (Ofori, 2007). Estimates by Assaf and Al-Hejji (2006) reveal that only 30% of projects in the developing world have been completed within schedule. Although the factors that cause these delays are many and may depend on the different contexts of individual countries, the most important and common ones are finance and payment arrangements, poor contract management, shortage of materials, inaccurate estimation and overall price fluctuations. Despite the various alleged limitations, estimation is nonetheless a *sine qua non* in mitigating most of the factors that cause project delays. An accurate estimation will ensure optimum exploitation of most construction resources. This article attempts to discuss further the issue of estimation but narrowing the debate down to examining the labour-related costs of building projects in Cameroon, informed by an ontology-driven approach.

The rest of the paper is divided into eight sections. In section 2, the challenges involved in construction labour costing in Cameroon are examined. Section 3 presents an overview of current information and knowledge representation techniques about labour costing in Cameroon. Section 4 elaborates on the development of the labour cost ontology. Based on the labour cost ontology developed in section 4, section 5 extends the ontology to include Semantic Web rules to support reasoning. In section 6, the outcomes from sections 4 and 5 are implemented in a software environment. Section 7 is a demonstration of how the ontology can be used in reasoning and computation. Section 8 is about the validation of the developed labour cost ontology implemented in section 6. The paper concludes in section 9 by way of summary and recommendation for further research.

2. AN OVERVIEW OF BUILDING PROJECT LABOUR COSTING IN CAMEROON

Like in most developing countries, many building projects in Cameroon often exceed their initial labour cost. Recent studies on building development in Cameroon have focused on developing labour cost estimation models (Louzolo-Kimbembe 2005; Louzolo-Kimbembe and Pettang 2006). The two common models developed by these authors are the Simple matrix and Statistical matrix models respectively. In addition to these models, other mathematical models used in the country include Artificial Neural Networks (Sodikov, 2005), Transcendental functions (Udegbe, 2007), Statistical models (Attalla and Hegazy, 2003), and Regression models (Attalla and Hegazy, 2003). Despite the implementation of these models in estimating construction cost in general and labour cost in particular, overruns in labour costs in many construction projects are not uncommon (Sodikov, 2005). Not only are cost overruns common, but the difficulties in the computation of labour cost as a result of so many different factors affecting labour costing are overwhelming. The reasons to labour cost overruns and computation difficulties have often been attributed to the following:

- Challenges in predicting labour cost: Unlike construction materials where prices can readily be obtained from suppliers, labour cost is generally not available as it is often dictated by labourers. This is partly due to the fact that the sector is mostly informal (Pettang et al., forthcoming), and labourers can dictate their pay which often at times is not in agreement with contractors budget;

- Labour skill shortages: In Cameroon, although there is a significant level of unemployment, contractors are still not able to find skilled trade professionals such as electricians, plumbers, painters, etc. (Carpaneto et al., 2003). The lack of skilled workers varies from region to region, with villages impacted the most. This poses serious challenges in the establishment of the different types of labour to be used in construction projects. Consequently, it is not very straight forward to establish the different labour costs associated with the different labour types;

- Constraints by international donors to recruit local labour: The Cameroon government and most international projects' sponsors often impose conditionalities on many construction projects for contractors to meet before and during the execution of a project. For instance, most international organisations would require that most of the labourers should be sourced from the community where the project is to be executed (Carpaneto et al., 2003). To reinforce this, local traditional chiefs are often called in to facilitate the task of ensuring that both unskilled and skilled labour is from the community where the project is to be executed. The implications of this constraint are: Firstly, there are higher chances of employing labour with no skills and paying wages for little or no job done. Secondly, bringing in third parties such as the chief to ensure locals are involved in the project often incurs some additional cost which can be factored into labour cost. In any case labour cost is affected and cannot be straightforwardly determined;

- Fluctuation of labour cost in different regions of Cameroon: There is a wide margin between cost in villages and cost in cities. Most labour costs of building construction standard task in cities are fairly known to contractors but those of villages tend to differ with no established and well known pattern.

The above challenges portray the different parameters and their complex relationships that affect building construction labour costing in Cameroon. Developing a knowledge base with the different regions of Cameroon being a core parameter so that other parameters are mapped or tagged onto the different regions can be a great way of aiding building developers in decision-making. A knowledge base that can provide the capability of selecting a region, and being able to establish the different types of labourers, their different pay rates, and the languages spoken in the region is a great tool for developers in deciding whether or not to engage in a building project. The need to develop knowledge-based systems that can model labour costing for use as a predictable and computable tool in decision support during early design and construction execution phases of construction projects has become more pressing. Tools that can provide ways of using different hypothetical projects located in different regions to match against different labour cost on the different tasks in a project are just the few parameters that can be used in making informed decisions. Recent studies (Arman et al., 2010) reveal that ontologies have the potentials of playing a key role in knowledge-based systems. In particular, although the traditional relational database management system is still being widely used, recently there has been an upsurge towards the use of ontologies in developing knowledge-based systems in different areas including the construction domain. In the construction domain, ontologies have been used in the field of construction education, supply chain, project and construction management, material storage, project design, architecture and graphic designs, etc.

In the field of construction education, repositories have been developed in managing objects as well as metadata using ontologies that offer a set of services such as storing, retrieving and searching of learning objects using Semantic Web technologies (Ahmed et al., 2007). In the domain of supply chain, great use of ontologies about information from different partners on same or different projects have been undertaken (Zou and Seo, 2006). Furthermore, a rule-based ontological knowledge base has been developed for monitoring partners across supply chain networks (Chi, 2010). In construction and project management, ontologies have been developed to enhance interoperability over computer systems to facilitate different construction companies' projects' information (Aziz et al. 2004; El-Diraby et al. 2005; Ruikar et al. 2007; Shelbourn et al. 2006).

In this article, a rule-based ontological knowledge base has been developed for computing building labour cost for construction projects in Cameroon. In addition to labour cost computation, the rule-based ontological knowledge base can be used in selecting the different projects that can be executed, determining the availability of labour and characterising construction labour in different regions of Cameroon. In order to develop such an ontological knowledge base, it is imperative to investigate the current labour cost information and knowledge representation systems.

3. CURRENT LABOUR COST KNOWLEDGE REPRESENTATION IN CAMEROON

While it is important to develop fair and justifiable models to estimate labour cost in building projects (Louzolo-Kimbembe 2005; Louzolo-Kimbembe and Pettang 2006; Sodikov 2005; Udegbe 2007; Attalla and Hegazy, 2003), it is equally important to make appropriate tools available that incorporate the models for practitioners to use. An investigation by Choon and Ali (2008) reveals that cost estimation methods that have been developed and extended to include database management tools increase efficiency and speed of construction cost estimation. The most common cost estimation tools are developed using Excel spreadsheets (Attalla and Hegazy 2003; Hegazy and Ayed 1998) and Web-based applications (Min-Yuan Cheng 2009; Jui-Sheng Chou 2009). However, the fundamental back-end technologies of Excel and current Web technology does not provide them with capabilities to manage construction labour costing information. For instance, most Excel applications are locally-based on individual computers, and cannot easily be shared with other partners. Similarly, although the current Web technology can be used in sharing information, it is still very primitive in this process. This is because the current Web technology is built using HyperText Markup Language (HTML) languages. One of the disadvantages of HTML is that it is only suitable for structuring documents by humans and not machine-processable. Interestingly, Semantic Web technologies, the next generation of the Web technology, can be used to contribute towards overcoming these limitations. Semantic Web technologies can considerably improve information representation, sharing and re-use (Tim et al., 2001). The development of an efficient Semantic Web repository depends on the underlying knowledge representing the domain for which the Semantic Web is about. Representing domain knowledge using ontologies is the kernel of Semantic Web technology and the first step towards building an efficient Semantic Web repository. Cognizance of the hugeness of the different technologies in the Semantic Web technology domain and the fact that it is an emerging technology, this article will focus on presenting an innovative approach using ontologies in modelling labour costing in building construction projects. An extension of the labour cost ontology developed is undertaken to include rules using the Semantic Web Rule Language (SWRL), which facilitates reasoning and computation in construction labour costing. Given that the Semantic Web is an emerging technology and being applied in developing an application to be used in a developing country like Cameroon, challenges to its uptake are very likely. Some examples of challenges may simply be institutional barriers; construction companies may not be willing to embark on a new technology. As acknowledged by the founder of the Semantic Web, the Semantic Web is yet to overcome institutional challenges to its uptake in developed and developing countries (Updegrove, 2005). This article does not dwell on whether or not the labour cost ontology will ever be used in Cameroon. The approach here is to take a first step and experiment an aspect of the Semantic Web technology and prove its usefulness which can potentially serve as one of the promising ways of overcoming institutional barriers. In the ensuing sections, the development of the labour cost ontology is examined.

4. LABOUR COST ONTOLOGY DEVELOPMENT

In the Artificial Intelligence domain, many ‘ontology’ definitions have been coined. However, the common feature highlighted by these definitions is that of sharing common understanding of the structure of information among people or software agents (Antonio and van Harmelen 2004; Gruber 1993). For the purposes of this study the often-quoted definition of Gruber (1993) which defines “ontology” as “a specification of a conceptualisation” has been adopted. This is the most popular and the most widely used in the ontology research community (Antonio and van Harmelen 2004; Noy and McGuinness 2001). In developing ontologies for any application, it is important to establish the methodologies, tools and languages to be used in the process. The decision of the implementation of these elements depends on the aim and purpose of the ontology.

From the literature there are so many different ontology methodologies that have been used. In this study, the most commonly used methodology developed by Noy and McGuinness (2001) has been adopted. This methodology is easily implemented in the most popular ontology editor, protégé-OWL (Web Ontology Language). The OWL language was chosen because it is richer than most existing ontology languages such as the extensible mark-up language and Resource Description Framework. The key steps in the methodology developed by Noy and McGuinness (2001) are:

a. *The determination of domain and scope of ontology:* This is achieved by using competency questions such as *what is the domain the ontology will cover? what will the ontology be used for? for what type of questions the knowledge in the ontology provide answers?* The answers to these questions were guided by the motivation to develop an application that would enable professionals to estimate labour costing in building construction projects. Thus the domain of this ontology is building construction labour costing and the scope will be limited to informal-private development projects in Cameroon. This is because the informal-private building sector dominates the Cameroonian building sector (Pettang et al., 1995).

b. *The re-use of other ontologies:* In ontology development the re-use of other ontologies is often recommended. Consequently, all the concepts in the labour cost estimation ontology were built using some existing classifications. The main concepts are the construction project (*ConstructionProject*) (Pettang et al. 1994; Pettang et al. 1995), construction task (*ConstructionTask*) (Pettang et al. 1994; Pettang et al. 1995), construction worker (*ConstructionWorker*), the different projects' location in Cameroon (*ProjectLocation*) (Annuaire Statistique du Cameroun, 2006) and the organisation or building development stakeholders (*Organisation*) (Fokou, 2003). The *ConstructionProject* denotes the different types of building projects in Cameroon. Some examples are *Bungalow* and *Storey-Building*. The *ConstructionTask* and *ConstructionWorker* define the different construction activities and tradesmen involved in a given *ConstructionProject.* The projects' location (*ProjectLocation*) denotes the different administrative regions in Cameroon where building construction projects can be executed. The *Organisation* concept denotes the different stakeholders involved in a building construction project.

c. *Enumeration of terms in the ontology:* From literature, the terms in the labour cost ontology are listed without necessarily following any systematic order. Some of the terms are *labourCost, hasAddress, hasLocation, ConstructionWorker,* etc.

d. *Definition of taxonomy:* There are several approaches to developing class hierarchy (Uschold and Gruninger, 1996). Given that the labour cost ontology was constituted from existing classifications, hierarchical structure of the existing classifications was inherited. The top-down structure considers the most general concepts before descending to more specific concepts. In the labour cost ontology, the *ConstructionTask, ConstructionProject, ConstructionWorker, Project Location* and *Organisation* are general concepts. Each of these top concepts further breaks down into more specific concepts. The classes have been organized into a hierarchical order.

e. *Definition of properties:* Three types of properties have been considered. The annotation properties which comment on some key components of the labour cost ontology. Given the fact that annotation properties are used in clarifying data (meta-data), it is often captured at the implementation stage in the ontology editor. The object property defines the relationship between individuals of the various concepts. Some examples of object properties in the labour cost ontology are *isExecutedBy* and *isManagedBy.* Statements formulated based on these examples are: A "ConstructionProject *isManagedBy* a ConstructionWorker". A "ConstructionTask *isExecutedBy* a ConstructionWorker". The data-type property defines quantitatively and qualitatively characteristics of individuals. For instance, the name of a construction worker, say John. This means, an instance of a ConstructionWorker class, has a data-type property called "name" often denoted "hasName" with data value "John". Some data-type properties in the labour cost ontology are: hasAddress, hasArea, hasBuildingLevel, hasNumberOfLevel, hasVolume, etc.

f. *Definition of facets:* Facets entail stating the value of a property, the cardinality of the property value and the class to which the property has been attributed. The value of a property could be qualitative or quantitative. E.g. measuring the job satisfaction of construction workers could be measured qualitatively on a likert scale of not satisfied, satisfied, very satisfied, indicating an increasing level of satisfaction. On the other hand the wages of construction workers can be measured quantitatively using real numbers such as 100 X , with X being any monetary units.

g. *Definition of instances:* This step requires creating individual instances of classes which consist of choosing a class, creating an individual instance of that class and filling in the slot values. This was undertaken manually by extracting the different instances belonging to the classes involved in the labour cost ontology. For instance, instances of organisation were the concrete list of different stakeholders involved in building development projects in Cameroon.

The main outcome of the steps a-g highlighted above is a labour cost ontology knowledge model that can be used in different applications. To provide a highlight of the labour cost ontology knowledge model, a Unified Modelling Language (UML) is used in capturing the top (first) and second level concepts. UML is a standardized general-purpose modeling language often used in creating visual models in the field of software engineering. The main purpose for using UML is to create a semantically rich class diagram that can allow the graphical representation and visualization of concepts and relationships in the labour cost ontology. The class diagram is depicted in Fig. 1. It depicts five top level concepts which are the *Organisation, ProjectLocation, ConstructionWorker, ConstructionTask* and the *ConstructionTask* concepts. The subclasses of these concepts have also been indicated. Other than the subsumption relations that exist between the top level classes and subclasses, the object properties including their multiplicities have been used to relate the top level concepts. An example is the multiplicity of 1…* on the object property *isManagedBy* that relates the *ConstructionProject* and *Organisation* concepts. The multiplicity of 1…* on *isManagedBy* means one or more construction project(s) is (are) managed by one or more organization(s). The inverse of *isManagedBy* is manage(s) and relates the *Organisation* and the *ConstructionProject* concepts. The multiplicity of 1…* on object property *manage(s)* means one or more organisation(s) manage(s) one or more construction project(s).

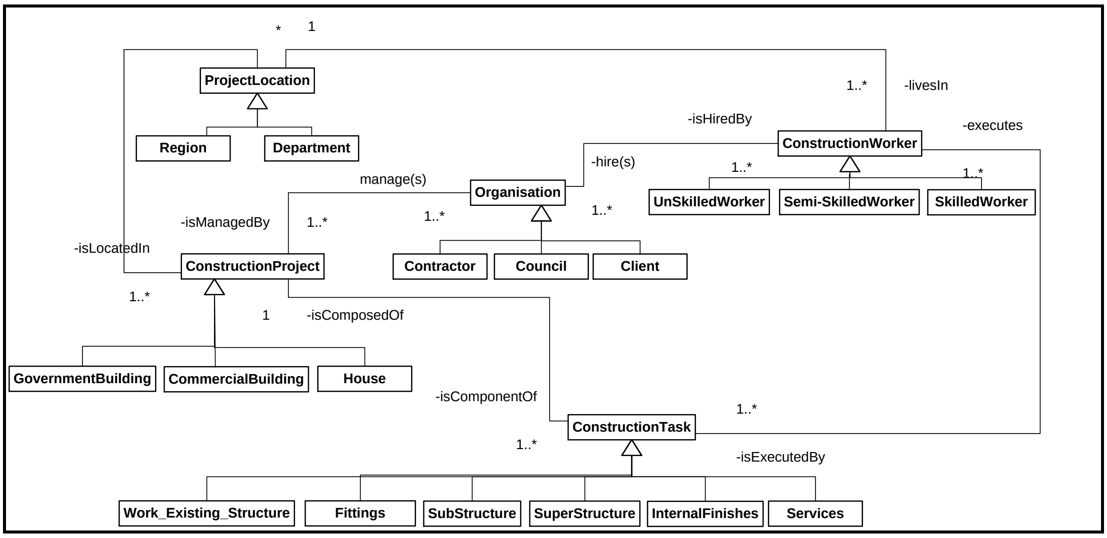

FIG. 1: First and second level UML model of construction labour cost

The UML model of Fig. 1 constitutes the basis used in developing the labour cost ontology. In general, the methodology developed by Noy and McGuinness (2001) and as examined in the preceding paragraphs provides a very useful capability of eliciting ontological knowledge about most domains. The aim of the methodology of Noy and McGuinness (2001), which is common to most ontology methodologies, has been to provide a common understanding of information and knowledge among multi-disciplinary participants based on the same or in different geographical locations. However, based on the fact that the ontology in this article is to be used in developing a rule-based application which computes the different labour costs of construction task and construction projects, there is need to extend the methodology to capture concepts that facilitate the computation of labour costs. Hence this article applies the ontology approach in improving information representation, sharing and re-use in labour costing issue and also includes rules and processes in computation of labour costs. Process mapping helps represent visually, the work processes and identifies problem areas and opportunities for process improvement. The process model for the computation of construction labour costing, and hence the selection of building projects is presented in Fig. 2. The literature and informal discussions with construction experts in Cameroon constituted the two main literature sources for the process model of Fig. 2.

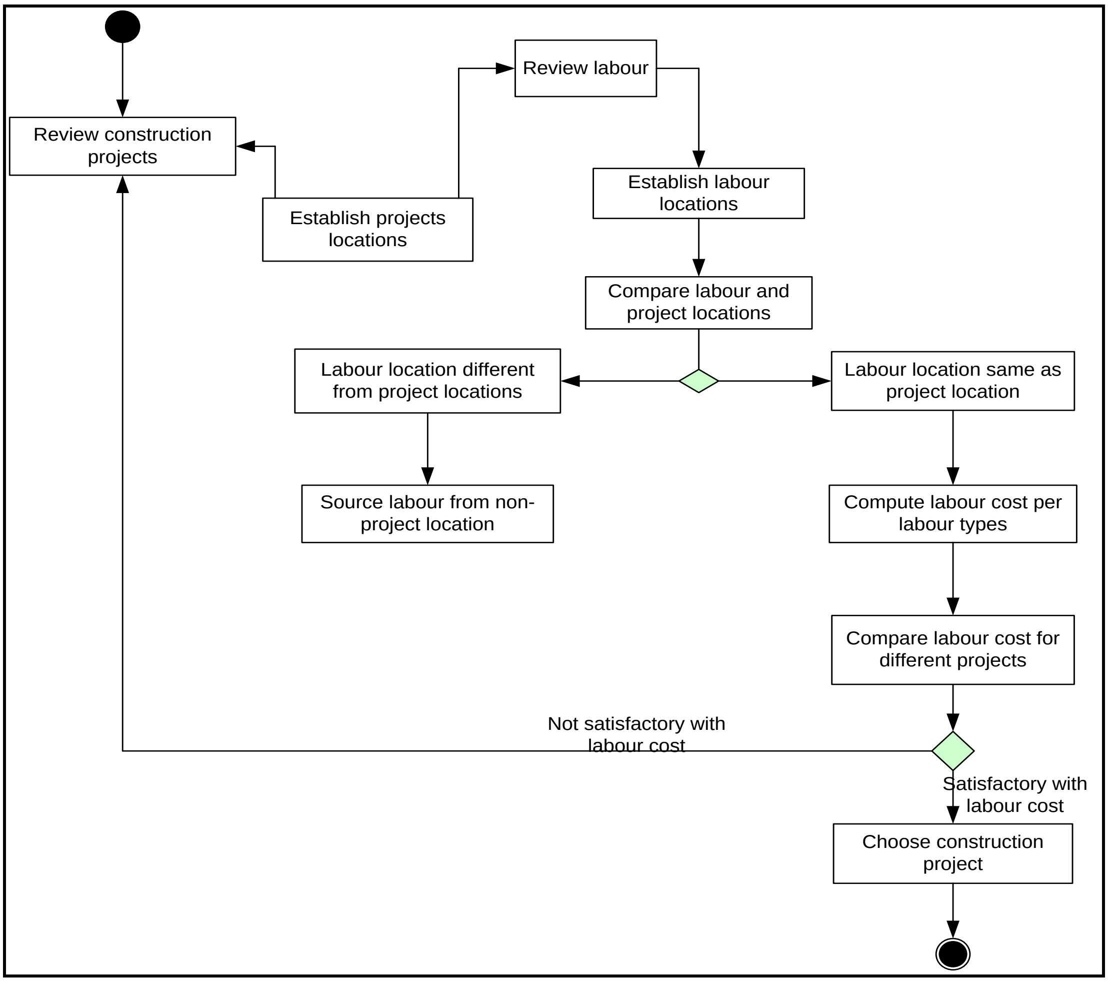

FIG. 2.The process model for the computation of labour cost in building construction in Cameroon

From Fig. 2 three new concepts have emerged. These are the selection, the comparison and the computation concepts. In the process model in Fig. 2, the first key step is where the labour and project locations are to be compared. This is captured as the concept *Compare Labour and Project Locations*. This concept establishes the different labour types for construction projects according to the different administrative regions of Cameroon. Before comparing the different project and labour locations, a selection process must be undertaken. The last concept that emerges from the process model of Fig. 2 is the computation of the building construction labour cost captured as *Compute Labour Cost Per Labour Types*. This is an important concept as it seeks to provide an insight of the cost of labour sourced from different regions other than the project's location. The concepts *Selection, Compare Labour and Project Locations, Compute Labour Cost Per Labour Types* have been modeled in the labour cost ontology as explained in section 5.

5. MODELLING RULES USING SEMANTIC WEB RULE LANGUAGE (SWRL) IN QUERYING LABOUR COST ONTOLOGY

The inability to reason with ontologies developed in ontology languages has been the motivation behind the existence of many ontology languages. Presently, although the OWL is more efficient than most ontology languages; it is still not possible to undertake reasoning that deals with most real life situations. In OWL, it is possible to undertake structural inferences such as subsumption and identity (Walton, 2007). However, OWL is very limited in undertaking rule-based reasoning which can be used in modelling most real life reasoning. Consequently an extension of OWL is undertaken to include a popular rule language called SWRL. The SWRL was used in editing rules that enhanced reasoning in the labour cost ontology. This was undertaken using the

SWRL plug-in called SWRLTab incorporated in protégé-OWL 3.4.4. In the ensuing paragraphs, the development of rules in reasoning in labour costing using SWRLTab is investigated.
In Artificial Intelligence using rules in reasoning is quite common and has been well researched (Walton, 2007). In general rules often take the form:

$$A_1, A_2, \ldots.., A_n \to B \qquad \text{(r-1)}$$

where A_i and B are the atomic formulas, $\forall i$ belonging to the set of natural numbers .

If the conditions $A_1, A_2, \ldots, A_n$ are true, then carry out the action B or if the conditions of the left hand side (LHS) are satisfied then the conditions of the right hand side (RHS) should be executed. The LHS and the RHS of rule r-1 are often called the antecedent and the consequent, respectively. Rule r-1 is generic and different rule-based systems use different syntaxes. The SWRL language syntax is used in editing rules in SWRLTab.

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

The process map of Fig. 2 provided a way of identifying concepts used in the estimation of labour cost, which would not have been easily captured by traditional ontology methodology such as the Noy and McGuinness (2001). From Fig. 2 the selection, comparison and computation activity concepts required in the estimation of construction labour cost were identified. The challenge is how the selection, comparison and computation concepts can be modeled in the labour cost ontology. Fortunately, in addition to the SWRL language syntax, SWRL comes with a built-ins library that enhances SWRL computational and reasoning capability. The built-ins library contains SWRL built-ins such as basic mathematical operators and routines for string and data manipulations. Some SWRL built-ins used in this article to deal with the selection, comparison and labour cost computation are the sqwrl:select, swrl:multiply, sqwrl:greaterThan.

The sqwrl:select built-in is used in selecting instances of an ontological concept. For instance:

ProjectLocation(?l)→sqwrl:select(?l) (r-2)

The sqwrl:select built-in used in r-2 will list all the instances in of the ProjectLocation class. The swrl:multiply(?x, 2, 3) means that the product of 2 and 3 should be assigned to the variable x. An example of an application of the swrl:multiply built-in is illustrated in r-3 below.

ConstructionWorker(?x) Λ hasPayRate(?x, ?z) Λ hasTaskDuration(?x, ?a) Λ swrlb:multiply(?b, ?z, ?a)→hasTotalLbourCost(?x, ?b) (r-3)

The swrlb:multiply(?b, ?z, ?a) provides a way of computing the total labour cost of a construction worker by multiplying the task duration denoted ?a by the worker's pay rate denoted ?z. and the result bound in ?b. The built-in sqwrl:greaterThan(?r, m) means that the variable r is greater than m, where m is real number. The sqwrl:select(....), is a built-in that selects rule variables. An example of a rule in SWRLTab using sqwrl:greaterThan built-in is:

ConstructionWorker(?p) Λ hasPayRate(?p, ?r) Λ sqwrl:greaterThan(?r,4000)
→Expensive(?p) (r-4)

What this means is that, if there is a construction worker (ConstructionWorker) p and the worker's pay rate(hasPayRate) r is such that it is greater than m=4000 monetary units (i.e. FCFA used in Cameroon) , then classify the worker as Expensive.

The built-ins used in rules r-2 to r-4 are simply the few examples that have been used based on the processes that emerged from the process map of Fig. 2. There are many others that have been explored and incorporated in the labour cost ontology.

In general, SWRL are of the form:

If <<all the conditions in the antecedent are satisfied >> Then <<execute the consequent>> (r-5)

To illustrate the application of SWRL rules, use case scenarios will be presented in section 6.

6 IMPLEMENTATION OF ONTOLOGY IN A SOFTWARE ENVIRONMENT

In order to develop an application it was imperative to implement the labour cost ontology in a software environment. To decide on which software to use, it was imperative to establish the requirements of the ontology knowledge-based system. How and what will the labour cost ontology be used for? Therefore the following requirements have been established:

a. Provision of an ontology knowledge-based system where labour cost information can be stored and retrieved;

b. The system should support reasoning. An ontology that will support reasoning. That entails the creation of some constraints and rules that may contextualize the information related to the role of class and properties for reasoning;

c. Provision of the possibility of the labour cost ontology to adapt and evolve with minimal disruption. New ontologies can be defined and added incrementally without the need for the redesign of the environment.

To meet the requirements (a-c), the following software and components tools have been used:

a. Protégé-OWL 3.4.4: This is an ontology development editor developed by Stanford University, USA. It is an open-source tool that enhances end-users skills in creating, visualizing, and updating ontologies. It is very extensible and can accommodate other plug-ins that can be used in developing other applications. The plug-ins used in support of protégé-OWL are:

b. SWRLTab: This is a protégé plug-in and editor that facilitates the writing of SWRL rules;

c. JessTab: This is a protégé plug-in that allows the use of Jess (a rule language) and protégé together;

d. Pellet 1.5.2: Pellet is an OWL 2 reasoner which provides standard and cutting-edge reasoning services for OWL ontologies. Although pellet currently exists in different versions, pellet 1.5.2 is the version that has been incorporated in protégé-OWL 3.4.4, the ontology editor chosen for this study.

The implementation of the labour cost ontology based on the methodology examined in section 4 in the protégé-OWL 3.4.4 environment is presented in Fig. 3. The figure depicts the main labour cost ontological components including some classes' instances, properties and SWRL rules.

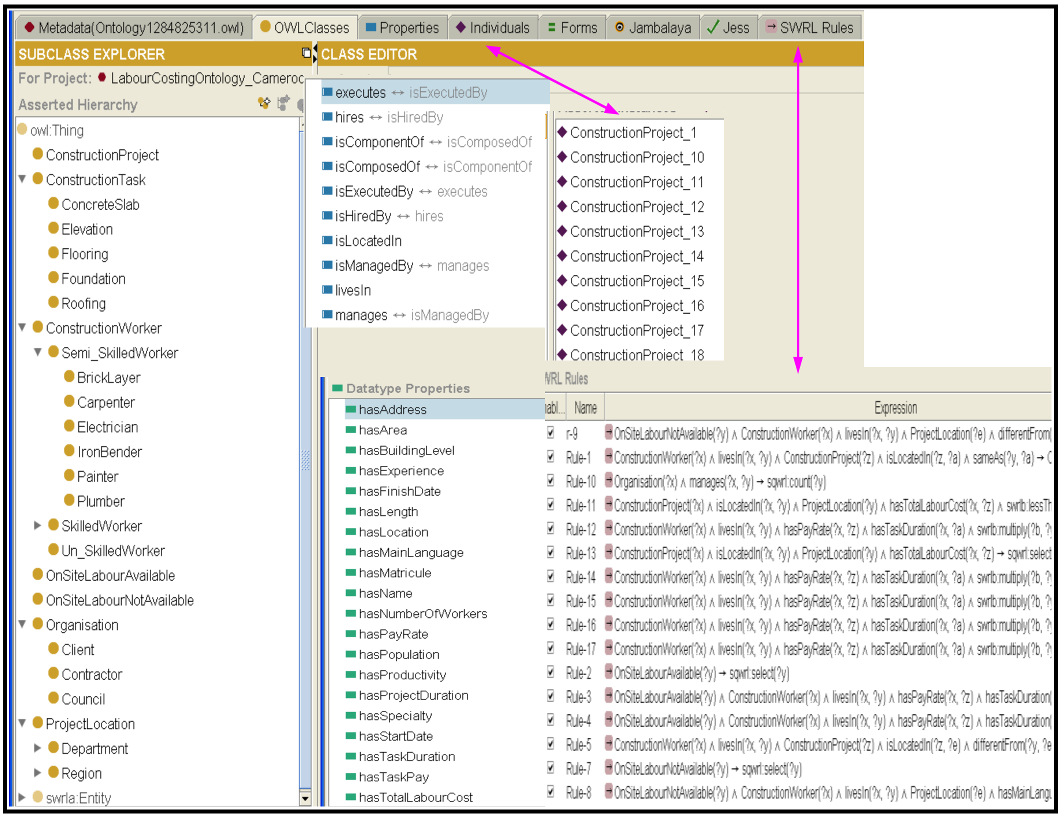

FIG. 3: Labour Cost ontology in protégé-OWL 3.4.4 screenshot

The main ontology components captured by protégé-OWL and shown in Fig. 3 are the classes, instances, properties and rules. In section 7, scenarios are presented depicting how the labour cost ontology is queried using SWRL rules highlighted in Fig. 3.

7 USE CASE SCENARIO: QUERYING THE LABOUR COST ONTOLOGY KNOWLEDGE BASE

In order to implement SWRL and use rules in inferring decisions about labour cost, three scenarios depicting three different construction practices will be presented to illustrate how decisions can be made about labour cost estimation in a building project.

The first scenario demonstrates the formulation and implementation of a rule used in the establishment of the availability of labour in a given construction project location and then computing the labour cost of the project. As previously reviewed in section 2, the different regions of Cameroon suffer differently with respect to the different construction labour types. In the different regions, there may be lack of labour, labour may be too expensive, etc. Lack or availability of labour is the most important factor as it is important to establish whether where the construction project is to be executed, there are workers and if there are workers, are they expensive or cheap? Hence in the establishment of whether there is available labour the ontological concepts in rule r-6 have been captured. The *ConstructionWorker* class captures instances of subclasses Unskilled, Semi-Skilled and Skilled workers in any given region. The object property *livesIn* captures the residence of the workers captured by the concept *ConstructionWorker*. The *ConstructionProject* concept captures the different types of project in Cameroon. The object property *isLocatedIn* captures the different locations where the different projects can be located in Cameroon. This concept can be combined in an SWRL rule antecedent as in rule r-7.

$$ConstructionWorker(?x) \wedge livesIn(?x, ?y) \wedge ConstructionProject(?z) \wedge isLocatedIn(?z, ?a) \rightarrow sqwrl{:}select(?x,?y,?z,?a) \qquad (r\text{-}6)$$

The consequent of rule r-6 uses sqwrl:select built-in function of SWRLTab which selects the results that satisfy the conditions of the antecedent. The results from rule r-6 provide the different locations of the different types of projects and the different labour available in the different regions of Cameroon. However, the results do not offer a possibility to establish whether the different locations have labourers in the different project locations. Thus, *sameAs* OWL axiom is used to determine if the construction project location is the same as the construction worker location. By definition, *sameAs* is used in SWRL to deduce whether two individuals are the same as each other if there is an explicit owl:sameAs OWL axiom defined for the individuals in an ontology or if their sameness is entailed by other axioms in an ontology.

ConstructionWorker(?x) Λ livesIn(?x, ?y) Λ ConstructionProject(?z) Λ isLocatedIn(?z, ?a) Λ sameAs(?y, ?a)→ sqwrl:select(?x,?y,?z,?a) (r-7)

The interpretation of rule r-7 is that if there are construction labourers in the same place where the project is located, then output the labourers, where they live and the different projects in the region. In reality, although modelling rules with the sqwrl:select built-in as the consequent is a compact way of representing SWRL rules, it suffers from two main disadvantages. Firstly, all necessary requirement characteristics of a given concept need to be defined right upfront in the antecedent part of the rule before the consequent can be executed. Including all the necessary requirements or atoms on the left tends to be too long and the fact that we need to know all these requirements right upfront is a challenge. Secondly, ending a rule with a built-in makes the rule static and cannot be exploited further for other purposes such as inferring new knowledge. For instance, after determining the available labour in a region, it might be of interest to subsequently determine the labour cost and other labour cost properties.

In order to overcome the challenges posed by modelling as in r-7, the capability of the JESSTab is used. In the first instance, a class is created called the OnSiteLabourAvailable to capture location instances where the project and the labour location are the same. As the *OnSiteLabourAvailable* on its own does not contribute to the labour cost ontology, it is modelled to be a subclass of the general *Thing* concept. The *Thing* concept can be used at any level in an ontology hierarchy (Noy and McGuinness 2001). The *Thing* concept encompasses any tangible and non-tangible concepts and so any concept can always be modelled as a sub-concept of the *Thing* concept. Therefore, on replacing *sqwrl:select* built-in with *OnSiteLabourAvailable* class rule r-7 becomes r-8.

ConstructionWorker(?x) Λ livesIn(?x, ?y) Λ ConstructionProject(?z) Λ isLocatedIn(?z, ?a) Λ sameAs(?y, ?a)→ OnSiteLabourAvailable(?y) (r-8)

Executing r-8 leads to the selection of projects that have workers in the region or project location. It is important to note that r-8 is an SWRL rule made up of OWL class and property atoms defined in the labour cost ontology, hence the combination OWL+SWRL. The JESS engine converts a combination of OWL+SWRL into jess facts (i.e. new facts) and the new facts are then sent into the OWL ontology knowledge. These new facts in the OWL ontology can be used to infer new knowledge. For instance the list of locations where labour is available generated from r-8 yields some instances that are fed back into the *OnSiteLabourAvailable* class in the labour cost ontology. The end-user may be interested in knowing the type of labour, their pay rate and the task duration and so the new knowledge generated from r-8 can be combined with a property atom that characterises the location of a labourer. This is modelled as in rule r-9.

OnSiteLabourAvailable(?y) Λ ConstructionWorker(?x) Λ livesIn(?x, ?y) Λ hasPayRate(?x, ?z) Λ hasTaskDuration(?x, ?a) Λ swrlb:multiply(?b, ?y, ?z) sqwrl:select(?y) (r-9)

An SWRL multiplication built-in function (swrlb:multiply) is used in relating pay rate to work duration in rule r-9. The output of this uses the sqwrl:select built-in function of SWRLTab which selects the results that satisfy the conditions of the antecedent.

In the second scenario, a possibility that the construction project may be executed where there is no labour is considered. In such a circumstance, labour is sourced from a different location. Like in the case where labour is available, the *differentFrom* axiom is used to determine instances of labour that can be sourced from locations other than the project's locations. Also a new class OnSiteLabourNotAvailable is created to receive new knowledge generated from the antecedent to the consequent. The models for this second scenario are presented in rules r-10 and r-11.

ConstructionWorker(?x) Λ livesIn(?x, ?y) Λ ConstructionProject(?z) Λ isLocatedIn(?z, ?e) Λ differentFrom(?y, ?e) → OnSiteLabourNotAvailable(?y) (r-10)

OnSiteLabourNotAvailable(?y) Λ ConstructionWorker(?x) Λ livesIn(?x, ?y) Λ ProjectLocation(?e) Λ differentFrom(?y, ?e) Λ hasPayRate(?x, ?z) Λ hasTaskDuration(?c, ?a) Λ swrlb:multiply(?b, ?a, ?z) Λ ConstructionTask(?c) → hasTaskPay(?c, ?b) Λ sqwrl:select(?c, ?y, ?e, ?a, ?b, ?x) (r-11)

On executing r-11, the different projects' locations are determined, the different sources of labour and corresponding pay rates, and duration are selected and hence the labour cost computed.

The third scenario is about a construction company that wants to find out about the relations between the total labour cost, the location of each project and the project type given a cost constraint. This is modelled as in rule r-12.

ConstructionProject(?x) Λ hasLocation(?x,?y) Λ hasTotalLabourCost(?x,?z) Λ swrlb:lessThan(?z,50000) Λ hasExecutionDate(?x,?a)→sqwrl:select(?x,?y,?z,?a) (r-12)

In executing the LHS of rule r-12, the system selects all construction projects; their corresponding locations and their total labour cost, and verifies that the total labour cost should be less than 50000 monetary units. This means only projects whose monetary values are less than 50000 will be selected. The execution dates of the selected projects are also selected. When the conditions on the LHS are fulfilled, the RHS is executed and the different projects, locations, project labour cost and the year of execution are established. Fig. 4 depicts an overview of the labour cost ontology rules implemented in SWRLTab rules r-2, r-3, r-4, r-6, r-7, r-8, r-9, r-10, r-11 and r-12.

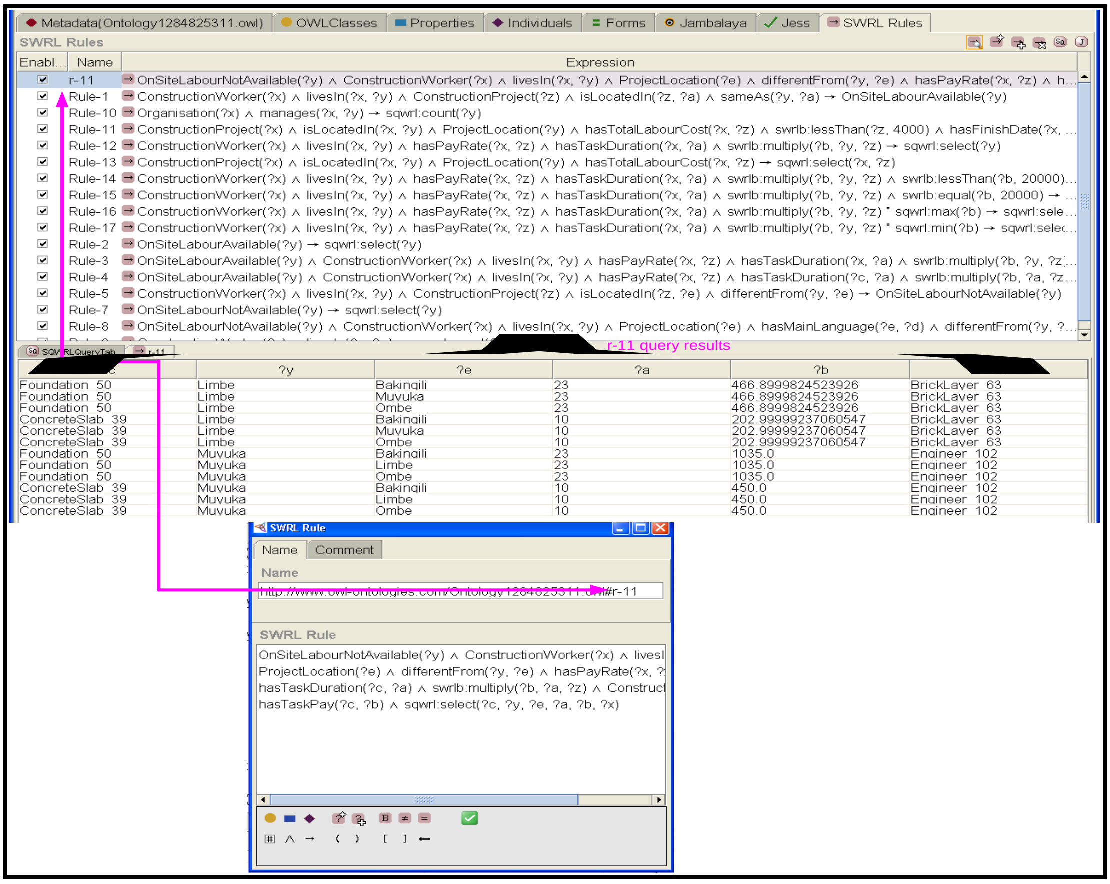

FIG. 4: Labour cost rules in SWRLTab plug-in in protégé-OWL 3.4.4

From the query results presented in Fig. 4, some decisions can be made in a housing development project. For instance, from the results obtained from rule r-11, the management can actually compare the different labour cost of construction projects in the different regions of Cameroon. This can help the management to decide on which type of projects to tender for/invest in in which type of region. Similarly, from the results obtained from rule r-3, the total labour cost of each construction worker is computed for a given construction task. This can be used in determining the overall construction labour cost of a given building project.

8. VALIDATION OF THE LABOUR COST ONTOLOGY KNOWLEDGE BASE

A major recommendation by most methodologies is the validation of any ontology knowledge base. This activity consists of ensuring the semantic correctness, the syntactic correctness and also to verify if the ontology meets the requirement conditions or does what it was intended to do. In this section only the semantic and syntactic validation will be examined. This is because the third validation activity which consists of verifying whether intended purpose of the ontology has been achieved has been examined in section 7 where exemplary queries have been examined.

With regards to semantic validation, two main methods can be pursued depending on how the ontology was designed. If the ontology was developed from scratch, then consultation with domain experts to validate the concepts modelled in the ontology is often recommended. This is often time consuming and costly (Völker et al., 2008). In the second approach, if the ontology is developed from the re-use of existing ontologies then depending on the degree of the re-used ontology the automated or manual alignment, merging or comparison semantic validation techniques can be used (Noy and Musen 2003; Gómez-Pérez 1994; Hovy 2001). In this technique of semantic validation, a given ontology is aligned to another ontology often referred to as a reference ontology or golden standard ontology (Gómez-Pérez 1994; Hovy 2001). For instance, ontology evaluation through alignment is described as an activity that given two arbitrary ontologies O1 and O2, aims to find for each concept in the ontology O1 a corresponding concept in ontology O2 that has the same intended meaning. By the latter methodology, if the re-used ontology has been adopted in its entirety, then there is no need in semantically validating the ontology. On the other hand if it is partially re-used the new ontology components introduced needs to be validated most preferably by domain experts and the re-used component by the alignment or comparison methodology. Based on the fact that the top level concepts of the labour cost ontology have been re-used the alignment or comparison technique of semantic validation was deemed more appropriate and hence was adopted in this article. Each re-used concept was analysed and semantically validated differently.

The ProjectLocation concept was adopted without any change or need to compare with any existing ontology as this is an administrative regional hierarchy of Cameroon examined in the "Annuaire Statistique du Cameroun" (2006). With regards to the *Organisation concept*, a comparative alignment process was undertaken to ensure the Organisation, ConstructionWorker, ConstructionTask and ConstructionProject concepts were semantically correct. The "Organisation" reviewed in Fokou (2003) was manually aligned with the Organisation concept in the TOVE project ontology (Grüninger and Fox, 1995), which is well-established ontology. The construction project (*ConstructionProject*) (Pettang et al. 1994; Pettang et al. 1995), construction task (*ConstructionTask*) (Pettang et al. 1994; Pettang et al. 1995), construction worker (*ConstructionWorker*), were manually aligned against the UK Standard Industrial Classification of Economic Activities (UKSCE) (UKS, 2010) and the UK new rules of measurement (RICS 2009).

However, some challenges were experienced in the implementation of this merging process in semantically validating the Organisation, ConstructionWorker, ConstructionTask and ConstructionProject concepts. For example, word synonyms emerged and it was a challenge in deciding which word to include and which not to include. For instance, the word "labour productivity" and "labour efficiency" were used to mean the same. "Labour experience", "Labour longevity in service" and "ancienneté de service" were used to mean the same. Following the methodology proposed by Noy and Musen (2003), Gómez-Pérez (1994) and Hovy (2001) the labour productivity and labour experience were adopted and modelled as *hasProductivity* and *hasExperience* respectively. Another challenge that emerged was the fact that, although the UK Standard Industrial Classification and the UK new rules of measurement are quite comprehensive and include so many building components, some of the components were not applicable to the type of construction common in Cameroon. While glazing is a common part of a wall in the Standard Industrial Classification of Economic Activities (UKSCE), buildings in Cameroon do not include glazing. Hence glazing and other non-applicable terms were dropped out from the labour cost ontology.

After semantically validating the ontology it is imperative to syntactically check the ontology consistency. With respect to consistency checking, the labour cost ontology was checked against subsumption, equivalence, instantiation and consistencies (Antonio and van Harmelen, 2004). Currently, there exist two major methods of performing consistency checking of an ontology (Noy and Musen, 2003), i.e. manually and automatically. Automatic validation is achieved through the use of pellet 1.5.2 reasoners. We therefore adopted the latter method of consistency checking of the labour cost ontology. This choice was guided by the availability of the reasoner pellet 1.5.2 plug-in incorporated in protégé-OWL 3.4.4.

A probe test (Horridge et al., 2007) aims to test an ontology design by deliberately introducing predictable faults to the ontology mode and then observe its effects on the model when used. The probe test is often used to test the disjoint axiom between concepts. For example, in the case of the labour cost ontology, a new concept called "ProbeInconsistencyOfConstructionTask" was introduced as a sub-class of the "elevation" concept and also as a sub-class of the "flooring" concept. Next a consistency test was conducted using pellet as explained above. There was an inconsistency error message for "ProbeInconsistencyOfConstructionTask" in the result report, hence the test is complete and the "ProbeInconsistencyOfConstructionTask" was then removed. If the inconsistency error message had not occurred, then the disjoint axiom specifications in the "elevation" and "flooring" concepts would have been revisited.

9. DISCUSSION AND CONCLUSION

In this article, we have investigated the application of the Semantic Web technologies to the building construction domain with focus on the construction labour costing. Despite being an initial exploratory study, this work is an important step towards exploring in greater detail the possibilities of implementing the Semantic Web technologies in the building construction domain. The growing importance of minimizing labour cost in building construction projects creates the need for systems that can be used efficiently in computing labour cost at any stage of the construction project. This in turn imposes the need for an effective way to manage information being generated from emerging building construction labour costing. To this end, an ontology rule-based system is proposed and developed in this article. An extension of this ontology to include rules was undertaken and some exemplary rules presented depicting how decisions can be made based on the execution of the rules. Given that the labour cost ontology presented in this article was developed from mostly existing primitive categories, domain knowledge validation was performed by making a comparative alignment/merging process against standard ontologies. The technical validation against subsumption, equivalence, instantiation and consistencies was undertaken using the Pellet 1.5.2 reasoner.

Although the labour cost ontology developed in this article is aimed at facilitating decision making in construction projects in Cameroon, it can also be applied to building projects in different countries. This is particularly because the ontological classes and properties are generic concepts that can be used anywhere. For example, as depicted in Fig. 3, classes such as *Organisation*, *ConstructionWorker, ConstructionProject* and properties such as *hasLocation*, *hasProductivity*, *hasTaskDuration*, *isComposedOf* are generic ontological concepts. However, a challenge lies at the level of specifying instances of the classes and establishment of rules. A project type executed in Cameroon is unique. Such a project is an instance of the *ConstructionProject* class and may not be useful in a country other than Cameroon. Another example is about rule r-4, where every worker with pay rate of greater than 4 000 FCFA is classed as expensive. This rule may not be applicable in some countries as pay rates depend on the economy of each country. However, instances and rules can be changed depending on the different applications and locations without necessarily changing the ontology schema.

Despite the constraints on some rules and instances in the labour cost ontology which are dependent on the Cameroon's context, the labour cost ontology can be used in decision making processes which are related to problems in construction projects in developing countries. The labour cost ontology can be used in the following:

- Determination of cost and labour: SWRL rules incorporated in the labour cost ontology can be used in determining the different labourers working on a given task and their respective labour cost over a time frame;

- Investment on different types of projects: The labour cost ontology classifies information about the different types of labour, their respective cost, according to different construction task and by different locations in Cameroon. This can be used in the early design stage where construction building professionals have to make decisions whether or not to invest in a project;

- The re-use of the labour cost ontology: Like most ontologies, the labour cost ontology can be re-used in building different construction Semantic Web applications.

The practice of re-using existing ontologies is a key advantage in terms of interoperability with respect to the Semantic Web vision.

As part of further work, it is important to develop a prototypical user-friendly interface which can simply receive input data and generate output results. An example of input data is the project location address introduced in a user-friendly interface and instances of correspondent labour pay rates, labour availability or non-availability are generated as outputs. The advantage of such a user-friendly interface is to facilitate accessibility by construction practitioners.

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