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Ontology-based semantic modeling of regulation constraint for automated construction quality compliance checking

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A B S T R A C T

Regulations play an important role in assuring the construction quality. However, due to the large amount of regulation needs considered, the construction quality compliance checking against regulations can be cumbersome/time-consuming and error prone. In order to give more computerized support to the construction quality compliance checking against regulations, an ontology-based semantic modeling approach of regulation constraints is explored. A meta model for construction quality inspection and evaluation i.e. CQIEOntology is proposed in this paper. Based on CQIEontology, the regulation constraints are modeled into OWL axioms and SWRL rules. By these OWL axioms and SWRL rules, the regulation provisions imposed on construction quality inspection can be translated into a set of inspection tasks, and get associated with the specific construction tasks. Once the construction starts, the applicable inspection tasks, including a series of quality checking and evaluation, will be reminded and recommended. Obviously, the proposed approach facilitates taking the construction quality compliance checking as a paralleling activity to the construction rather than an afterthought, and helps the inspectors in quality inspection. Finally, the approach is demonstrated in Protégé 3.4.6 through case studies based on regulation examples taken from "Code for Acceptance of Construction Quality of Building Foundation (GB50202-2002) and the validation and discussion are given for it."

1. Introduction

The construction phase of a project is governed by lots of regulations. It is important to inspect the construction process according to regulations to assure the construction quality, which is called regulation-based construction quality compliance checking or inspection. The quality inspection involves many regulations, however, due to the reasons, such as unfamiliarity with or even lack of the regulation knowledge, or being overwhelmed of the amount of regulation text, from which the applicable regulation provisions should be referenced (this is a common case especially to the new hand), during quality inspection, the inspectors may do their quality decision-making relying on the their own experience, such as which construction activities should not be neglected, which construction tasks should be inspected, what quality data need to be collected and checked, what are the quality acceptance criteria, and so on, which may vary from inspector to inspector. Therefore, manual construction quality compliance checking has been a time-consuming and error-prone task [11,14,15]. Regulation-based automated construction quality compliance checking would reduce quality inspection errors, consequently improve quality compliance and reduce violations to the regulations that govern the construction process.

In terms of construction quality compliance checking, to inspect the whole construction process is more important than only to inspect the outcome of the process. Therefore, how to support the inspectors to inspect the whole construction process under the guidance of the regulation knowledge becomes the starting point of this paper.

Nowadays, in order to improve the efficiency and reduce the cost of compliance checking, the ontology and semantic web technology have been applied to model building of code-related knowledge and implement compliance checking in the construction industry (the related research review is given in the following Section 2). Most of the researches are mainly in the architectural and structural design domains, also, some efforts have been put into the construction domain.

In order to make the construction quality compliance checking an easier and more efficient process for the inspectors, an ontology-based semantic modeling of regulation constraints is explored. A meta model for construction quality inspection and evaluation i.e. CQIEOntology is proposed, based on which, regulation constraints can be modeled into OWL axioms and SWRL rules. The proposed approach will facilitate integrating the regulations with the construction process and improve the construction quality inspection during the construction stage, from the definition and execution of the construction process to construction quality acceptance evaluation, by enabling treating the construction

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quality compliance checking as a parallel activity to the construction, rather than an afterthought.

The remainder of this paper is organized as follows. The research background is sketched in Section 1. Section 2 provides a brief review of related work. A construction quality inspection and evaluation ontology i.e. CQIEOntology is proposed in Section 3. Section 4, based on CQIEOntology , discusses how to model the relevant regulation constraints into OWL axioms and SWRL rules to support the automated construction quality compliance checking during the construction stage, from the definition and execution of the construction process to construction quality acceptance check. In Section 5, the proposed approach is illustrated with regulation examples, and the validation is discussed. Finally, the conclusion is drawn in Section 6.

2. Related work

2.1. Computer-based system for construction quality management and inspection

Quality management and inspection is a complex process. Significant work has been done in computer-based quality management and inspection system in construction. Battikha, M.G. [8] developed the computer-based system for construction quality management (QUALICON), which can deal with a diverse range of information related to requirements/criteria, inspections/tests, actual results, inspection and test plans, etc. and can integrate them with the project physical aspect. Young et al. [9] proposed a computerized Quality Inspection and Defect Management System (QIDMS), which can collect defect data at a site in real time using Personal Digital Assistant (PDA) and wireless internet, and effectively manage statuses and results of the corrective works performed.

These researches play an important role in the way to automated quality inspection. However, these systems are developed to facilitate the quality data collection, storage, and comparison between these data and the standard data extracted from the regulation. They are not developed as an assistance tool for regulatory compliance checking. In addition, to assure the construction products' high quality, it is very important to monitor the quality of (semi-) finished products as well as the construction activities and procedures. Nevertheless, these systems only focus on the final quality data checking rather than the construction process.

2.2. Regulation knowledge modeling and compliance checking

The study of regulation knowledge modeling and automated compliance checking in construction has received much attention from the academic community and industry over years. As Demir et al. pointed out, most regulations are presented as texts, whether paper or electronic, in order to give more computerized support to the users of regulations, it is necessary to represent the regulation knowledge in a formal and computer-interpretable way [12].

The review of regulation knowledge modeling and automatic rule-based checking (although dedicated in building design domain) can be obtained in refs. [12–14].

Previous research efforts mainly focused on the procedural implementation approach. Recently, attention has been directed towards the study of rule-based approach. Many researches, such as CORENET project [16], embeds the logic within the programming code, using parameterization and branching (namely, rules are hard coded in computer programming language). It requires high-level expertise to define, write and maintain the codes. It is time-consuming to update the computer programming code, because the building codes tend to change frequently by their nature. In addition, rules written in computer codes can be used only in dedicated applications, they are not likely to support widespread use. Evidently, rules, which reflect technological constraints, national regulations, etc., are an intuitive way of implementing the logics in building codes. However, in many rule-driven approaches, the actual implementation method is seldom based on a logic theory [23].

Ontology is defined as the conceptualization of terms and relations in a domain [1]. Ontology and semantic web technology offer a means to structurally represent and reuse domain knowledge [2–5]. Ontology and semantic web technology have been applied to model building code-related knowledge and implement compliance checking for the construction industry. Kim and Grobler [17] employed an ontology reasoning mechanism to detect conflicts between diverging participants' requirements in collaborative design scenarios. Yurchyshyna et al. [24] conducted the research in which the norms are extracted from the electronic regulations and formalized as SPARQL queries in terms of the IFC model. The compliance checking process is based on matching an RDF representation of a project to a SPARQL conformity query. Pauwels et al. [23] explored how to establish a semantic rule checking environment for building performance checking, the N3-logic was selected as rule language to represent the logic in regulations. Han-Hsiang et al. [28] use ontologies to structure the knowledge about activities, job steps, and hazards, for improving access to a company's JHA knowledge, and discuss an ontological reasoning mechanism for identifying safety rules applicable to given activities. These researches provide useful declarative implementation formalism.

Some researches focus on integrating building regulations with BIM/IFC and making the automated checking against constraints [21]. Ding et al. [21] implemented the Australian disabled access code on the basis of IFC models. These approaches are based on IFC (Industry Foundation Classes). The International Code Council (ICC) has created the SmartCodes initiative in this direction (Nisbet et al. 2009). These constraints are applied only to the IFC schema level; it is hard to set constraints on the instance level so as to affect only specific objects. Nguyen [18] and H.M. Satti et al. [19] integrated building code compliance checking into CAD System. However, it is not economically viable for the major CAD vendors to develop multiple local flavors of their product, since the constraints come from the national, provincial, local governments or the corresponding industry administration.

Undoubtedly, these current research efforts have paved the way for automated compliance checking in construction industry. However, from the literature review given above, it can be concluded that most of the research efforts mainly focus on the architectural and structural design domains while little efforts have been put into the construction domain. In addition, the existing automated compliance checking efforts lay more emphasis on the constraints such as wall thickness, the overlaps and intersections of building components and so on, namely, these constraints usually are about the quality requirements for the (semi-) finished products. Nevertheless, the regulation knowledge not only includes the quality requirements for the (semi-) finished products, but also includes the requirements/constraints about the construction activities and procedures of the (semi-) finished products, and the constraints about quality inspection tasks.

The existing research efforts closely related to the construction quality compliance checking in construction industry are made by Jirapon Sunkpho, Garrett, J. H., et al. (2001, 2005), Boukamp, F., Akinci, B., et al. (2007) and [12], from Carnegie Mellon University. Jirapon Sunkpho, J.H. Garrett Jr., et al. [20,22] (2001, 2005) developed a Java-based Inspection Framework (JIF), in which, an XML-based inspection modeling for developing field inspection support systems is proposed by capturing the common components and their relationships found in several field inspection support systems. Their study has given us much inspiration. The obvious differences lie in that, in our paper, the model is for the regulation constraint knowledge representation and reasoning, and used in ontological and semantic approach. Akinci et al. [10] provided an approach for automating the processing of construction specifications to support inspection and quality control tasks in construction projects. Demir et al. [12] proposed a semantic web-based approach for representing and reasoning with vocabulary for computer-based