Automation in Construction 55 (2015) 47–57

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

An ontological approach for technical plan definition and verification in construction

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ARTICLE INFO

Article history:
Received 24 October 2013
Received in revised form 12 November 2014
Accepted 13 February 2015
Available online 15 April 2015

Keywords:
Construction technical plan
Ontology
Semantic modeling
Verification

ABSTRACT

Construction planning is a fundamental and challenging process in the management and execution of construction projects. The task of developing technical plans is critical to ensuring the success of a construction project. This task of preparing a technical plan is usually undertaken manually using two separate processes: (1) plan definition and (2) verification/checking. This paper introduces an ontological approach to support the plan definition and verification process. Using this approach, the technical plans are modeled into plan ontology in a layered modeling structure. The verification knowledge is modeled into ontology axioms and semantic rules. A case example is used to demonstrate the proposed approach for pit excavation. In addition, the proposed approach enables the compliance verification process to be undertaken in parallel with the technical plan definition. As a result, the plans' compliance can be ensured during the project delivery process. The research provides a novel ontological and semantic mechanism for reusing plans and their automatic verification in construction, which is semantically reasoned.

1. Introduction

Planning is a fundamental and challenging process in the management and execution of construction projects. The task of developing construction technical plans is critical to ensuring project success. The process associated with the creation of the technical plan definition involves selecting methods and/or technologies for construction, defining tasks and precedence relationships among activities, estimating activity durations and resource requirements for work activities, making organizational decisions about the relationships between project participants and their subsequent selection [1].

In this paper, we focus on the creation of the definition and verification of a construction plan where defining tasks, methods, operations/activities and their procedures as well as resources are determined. The development of a technical plan is a knowledge-intensive task. Such plans need to satisfy the constraints imposed by regulatory bodies and the requirements of client. To ensure the compliance of constraints, a process whereby the plan is verified should be undertaken by experts through a review meeting [2]. The process of developing a technical plan can be divided logically into two sub-processes, which are undertaken separately in engineering practice: (1) plan definition and (2) verification/checking. In engineering practice, the technical plan is developed by adapting one from a similar project that has been completed [3]. Upon completion of the plan definition, the verification process is then undertaken by independent professional experts. These two sub-processes are typically undertaken manually, which is time-consuming and can lead to errors being made. Furthermore, plans developed on paper and electronic forms are not represented in a semantic format and therefore not understandable by computers. Thus, plans cannot be automatically checked to ensure they comply with statutory regulations, building codes and client's requirements. The aim of the research presented in this paper is to provide computerized support to these processes so as to ameliorate the effectiveness and efficiency of plan definition and verification. We develop an ontological approach to support the definition and verification process of a construction plan, which includes the definition of tasks, selection of construction methods, specifying operations/activities and their procedures, and the selection of key resources.

The proposed approach lays the foundation for the development of a semantic system to define a technical plan (including constraints) and its subsequent verification. By developing a semantically-rich, explicit, and formal representation of knowledge for the plan definition and verification enables them to be integrated and undertaken in parallel. As a result, compliance reasoning can be undertaken as a parallel function to the plan definition, rather than an afterthought, and parts of the plan to be re-used in other projects. The paper commences by providing an overview of the ontology and then presents a review of

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http://dx.doi.org/10.1016/j.autcon.2015.02.002
0926-5805/

the normative literature with respect to knowledge modeling and compliance checking. Based on the ontology and semantic technology, a plan definition and verification knowledge modeling framework is proposed and case examples are presented.

2. Key technologies

2.1. Ontology

Ontology is a formal representation of an abstract. It is a simplified view of a domain that describes the objects, concepts and relationships between them [4]. Ontology can be seen as:

$$O := \{C, I, R, A\}$$

O	an ontology for a domain of interest;
C	a set of concepts/classes in a domain;
I	a set of individuals/instances in a domain;
R	a set of relations among concepts, relations and objects;
A	a set of axioms holding among concepts, relations and individual, axioms provide explicit logical assertions about these three elements.

An important feature of ontology is its ability to present knowledge in a form that considers its complex semantics and reasoning. In contrast to a relative database and Exchange Mark-up Language (XML) schema, where semantics are not explicitly expressed, the ontology aims to share and make explicit the semantics of information. Ontologies are flexible data structures that can be changed and adapted to enable the semantics of planned knowledge to be interpreted in a formal way using a computer.

2.2. Web Ontology Language

Semantic web promotes common data formats on the World Wide Web (WWW). It empowers software to automatically process and integrate information and further conduct logical reasoning over a set of asserted facts based on formalized ontology applicable to various domains. The Web Ontology Language (OWL) is a language for defining and instantiating WWW ontologies. The OWL was designed to add the constructs of description logics (DL) to Resource Description Framework (RDF) schema, significantly extending the expressiveness so as to characterize classes and properties.

OWL can be used to ensure that ontology knowledge is understandable to computers and human beings. OWL is a World Wide Web Consortium (W3C) recommended language for ontology representation. It offers a relatively high level of expressivity while still being decidable. In addition, OWL, as a formal language with description logic based semantics, enables automatic reasoning with regard to inconsistencies of concepts, and thus provides RDF/XML syntax to represent ontology knowledge. OWL can be used to link information from different knowledge domains together. However, OWL provides limited deductive reasoning capabilities, in order to represent the rule, W3C has developed Semantic Web Rule Language (SWRL) [35]. The SWRL enables users to write Horn-like rules that can be expressed in terms of OWL concepts and therefore can reason with OWL individuals. Furthermore, the SWRL provides deductive reasoning capabilities that can infer new knowledge from an existing OWL ontology. A SWRL rule has the following form: antecedent is → consequent, where both antecedent and consequent are conjunctions of atoms. Atoms are the form C(x), P(x, y), same as (x, y) or different from (x, y), where C is an OWL description, P is an OWL property, and x and y are variables, OWL individuals or OWL data values.

Ontology and semantic web technology offer the means to structurally represent and reuse domain knowledge. According to Shen et al. [7] the domain of project planning and control can be significantly improved by adopting semantic web technology. Similarly, Lautenbacher et al. [8] have espoused the benefits and capability of semantic business process modeling, automatic process execution and the reuse of process fragments. J.H.M. Tah, et al. [9] explored the extent to which semantic web technologies can be exploited to both represent information and knowledge about sustainable building technologies.

The ontology and semantic technology are selected for modeling technical plans and constraint knowledge in construction as they provide the basis for:

(1) sharing knowledge and understanding between stakeholders (e.g. general contractor, sub-contractor, and suppliers) by defining domain terminologies, vocabularies and relationships in a unified format. It is suggested that this will facilitate the interaction between project stakeholders as the plan is developed and checked;
(2) the opportunity for a semantic search for the similar plans, which will improve the efficiency of their retrieval. They also enable the integration and combination of data from different (sub-) plans which can be used to create the overall master plan; and
(3) supporting the separation of the plans from the constraint knowledge, so that the user can modify and reuse this acquired information on other projects. This feature is useful as constraint knowledge often changes according to regulations or project requirements.

3. Related work

3.1. Constraints knowledge modeling and compliance checking

Most regulations are presented as texts (either paper or electronic) so as to provide computerized support to end users so that knowledge can be represented in a formal and computer-interpretable format [18]. The study of regulation knowledge modeling and automated compliance checking in construction has received a considerable amount of attention. A detailed review of regulation knowledge modeling and automatic rule-based checking can be found in Eastman et al. [19]. Notably, research has tended to focus on the procedural implementation whereby constraint knowledge is embedded into the programming code, using parameterization and branching (i.e., rules are hard coded in computer programming language). The updating of the computer programming code is an arduous and time-consuming process as building codes and regulations are often changed. Moreover, rules written in computer codes can be used only for dedicated applications.

Within construction, ontology and semantic web technology have been applied to model building code-related knowledge and compliance checking. A. Yurchyshyna, et al. [20] conducted research in which norms are extracted from electronic regulations and formalized as SPARQL Protocol and RDF (Resource Description Framework) Query Language 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. Similarly, Pauwels et al. [21] established a semantic rule checking environment for building performance checking and used the N3-logic rule language to represent the logic in regulations. Wang et al. [24] used ontologies to structure knowledge about activities, job steps, and hazards to improve a company's access to JHA (Job Hazard Analysis) knowledge. In addition, ontological reasoning was used to determine those safety rules applicable to given activities. Lee et al. [25] proposed an ontological approach that enabled most appropriate work items to be automatically inferred on the basis of work conditions through the use of semantic technology. Kim et al. [26] combined the ontology and semantic technology to solve the problem of arbitrary use of material names in BIM. Park et al. [27] developed the defect domain ontology on the basis of the six information categories in the defect data