Knowledge Based Tools to Support the Structural Design Process

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Abstract. In this paper we present an architecture and a system implementation for the exploitation of semantic aspects in the computer assisted design of Steel Detailing Structures (Structural Design). We support our approach in domain specific standardization efforts (CIS/2) by modeling the knowledge of the product structure and the design process as OWL ontologies in order to provide the designer with additional tools for his everyday work. As test case we present a collection of applications based in the proposed schema and developed in the frame of an R&D project together with an actual structural engineering company.

1 Introduction

The consideration of semantic aspects in traditional computer applications brings new possibilities as it increases on the one side accurate knowledge sharing, and on the other side the reliability and performance of such systems. The main advantages of using embedded semantics are: (*i*) the improved information management, (*ii*) searching and sharing enhancements, and (*iii*) the empowerment of the intrinsic knowledge embedded in the elements being described.

In this paper we introduce an architecture intended for the exploitation of semantic aspects embedded in a CAD (Computer Aided Design) model in the steel detailing domain. Our implementation handles its storage model in an OWL (Web Ontology Language) compliant ontology where the concepts and relations are mapped from an international standardization initiative in the domain called CIS/2 [2].

As test case, we present a set of tools developed in the frame of a research project with an actual structural design company, who has identified some critical stages in the design flow that can be clearly benefited by an implementation based on semantics. The tools implemented allow the designer to improve the design workflow by exploiting the semantics both in the product model and the design process.

This paper is organized as follows: In chapter 2, a review of related works and some background information is presented. In chapter 3 we introduce our architecture to implement knowledge based tools for the Steel Detailing process. In chapter 4 we show some results as tools developed following our architecture, explaining briefly some highlights, and in chapter 5, we present our conclusions and lines for future work.

2 Conceptual basis and background

In recent times, different approaches to extend an existing system capability using semantics in the engineering domain have been presented by the scientific community. Marcos [10] discusses a methodology to perform multimedia retrieval of engineering data by explicitly modeling and queering the semantics of the specific domain. Malkewitz [9] presents an alternative for the interactive design of 3D objects in specific domains (e.g. furniture or toys) where semantics are exploited to model explicitly the concepts and relations between the related objects in a context design approach. In a similar initiative, Sevilmis [14], presents a framework for the use of semantic web based techniques in the workflow of a community of engineers and designers in the car design industry. In the work by Posada [12], semantics are used as a basis for the consideration of user profile, intention and available resources in the Large Model Visualization of massive CAD models representing industrial facilities.

2.1 Standardization focused on Steel Detailing Design : CIS/2 LPM/6

CIS/2 (CIMsteel Integration Standards, Version 2) [2] is an effort led by Leeds University (UK) and SCI (Steel Construction Institute). This approach is based on the ISO-STEP (10303) protocol, extending the standard to cover conditions encountered in structural steel design. The CIS/2 data model is called the Logical Product Model (LPM) and it is currently on its 6th revision (LPM/6). The main purpose is to support the engineering of low, medium and high rise constructions for domestic, commercial and industrial contexts. Although CIS/2 has been developed primarily to enable the engineering of building frames, it can also be applied to other types of steel frames, such as process plant installations, transmission towers, and (to some degree) offshore structures. To refer some examples of use of CIS/2, we can mention the work by Danso-Amoako [4] who presents a case study for the support of steel supply chain processes, showing that the standard can be used not only for information exchange in design but also for information management during long term stages of the supply chain. In contrast to Danso-Amoako, we focus on the geometry modeling aspect of the design process and not in the supplier-customer relationship. Lipman [8] presents an approach to use CIS/2 as a kind of storage model for an immersive virtual reality system inspiring one of our test tools; we follow a similar approach and introduce some enhancements provided by the use of semantics, like the adaptive coloring of elements according to the design stage. Alda [1] uses the CIS/2 framework for the supporting of collaborative design in a peer to peer basis, showing the importance of a common base in a Virtual Reality (VR) design scenario. Our work is not focused on collaborative design, but could be extended in a near future to support such scenario.

2.2 The Analytical, Design and Manufacturing views in CIS/2

The structural steelwork lifecycle supported by CIS/2 is shown in Figure 1. This is a high level overview of the process model. CIS/2 describes three major stages needed to design a structural steel frame for a building: *(i)* Analysis, *(ii)* Design and *(iii)* Fabrication, each phase has its own data model that serves for information exchange between each other and possible external applications. The three different models of a steel structure are called “Views” [3]. These views served as the initial source for our process ontology implementation where they are used as a simplified model of the structural design process (this process ontology will be extended in a future work to reflect a more explicit representation).

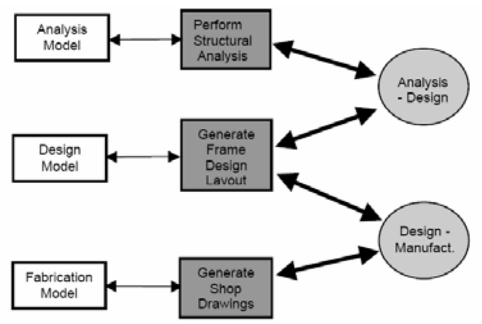

Fig. 1. Simplified process model identifying the various CIS/2 views and major exchanges, supported by high-level conformance classes [2]

2.3 Knowledge representation using Ontologies – The OWL approach

An ontology is the explicit *specification* of a conceptualization [5]. In simple terms, it is a description of the concepts and relations in a domain for the purpose of enabling knowledge sharing and reuse. A body of formally represented knowledge is based on a conceptualization: the objects, concepts and other entities that are assumed to exist in some area of interest and the relations that hold among them [5]. The existence of tools for ontology definition, querying and reasoning gives interesting possibilities to several application domains, including the engineering domain. A widely used ontology language is OWL, which is a semantic mark-up language for publishing and sharing ontologies on the World Wide Web. OWL is developed as a vocabulary extension of RDF (the Resource Description Framework) and it is derived from the DAML+OIL Web Ontology Language allowing more expressiveness than RDF depending on the OWL flavour used [7]. There exist several OWL API’s to handle computationally an ontology, between the most known ones, we can mention the Protégé OWL API [7], KAON2 [6] and the WonderWeb OWL API [11].

3 An architecture for the implementation of semantically based tools aimed for the steel detailing design process

We present in this chapter our proposed architecture for the semantic enhancement of the structural design process.

3.1 Modules description

The architecture can be divided in 5 layers (figure 2). The *User Layer* is in charge of the bidirectional interaction between the user and different application modules of the system, which belong to the *Application Layer*. The latter has three modules: first one is the Process Stage Identifier Module, whose work is to determine the state of the process in the work flow in order to provide the user with the collection of available tools for that stage. The second module is the Knowledge Based Tools Module that actually stores the collection of tools and where new tools can be added a *posteriori*. The third module is the CAD system itself. The *Reasoning Layer* contains both an OWL reasoner and a CAD reasoner which perform the semantic processing over the ontologies. The reasoner can be a typical OWL query engine (as in our case study) or a more powerful tool like RACER [7].

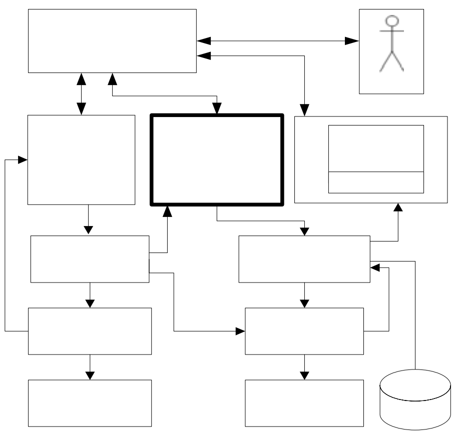

Fig. 2. Our Semantic Based Proposed Architecture

Next layer is called *Semantic Abstraction Layer* and it contains the Process Ontology and the CIS/2 Ontologies that actually represent the knowledge contained in the domain. Last layer is called *Instances Layer* and its main purpose is to contain the Process Instances and the CIS/2 Instances, as well as the concrete CAD model.

Interaction Module

3.2 - Interfacing a Steel Detailing CAD applications and OWL

Most of today's CAD programs offer an API (Application Programming Interface) in C++ to extend the system capabilities. On the other hand ontology programming is mostly done thru a Java interface. Interfacing C++ with Java is a technical problem that can be partially solved using JNI (Java Native Interface) allowing Java code to be called from a C++ based application. The problem arises when third party applications, like databases and specialized plug-ins with their own API's are used. In order to communicate from a specialized CAD for Structural Design and an OWL API, we developed an interface that allows the ontology instantiation of elements from the CAD program and the queering of the model from both environments. The interface uses socket technology in order to send and receive tokens that represent function calls and returns. Using this technique we are able to handle OWL API manipulations programmatically right from the CAD coding environment.

4 Case study – Semantic based tools

We present in this chapter three tools based on the architecture introduced in the last chapter. These cases were chosen specifically to solve particular problems reported by an actual Structural Design Company.

4.1 Tool 1 - Parts Generation and Verification from FEA (Finite Element Analysis) Results

In the design of a steel structure, usually different engineering software packages are used. Some of them are used to calculate stresses, allowed forces and other material static and dynamic issues. Those calculations are commonly performed by FEA packages who give as output the suggested dimensions of the needed elements. A common design process starts with a 3D wire frame sketch drawn by the designer; this sketch passes through the FEA software and produces the mentioned outputs. The information obtained is not always a 3D CAD model, and even if that is the case, these elements are not 100% compatible with other stages of the design without the use of importers and exporters. The semantic based tool we developed is applied to this stage of the design to automatically generate the CAD elements that FEA software recommends in their proper places. The generated elements are CIS/2 compliant, allowing the data to be backward and forward compatible with other software tools. The OWL Reasoner Module is used for query purposes over the CIS/2 instances using description logics. The initial sketch drawn by the designer and the post- FEA model are compared by the Reasoner (see Fig. 3).

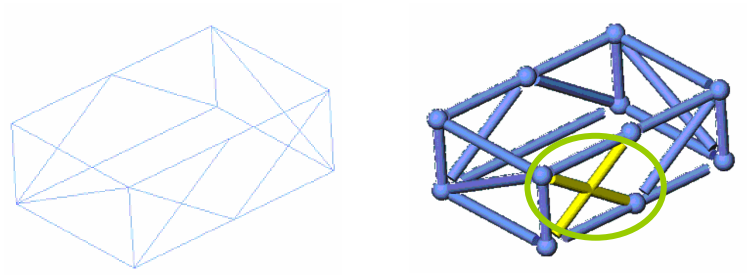

Fig. 3. Parts generation tool. Left: Frame drawn by designer. Right: CIS/2 element generation with automatic collision detection between created elements.

If the designer committed a mistake drawing the wire frame, the system can be used to check element intersections (collision detection) in order to avoid potential problems during the assembly phase of the structure. This checking is done not based on the geometry but via a query to the ontology thru the OWL API.

4.2 Tool 2 - Semantic Visualization of the CAD model in Virtual Reality

The model can be visualized in a VR environment using the geometries and relations between elements. User intention is taken into account as the system presents this tool in the Design stage of the structure (see Fig 4). A fast visualization helps the user to locate certain parts in the drawing to modify or add elements from a renderized view that gives a better impression that the common wire frame used in traditional approaches. Although it is true that modern systems allow faster visualizations, our implementation deals directly with the ontology and its instantiation of CIS/2 elements, given an extra aid as every entity is handled semantically. This tool is similar to the approach presented by Lipman [8] and Posada [13]. The novel aspect in this case is the exploitation of semantic aspects to generate simplified versions of the model according to certain stages in the Design Process, enhancing specific parts (e.g. coloring) and adapting the camera position (see Fig. 4).

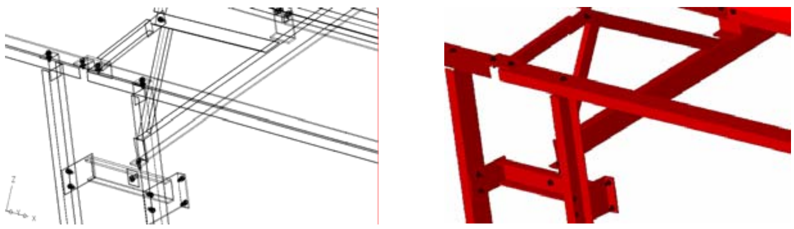

Fig. 4. Visualization tool, left wire frame in CAD, right VR output (CIS/2 compliant), this screenshot was taken in the design stage. Beam's color is automatically changed to help the differentiation of elements.

The interaction module allows the simultaneous interaction with the user interface inside the 3D CAD system and with the VR environment. The possibility to change an entity's color upon the stage of the design is taken by the OWL Reasoner. The values can be returned to the CAD in a bidirectional interaction (e.g. camera position, etc). This parameter exchange of non geometric data between the knowledge model and CAD is one of the clear benefits of our proposed schema.

4.3 Tool 3 - Special Beams dimensioning for workshop manufacturing

Besides Steel Structures, some companies in the steel detailing field manufacture wood based frames for small facilities. These wood-based structures are designed with both a functional and an aesthetic intention. Usually, wood beams manufacture is still carried out in large spaces by artisans, without the support of NC (numerically controlled) machines. These structures should be dimensioned considering that the actual workers, who cut the pieces, have difficulties in the interpretation of traditional CAD dimensioning. In many cases, they only have a metric tape to measure distances in a frame where very long beams are being shaped (in some cases reaching 20 meters long). The semantic system is activated in this case when a free-form beam sketch is drawn in the CAD program. When the beam doesn't match with a steel shape modeled in the CIS/2 LPM/6 Ontology, the semantic system activates a non steel frame and the user is presented with new dimensioning tools intended for the manufacturing workshop described above. Factors like the lamination direction of the wooden beams and special considerations that must be fulfilled in critical zones like corners and attachments are immediately taken into account (see Fig. 5).

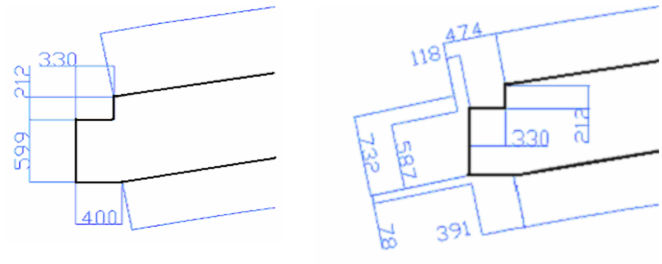

Fig. 5. Dimensioning tool. Left traditional CAD dimensioning. Right using our tool.

5 Conclusions and Acknowledgements

We presented in this paper an architecture and a system implementation for the exploitation of semantic aspects in the computer assisted design of Steel Detailing Structures (Structural Design). The architecture is based on two ontologies (process and domain model) whose elements and relations are instances based on a standardization effort called CIS/2. As test cases, we developed three tools intended to aid in particular stages of the structure's design process that were presented by a real Steel Detailing company in the frame of an industrial research project. As future work, we will extend the Process Ontology in order to identify stages where new tools can be developed from a deeper process oriented philosophy. We will also explore the collaborative design possibilities of our architecture. We want to thank the Basque Government for the partial financing of the MiroView Project (INTEK-4140/2004). A special mention is given to our Steel Detailer partner LANIK S.A, who served as test users, providing key points in their design workflow to apply the results presented in this paper. We also thank SOME for their participation in this project.

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