Weave Semantics Into Building Product Models: The Potential Role of Ontologies for Collaborative Design

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Abstract
With the application of Information and Communication Technology (ICT) in the construction industry, people aim to integrate heterogeneous information flow across the disparate disciplines throughout the project lifecycle. To achieve interoperability, several platforms or industry standards have been established, for example, Industry Foundation Classes (IFC) and aecXML developed by International Alliance for Interoperability (IAI). However, to exchange compatible information is insufficient for interoperability. Without necessary knowledge support, computing tools cannot “understand” what the information means and thus fail to integrate them. Ontologies, as concept models to support semantic interpretation of information, have aroused much research awareness in diverse industries. This paper starts from the delineation of a future collaborative design scenario, with the highlight of the potential role of ontologies for the collaborative design. Then we illustrate the rationale of ontologies with particular focus on the drawbacks of IFC. After a review of the current relevant researches in the construction industry, e.g. STABU LexiCon, eConstruct, ISTforCE, etc., we address the advantages of Protégé-2000 as an ontology editor in developing ontologies, and also state how prevailing languages, e.g. XML, RDF, and OWL can support ontology representation and exchange. We draw conclusion with depicting the future use of building product models in the whole project process.

Keywords
Building Product Model, Collaborative Design, Construction Industry, Ontologies

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1. Introduction – An Evolution of Collaborative Design

In Andy’s office, when he tried to design two columns to support the deck in the living area, as shown in Figure 1, he got a warning note from John’s agent, which represents the architect John, stating no columns would be preferred in this area. He asked the agent to explain on it. He was told that this design would definitely affect the functionality of the living area. Then Andy agreed and substituted the columns with some steel wires hanging down from the roof to support the deck. After this, he set his agent, to negotiate with John’s agent. Finally this new design was approved and the conflict was solved.

Behind these activities, there are some backstage processing works undertaken by agents. When John and Andy were doing their designs, their information organizing agents were developing ontologies for them. These ontologies also can be shown to the designers if they want to check them. Otherwise they are developed for information exchanging agents to access and exchange information.

What we describe above is not a typical collaborative design process today, but rather a new one that will evolve into tomorrow. Current drawings are designed for human to read, not for computer programs to manipulate meaningfully. Therefore communication problems due to misinterpretation still occur. This paper investigates the potential role of ontologies for collaborative design. In the following parts, we illustrate the rationale of ontologies with particular focus on the drawbacks of IFC. Then we review the current relevant researches, and state how prevailing tools can support ontology development.

2. Why The Ontology

2.1 Communication Model For Collaborative Design

In the collaborative design process, for different agents to communicate with each other, the sender needs to encode its knowledge into sort of media, and send this information through sort of communication channel to be decoded by the receiver. This process can be modeled as...
Figure 2. During the design process, the design evolves by going through the repeated cycle of representing and interpreting the design media.

These design media are the shared representations for different professionals to access in. However, they are only the collections of individual understandings. If lack of shared understanding, every professional can interpret the shared representations from his/her own perspective. This process is ad-hoc, and always results in misunderstanding, disagreement and conflicts. Take the above example, in terms of a living area, the architect concerns about the space, and the structural engineer concerns about the building elements, e.g. column, floor, wall, etc. How can we unite these different design metaphors?

With the support of ontologies as the backbone of the agents and media in the communication process, we can help the sender and receiver process the semantics and achieve a shared understanding.

2.2 The Drawbacks of IFC

After we illustrate the idea of ontologies to support collaborative design in the construction industry, some may claim that the industry has already developed such standard/platform to help integrating the disparate disciplines to achieve interoperability, e.g. IFC developed by IAI. In the 1990s, IAI initiated a project to develop IFC as the international standard to exchange data in the drawings, thus different CAD systems can reuse the building product models if they are IFC compatible. This project developed the EXPRESS language and the schema EXPRESS-G based on the object-oriented modeling language to describe the building entities and their relationships. It has achieved quite a success and popularity that now it has been adopted by many new developed visual design tools. With this background, people may ask what the difference is between IFC and ontologies, and what the drawback IFC has that prompts the development of ontologies. We try to compare them and state the drawbacks of IFC as shown in the following table.

<table>
<thead>
<tr>
<th></th>
<th>IFC</th>
<th>Ontologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Modeling purpose</strong></td>
<td>Exchanging compatible data</td>
<td>Processing semantics and reusing knowledge</td>
</tr>
<tr>
<td><strong>Modeling focus</strong></td>
<td>Format</td>
<td>Content</td>
</tr>
<tr>
<td><strong>Modeling level</strong></td>
<td>Data</td>
<td>Information/Knowledge</td>
</tr>
<tr>
<td><strong>Modeling language</strong></td>
<td>EXPRESS &amp; EXPRESS-G</td>
<td>RDF &amp; OWL</td>
</tr>
<tr>
<td><strong>Highly structured</strong></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Hierarchy type</strong></td>
<td>Is-a, part-of</td>
<td>Defined by users freely</td>
</tr>
<tr>
<td><strong>Support dynamic changes</strong></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Support multi-perspective modeling</strong></td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

We argue that IFC is a subset of ontologies in the construction industry. That means ontologies contain more information than IFC by weaving semantics into the building product models. In this respect, ontologies do not compete with IFC, or any other product modeling languages, such as ISO STEP
(Katranuschkov et al, 2003).

3. How Ontologies Be Developed

3.1 Current Worldwide Researches in the Construction Industry

Due to the advantages of ontologies, currently there are lots of researchers carrying out worldwide researches across different fields, e.g. computer science, medicine, manufacturing industry, etc. In the construction industry, ontology is still in its infancy and of limited practicability. But researchers foresee its potentials and dedicate on prompting its use to achieve interoperability in the industry. We highlight some of these researches as follows:

- **STABU LexiCon³**:  
  The STABU LexiCon is an initiative to develop the ontology “dictionary” in the construction industry. It defines the object library including wall, floor, brick, bridge deck, etc. With this, it aims to reduce the possibility of miscommunication due to the misuse of the terms and the ad-hoc interpretation of the object definitions.

- **eConstruct⁴**:  
  This project’s full name is eCommerce and eBusiness in the European Building and Construction Industry: Exploiting the Next Generation Internet. Its result is the development of a XML vocabulary named bcXML to facilitate a fast, secured, open and cheap electronic business for the building and construction industry, and it can co-operate with other XML vocabularies, i.e. the aecXML⁵ developed by IAI.

- **ISTforCE⁶**:  
  The above acronym stands for Intelligent Services and Tools for Concurrent Engineering. This project developed a service platform for e-commerce, multi-media and electronic signature, multi-project participation and workflow support, legal framework support for legally binding work results and an audit trail, etc.

All these projects, just to name a few, aim to harmonize the heterogeneous information flow in the building and construction industry with the use of semantic electronic integration tools. Besides these ambitious initiatives, in other countries, i.e., USA, bunches of researchers are developing ontologies for specific projects. These ontologies may not be as comprehensive as those in European countries, but they are more practical to use and can merge with other ontologies easily. Such efforts can be referred to O’Brien, et al. (2003), Garcia, et al. (2003), etc.

⁴ [http://www.econstruct.org/default_frame.htm](http://www.econstruct.org/default_frame.htm)  
3.2 Ontology Editor – Protégé 2000

To develop ontologies, several ontology editor softwares can be chose, such as Protégé 2000\(^7\), Ontolingua, WebOnto, OntoEdit, etc. In this paper, we describe Protégé 2000, a graphical tool for ontology editing and knowledge acquisition with new and evolving Semantic Web language, i.e. OWL and ezOWL plugin. Comparing with other software, Protégé 2000 can interoperate with other ontology development platforms and support for most of the activities of ontology lifecycle (Corcho, et al, 2002). It concentrates on the concept models instead of the syntax of the languages to be used on the web. One of the advantages of Protégé 2000 is translating a model from one language to another is as easy as selecting a “save as…” item from a menu. Another key feature of Protégé 2000 is it allows the user to define the meta-class and meta-slots to fit the personal needs of concept modeling. For more technical information, please refer to its website.

3.3 Supporting languages: XML, RDF & OWL

To support the access and exchange of ontologies among agents, the ontologies should be represented in a sort of languages. We compare several languages as follows:

- **XML (Extensible Markup Language)**\(^8\) and XML Schema:
  XML evolves from Hypertext Markup Language (HTML) and Standard Generalized Markup Language (SGML). It provides a syntax for structuring documents to be published on the web. Comparing to HTML, it can have user-defined tags to be inserted in a document, thus it can extract pieces of text out of a document, and link to arbitrary portions of web pages. XML schema is a language for restricting the structure of XML documents. The limitation of XML is it has no semantics.

- **RDF (Resource Description Framework)**\(^9\) & RDF Schema:
  RDF is a data model for objects and relations between them, proving a simple semantics and can be represented in XML syntax. RDF schema defines the meta-data for the objects and their relations.

- **OWL (Web Ontology Language)**\(^10\):
  OWL adds more vocabulary for describing properties and classes, the relations between classes, e.g. “disjointness”, cardinality, e.g. “exactly one”, characteristics of properties, e.g. “symmetry”, and enumerated classes. It has three sublanguages: OWL Lite, OWL DL and OWL Full. OWL Full can be viewed as an extension of RDF, while OWL Lite and OWL DL can be viewed as extensions of a restricted view of RDF (Thuraisingham, 2002).

In Protégé 2000, the developed ontologies can be exported as OWL file, thus enabling agents to exchange and merge ontologies easily.

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\(^7\) [http://protege.stanford.edu/index.html](http://protege.stanford.edu/index.html)
\(^8\) [http://www.xml.com/pub/a/98/10/guide0.html](http://www.xml.com/pub/a/98/10/guide0.html)
\(^9\) [http://www.w3.org/TR/1999/REC-rdf-syntax-19990222/#intro](http://www.w3.org/TR/1999/REC-rdf-syntax-19990222/#intro)
\(^10\) [http://www.w3.org/2001/sw/WebOnt/](http://www.w3.org/2001/sw/WebOnt/)
4. Conclusion – The Future of Building Product Models

With what we discussed above, ontologies weave semantics into building product models and act as the backbone to support different agents to exchange meaningful information. Based on this, the potential role of ontologies in the construction industry is not merely to enrich the building product models. It will drastically change the way we use the product models today.

Let’s back to the scenario described at the beginning of this paper. During the design process, let’s suppose the architect change a door in a drawing, then this change can be propagate automatically to the fire engineer for fire rating, or the acoustic designer for noise control. By this means, all the information can be updated dynamically without human intervention. Furthermore, Current drawings only tell you what can be constructed in Auto CAD. It may not be constructed in the real world. With the integration of “how” knowledge in the building product models, we can have agents to represent the contractors to join the design to avoid the above problem. For project managers, we can also have agents to represent them to participate in the whole project process. Therefore, we can foresee this potential: when a set of activities (process model) presented in a screen, the related components (product model) could be activated in a second screen, the responsible players (organization model) in a third screen, the cost estimation based on the quantity surveying in the fourth screen, and the plan and scheduling in the fifth screen. This holistic view of the project management allows customized information feed in its proper context, facilitating shared understanding and enable the right information delivered to the right hand at the right time.

5. References


