Formal Specification of the IFC Concept Structure for Precast Model Exchanges

M. Venugopal[1], C. M. Eastman[2] and J. Teizer[3]

[1] Postdoctoral Research Fellow, School of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Dr. N.W., Atlanta, GA 30332-0355, PH (510) 579-8656, FAX (404) 894-2278. E-mail: manu.menon@gatech.edu
[2] Professor, College of Computing and Architecture, Georgia Institute of Technology, 247 Fourth Street N.W., Atlanta, GA 30332-0155. E-mail: charles.eastman@coa.gatech.edu
[3] Assistant Professor, School of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Dr. N.W., Atlanta, GA 30332-0355. E-mail: teizer@gatech.edu

ABSTRACT

The Industry Foundation Classes (IFC) provides a rich and redundant schema for interoperability. However, IFC lacks semantic clarity in mapping entities and relationships resulting in multiple methods to map the same information. This research explores a software engineering methodology based on engineering ontologies to develop a formal, consistent and machine-readable structure for IFC entities, attributes and relationships. Various issues such as the need for a logical framework, the current semantic approaches in AEC/FM and advantages of ontology for IFC are addressed. Details of the approach are illustrated by building application ontology for precast model exchanges. This research is expected to impact the overall interoperability of BIM tools by providing a formal and consistent taxonomy and classification structure for creating model view definitions (MVD) using IFC.

INTRODUCTION

The Industry Foundation Class (IFC) schema is accepted as the industry standard for interoperability (IAI 2003, ISO 2005) and is currently in the process of becoming an official international standard - ISO/IS 16739 (buildingSMART 2010). However, model exchanges based on IFC are still error prone and incomplete (Kiviniemi 2007). The current model view development methodologies, which are based on use-cases leaves scope for different interpretations based on end-user requirements and lacks a formal framework. Moreover, the granularity and atomicity with which such model views are defined is not consistent across the industry (Venugopal et al. 2012). This adds to the overhead for software developers and hinders IFC based implementations (Eastman et al. 2011).

This research aims to improve the interoperability of BIM tools in the AEC/FM domain by providing a formal definition of IFC entities, relations, attributes and methods for information exchange, using engineering ontology. Ontology is a formal representation of an abstract, simplified view of a domain that describes the objects, concepts and relationships between them that holds in that domain (Gruber 1993). There are different classifications of ontologies, based on parameters such as level of granularity, their use and types of relationships (Gruber and Olsen 1994, Van Heijst 1997, Fensel 2000, Gomez-Perez et al. 2004). Ontology in this regard can be considered as a machine-readable set of definitions that create taxonomy of classes and subclasses and relationships between them. Explanation of developing an ontological foundation for IFC is provided and is applied in the development of model exchanges for precast/pre-stressed concrete industry.

SEMANTICS AND INTEROPERABILITY

The scope and potential of BIM is ever-increasing as a result of new and IT-enabled approaches to facilitate design integrity, virtual prototyping, simulations, distributed access, retrieval and maintenance of project data between multiple disciplines (Fischer and Kunz 2004, Smith 2006). Interoperability enhancements require common understanding of industry processes and the information required for and resulting from executing these processes. Two sets of semantics are at the core of any model view specification, namely, (i) the user/application functional semantics defining the information that must be exchanged, and (ii) the representational semantics available in IFC or other data-modeling schema for representing the user intentions (Venugopal et al. 2012). There are parallel approaches to introduce semantics into building information modeling, by means of using web standard technologies (W3C) and techniques (Yang and Zhang 2006, Bohms et al. 2008, Beetz et al. 2009). *Semantic web* is an example of inter-linked data available in a standard format, reachable and manageable by automated tools. *Web ontology language* (OWL) is the formal ontology language developed for the semantic web. Similar sets of issues were faced by the semantic web development effort as compared to IFC interoperability. By building an ontology structure, we define the semantics of each of the objects, relations, and other constructs used in IFC according to their often-implicit meanings. With its highly intuitive, compact syntax and well-defined formal semantics, ontology is able to represent knowledge and defines the relationship between terms allowing applications to interpret their meaning in a flexible and unambiguous manner and enable reasoning capabilities.

AN ONTOLOGY FOR PRECAST MODEL EXCHANGES

The objective is to formalize IFC definitions for a robust model exchange solution. In terms of the modeling criteria, a corpus or body of knowledge needs to be constituted. Entities are selected from the available domain-specific documentation according to the ontology requirements. The *precast national BIM standard* model view (Eastman et al. 2010) in general and the building components in particular are selected as the corpus in this case. The objective of the ontology definition is to add detail where necessary, incorporating formalisms wherever helpful, and generally enhancing the consistency and modularity of IFC entities, attributes, and relations, as shown in Figure 1. A sound base is important for building any hierarchy. This is achieved in this research by structuring the ontologies on a foundational ontology such as *descriptive ontology for linguistic and cognitive engineering* (DOLCE) (Masolo et al. 2002). This is the most abstract layer, introducing the basic modeling concepts and generic design guidelines for the construction of actual ontologies. The second layer consists of super theories such as *mereology, topology* and *systems theory* (Borst 1997), that are reusable modules according to which ontology is organized. The final layer comprises of application specific ontologies such as structure of object (precast specific material, geometry, etc.) and properties. The application layer refines the ontology to be used for precast model exchanges by adding classes and relations for practical application of ontology. In this case, the precast application ontology is built from (i) components, (ii) connections, (iii) system, (iv) placement, (v) material, (vi) geometry and (vii) requirements ontology, as shown in Figure 2.

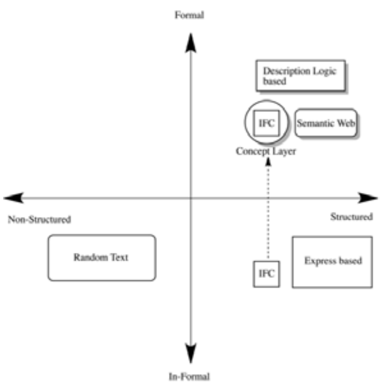

Figure 1. Ontology based concept layer to improve formalism of IFC.

Figure 2. Structure of the application ontology for precast model exchanges.

Ontology definitions: Application ontology is built on top of engineering ontologies. The *precast application ontology* defines how a precast model should be specified in general, in the form of a set of theories. A precast piece can be modeled using the above-defined engineering ontologies, which are a part of the application ontology. Depending on the needs we can define a precast piece ontology using component, connections, system, etc. and adding classes for requirements, placement, and geometry. The following paragraphs provide excerpts of the ontology definitions. The components ontology is used to represent the components in a building model and their part-whole decomposition in this research. A component is a general concept that encompasses all individuals used to describe the structure of an object. A component is considered to be atomic if it cannot be decomposed into any further parts. Components can be part of an assembly as well. However, assemblies can be made up of atomic components or smaller assemblies. Part-whole relationships are of two types, namely, *'part-of'*, and *'proper part-of'* relations. '*Part–of'* is the general relationship that covers all the individuals in this ontology, whereas *'proper part-of'* restricts this relationship, that implies the individual cannot be distinguished from the sum of its parts. A perfect example is the slab-beam aggregation. A slab is the aggregation of individual beams, which means that beams are a proper part of the slab. The project-site-building-building story hierarchy is simply a '*part-of*' relationship. Moreover, in the case of *'proper part-of'* relationship, the geometry of the parent is the resulting sum of the individuals. Taking binary product of two individuals can check overlap. A beam is resting on a column, these two individuals are not supposed to overlap. Hence, they cannot have a dot product, and therefore the shared part has to be assigned only to one of the individuals. The binary sum is the individual that encompasses at least one of x and y. The difference x-y is the individual that is a *'proper part-of'* x but does not share a part with y. Sum provides a boolean addition to a precast piece, such as a corbel. Difference can be used for voids. Any individual from the component ontology can be elevated to the level of type. Instances are related using the *'type-of'* relationship. Connection ontology provides the connections between objects by means of the *'is-connected-to'* relationship. The relationship *'in system'* aggregates individuals in to a system.

The structural ontology is qualified by three relationships '*has representation'*, *'has material association'*, and *'has placement'*. An object has material associated with it, however the material requirement is extended and defined in the *requirements ontology*. Every individual has a placement relationship and can be realized by three different mechanisms, namely, absolute placement, placement relative to a grid, and placement relative to another individual. The requirements ontology contains main concepts needed for the representation of the function and behavior of individuals. For example, the requirements for a precast piece can be decomposed into requirements related to performance, design criteria, delivery methods, etc.

The objective of the ontology layer is to remove the ambiguities associated with differing viewpoints. For example, Figure 3. (a) shows a precast piece to be exchanged between the structural engineer and a precaster. A precast piece such as a floor slab can be represented as a monolithic slab entity in the structural model (Figure 3. b) developed by engineer, whereas the fabrication model developed by precaster will include the high level details of discretized hollow core slabs for the entire span of the floor along with the connection details, finishes, joints, embeds, reinforcing, tensioning cable layout, lifting hooks, etc. (Figure 3. c). The corresponding IFC entities and relationships will also be different as shown in Figures 4 and 5. The structure of a model view for the exchange of product model data between various BIM application tools depends on the extent to which building function, engineering, fabrication and production semantics will be embedded in the exchange model at the source and the capability of any receiving application to comprehend them. In order for the importing application to infer knowledge from the exchange, the exporting application should structure the data based on an agreed upon standard. The ontology definitions provide a means to remove ambiguity in such scenarios, by using constraints that define the relationships and also provide equivalences between individuals.

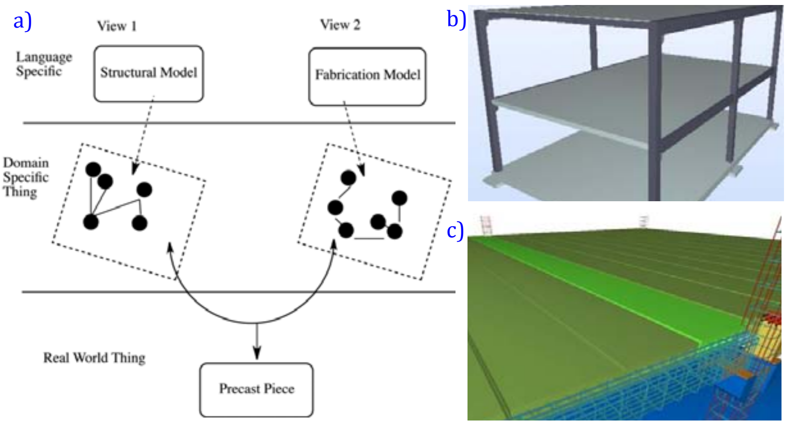

Figure 3. The different view points of same objects in different domains

APPLICATIONS OF THE ONTOLOGY LAYER

Ontology specifies how the application's functionality is to be implemented and it serves roles similar to ER diagrams, object models, and object patterns. In the case of model exchanges, the ontology is intended to provide the structure of the model view. For this purpose, the ontology layer developed in this research is converted to an object-oriented class library. This additional layer of mapping is used for implementations. IFC entities, relations, attributes, etc. are mapped onto the application ontology developed in the previous phase. This allows ontology language and definitions and modeling representations such as IFC to stay invisible to the end user (similar to data hiding in object oriented design). This significantly lowers the barriers for practitioners (software developers). This library is meant to be an extensible one and it is envisioned that future model views will be developed based on this library.

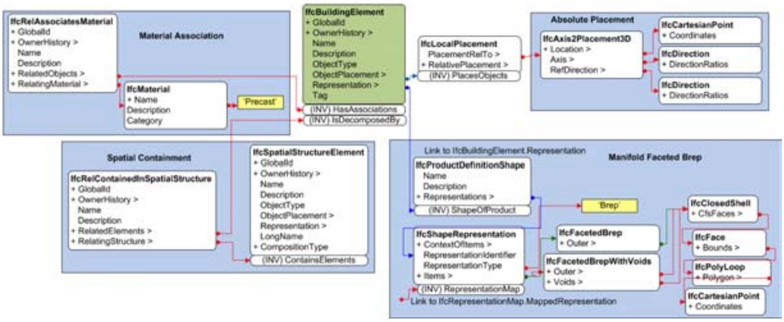

Figure 4. IFC mapping for a monolithic precast floor slab

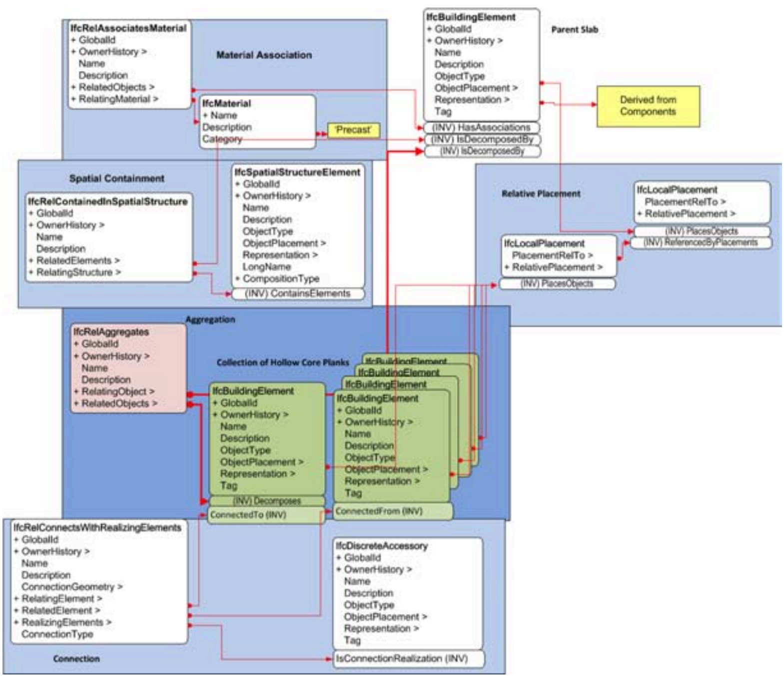

Figure 5. IFC mapping for a floor slab with discretized hollow core precast slabs

CONCLUSION

IFC is a rich model that addresses the needs of different applications and provides a variety of ways to define the same part of a building. Hence additional layers of specificity such as model views are required for IFC implementations. This brings to the forefront the need for a more logical framework to specify model views. The number of research and industry-based initiatives to develop model views in different areas underlines this need. This research specified a formal classification structure in the form of ontology, for the IFC entities, relations, and attributes to be followed in the development of model views for precast/pre-stressed concrete industry. The usefulness of ontologies for specifying model views in a consistent manner is illustrated. There are plans to develop an object-oriented library based on the ontology definitions and specify exchange requirements directly based on this library. Once fully implemented and tested, such an approach can be followed for creating industry-wide model views.

ACKNOWLEDGMENTS

The work presented here was funded by the National Institute of Standards and Technology (NIST), grant number 60NANB9D9152. All information presented is that of the authors alone.

REFERENCES

Beetz, J., Van Leeuwen, J., and De Vries, B. (2009). "IfcOWL: A case of transforming EXPRESS schemas into ontologies," *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, vol. 23, no. 01, pp. 89–101.

Bohms, M., Bonsma, P., Willems, P., Zarli, A., Bourdeau, M., Pascual, E., Storer, G., Kazi, S., Hannus, M., Sedano, J. (2008). "The SWOP Semantic Product Modelling Approach," Technical Report STRP NMP2-CT-2005- 016972 "SWOP", TNO-04.

Borst, W. (1997). Construction of engineering ontologies for knowledge sharing and reuse. PhD thesis, Centre of Telematica and Information Technology, Universiteit Twente: Enschede, The Netherlands.

BuildingSMART. (2010) Industry Foundation Class (IFC) data model, <http://buildingsmart.com/standards/buildingsmart-standards/ifc> (Oct. 23, 2011).

Eastman, C., Panushev, I., Sacks, R., Venugopal, M., Aram, V., and See, R. (2011). "A guide for development and preparation of a national bim exchange standard," technical report, buildingSMART, <http://www.buildingsmartalliance.org/client/assets/files/bsa/IDM- MVD Development Guide v4.pdf> (Oct. 23, 2011)

Eastman C. M., Sacks, R., Panushev, I., Venugopal, M., and Aram, V., (2010). "Precast concrete bim standard documents: Model view definitions for precast concrete", volume-1, Precast/Prestressed Concrete Institute Report <http://dcom.arch.gatech.edu/pcibim/documents> (Oct. 23, 2010)

Fensel, D., Horrocks, I., Van Harmelen, F., Decker, S., Erdmann, M., and Klein, M. (2000). "Oil in a nutshell," p. 1, Springer Verlag.

Fischer, M. and Kunz, J. (2004). "The scope and role of information technology in construction," *in Proceedings - Japan Society of Civil Engineers*, pp. 1–32, Dotoku Gakkai.

Gomez-Perez, A., Fernandez-Lopez, M., and Corcho, O. (2004). *Ontological Engineering: with examples from the areas of Knowledge Management, e-Commerce and the Semantic Web.* Springer Verlag.

Gruber, T. (1993). “A translation approach to portable ontology specifications,” *Knowledge acquisition*, vol. 5, no. 2, pp. 199–220.

Gruber, T. and Olsen, G. (1994). “An ontology for engineering mathematics,” in *Fourth International Conference on Principles of Knowledge Representation and Reasoning*, Gustav Stresemann Institut, Bonn, Germany, Morgan Kaufmann, pp. 241–245.

IAI. (2003). “Industry foundation class (ifc) data model,” tech. rep., BuildingSMART,<http://buildingsmart-tech.org/specifications/ifcreleases/summary> (Oct. 23, 2011).

ISO. (2005). “ISO/PAS 16739:2005,” Industry Foundation Classes. <http://www.iso.org/iso/> (Oct. 23, 2011).

Kiviniemi, A. (2007). “Ten Years of IFC Development- Why are we not yet there?,” in proceedings, *CIB-W78* Keynote, Montreal.

Masolo, C., Borgo, S., Gangemi, A., Guarino, N., Oltramari, A., and Schneider, L. (2002). “The WonderWeb library of foundational ontologies,” WonderWeb Deliverable D, vol. 17.

Smith, I. (2006). *Intelligent computing in engineering and architecture.* Springer-Verlag, GmbH.

Van Heijst, G., Schreiber, A., and Wielinga, B. (1997). “Using explicit ontologies in kbs development,” *International Journal of Human Computer Studies*, vol. 46, pp. 183–292.

Venugopal, M., Eastman, C. M., Sacks, R., Teizer, J., (2012). “Semantics of model views for information exchanges using the industry foundation class schema”, *Advanced Engineering Informatics*, (in press). doi:10.1016/j.aei.2012.01.005.

Yang, Q. and Zhang, Y. (2006). “Semantic interoperability in building design: Methods and tools,” *Computer-Aided Design*, vol. 38, no. 10, pp. 1099–1112.

BIM Approach for Automated Drafting and Design for Modular Construction Manufacturing

A. Alwisy[1], M. Al-Hussein[2] and S. H. Al-Jibouri[3]

[1]PhD student and Research Assistant at the University of Alberta, Department of Civil and Environmental Engineering, Hole School of Construction. 1-080 Markin/CNRL Natural Resources Engineering Facility. Edmonton, Alberta, Canada T6G 2W2. E-mail: alwisy@ualberta.ca
[2]Professor, Department of Civil and Environmental Engineering, Hole School of Construction. 3-011Markin/CNRL Natural Resources Engineering Facility. Edmonton, Alberta, Canada T6G 2W2. E-mail: malhussein@ualberta.ca
[3]Associate Professor, University of Twente, Faculty of Engineering Technology, Department of Construction Management & Engineering. P.O.Box 217, 7500 AE Enschede, The Netherlands; S.H.S.Al-jibouri@ctw.utwente.nl

ABSTRACT

Industrialization creates new requirements for design. Designers need to consider not only building performance, but also production plan needs. This requires a well-structured Building Information Model (BIM) to support the manufacturing needs for design and drafting. BIM, in combination with CAD tools such as AutoCAD and ArchiCAD, can be used for this purpose. These, however, are not sufficient to support the level of detail needed for the manufacturing process.
The proposed research establishes a methodology for the automation of design and drafting for the building manufacturing of residential facilities based on the platform construction framing method. The proposed methodology has been incorporated into a computer model called MCMPro, which was developed using Visual Basic for Applications (VBA) as an add-on to a CAD model. MCMPro incorporates BIM technology based on CAD parametric modelling and manufacturing requirements in a 3D-model, in order to generate sets of shop and fabrication drawings.

INTRODUCTION

A primary motivation behind a shift towards manufacturing industrializing the building process is to reduce cost and time-to-build, improve the quality of the buildings, and produce more energy efficient buildings. Industrialization creates new requirements for design. Traditionally, building performance has been the only factor considered by architects and engineers, and building drawings and specifications as the outputs of the design and engineering process. In factory-based construction, designers need to consider not only the building performance, but also production plans, transportation plans between the factory and the project site, and installation plans. Automating the design and drafting process is the first pillar of the industrialization of the building construction process or modularization. Design and drafting plays a major role in the cost-effectiveness, timeliness, and quality of the entire process. Advantages in terms of reducing redundant design activities, providing an infinite number of solutions, eliminating assumption and design errors, and shortening the time needed for any modification can be obtained from automating the design and drafting modeling process.

A novel systematic way of construction is the solution for current construction challenges. This systematic methodology covers a project's construction process from its early design stage until the final delivery. A special focus on the design process is required, because managing the design process is a core issue in the Architect/Engineer/Contractor (AEC) sector, it plays a major role in the cost effectiveness, timeliness and quality of the entire project (Chua et al. 2003). Having a well-defined and detailed set of construction drawings is also essential for better communication and coordination among construction project team members (Gao et al. 2006).

The proposed methodology in this paper focuses on two main directions: the development of a construction manufacturing technology and an automated system for design and drafting of manufacturing of buildings for the North American building construction industry, focusing on wood-framing construction. The manufacturing technology and the utilization of best practice for the platform-frame method has been incorporated into BIM models as a set of scenario-based analysis (SBA) rules that mimic human intelligence, incorporating the building code requirements and structural and architectural design needs.

LITRATURE REVIEW

STATE-of-the-Art Literature of the Application of Building Information Modeling (BIM) in Construction. The multidisciplinary nature of modular construction manufacturing, which implies the need for a model to integrate all the