AN IFC-BASED SEMANTIC FRAMEWORK TO SUPPORT BIM CONTENT LIBRARIES

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ABSTRACT

Building Information Modeling (BIM) has advanced from an innovative concept to a very practical technology which is now making a lot of sense to the construction industry in all sectors. Rich data associated with Building Object Models (BOMs) are the enabler of many analysis and simulation processes that were impossible using traditional 2D design approaches. However, there is no commonly agreed standard to define what information needs to be included in a BOM and how it should be organized. Furthermore, the organization and utilization of BIM content libraries are seldom studied. This paper proposed an ontology-based framework to support BIM content libraries. There are several issues in existing libraries: the dilemma between integrating more properties and proper model size, the difficulty to include commercial information of products, heterogeneous navigation system, and the difficulty to search or validate a model at property/parameter level. In order to address those issues, an IFC-based and IFD Library compliant Building Object Ontology (BOO) was created to support the semantics of BOM definitions at property level. Supported by this framework, a BIM content library can flexibly and dynamically instantiate a building product, support multi-view navigation, semantically search and validate models against properties, and support structured social annotations.

Keywords: BIM content library, ontology, IFC, IFD library, building object model

1. INTRODUCTION

Building Information Modeling or BIM has evolved from an innovative approach in design and construction for pioneering adopters just about few years ago to a firm place in all major sectors/players in the construction industry in 2012. Based on a survey conducted by McGraw-Hill Construction (Jones and Bernstein, 2012), the industry-wide adoption of BIM in 2012 is 71% in North America, compared to 28% in 2007.

The nature of BIM is that a facility is represented as a compositional model of many digital objects. With the advance of computer technology, it is now possible to enrich the digital objects with many kinds of data, not only geometry data but also information about functional features, material attributes, mechanical capabilities, construction schedule, cost, operation and maintenance. The scope of data association is still expanding to cover more application fields. As a result of the digitalization and parameterization of those data, it is now possible to enable real-time and on-demand analysis and simulation, and in turn to realize better collaboration and coordination in design and construction by filling the gap between business processes.

1.1 Building Object Models

Because digital building objects play an essential role in BIM, the way to model and organize those objects is becoming increasingly important. Every BIM authoring tool, such as Autodesk Revit, Graphisoft ArchiCAD, and Bentley AECOsim, has a predefined library of Building Object Models (BOMs), which either have fixed geometry or are with parametric dimensions. A BOM incorporated in BIM tools is typically a generic object defined based on the most basic and common data agreed by the majority of the industry for that type of object but does not include many manufacture-specific information (Eastman et al., 2011). For example, a window in Revit is defined by its geometry, material and finish, identity data such as manufacturer, model, description, URL, cost, and OmniClass information, and limited analytical data such as heat transfer coefficient, solar heat gain coefficient, thermal resistance, visual light and transmittance. Some of those properties are mandatory (for example, geometry) and others are optional and the values could be filled along the design progress. The final specification of an object defines what the final constructed or purchased product should achieve and serves as a guide for selecting or constructing the physical object in reality.

There is another type of BOMs which are manufacturer-specific building components. There are potentially hundreds of thousands of building products in the market – Reed Construction Data lists 14,099 building product manufacturers from North America as of February 3, 2013, in their database and each of them produces a few to many products. Those products are normally Make-To-Stock (MTS) or Make-To-Order (MTO) products which can be found from manufacturer's catalog, such as doors, windows, equipment, furniture, and fixtures. Some building components have to be customized to fit a specific location and fulfill certain building functions, such as some structural steel frame members or custom kitchens. They are called Engineer-To-Order (ETO) components.

1.2 BIM Content Library

Normally manufacturer-specific BOMs are not included in BIM authoring tools due to their overwhelming quantity, but managed by BIM content libraries. A BIM content library refers to a system that organizes a set of BOMs in a structured approach to provide easy access, management, search, and visualization of models. There are several advantages of using a BIM content library:

- A BOM includes the most accurate information if it is authored and maintained by it manufacturer.
- It enables the re-use of a predefined model, so that a designer does not need to create a generic component first then specify its properties based on the information obtained from the manufacturer.
- It provides designers with a large number of selections, ideally supported by an effective search mechanism.

Many BIM content libraries became available to the industry in last few years. Most libraries host a variety of types of building components from different manufacturers, while some manufacturers build a library dedicated for their own products. They are either online portals or offline desktop systems, and can be classified by many other features (see Table 1 for a summary of popular libraries):

- Some libraries are public/free and others are proprietary.
- Many libraries employ Revit family categories as their navigation system and others use different navigation systems such as manufacturers. Some support several navigation systems.
- Some libraries accept models uploaded by users and others are download-only.
- Some libraries publish modeling guidelines and others just follow rules from popular BIM tools.
- Many libraries host models in multiple formats and others are application specific.
- Some libraries rank models based on user ratings and other do not take social ratings.
- Some libraries are integrated with BIM tools and others are not linked with BIM tools.

2. PROBLEM STATEMENT

In order to better support BIM practices in design and construction, it is necessary to discuss object model definition and library organization. This section will review several topics to address the current practices and reveal associated problems: information included in BOMs, integration of commercial data, library navigation system, object search and validation, and social ranking and annotation.

2.1 Information in BOMs

It has been widely discussed what information should or should not be modeled for an object or a project (Hooper and Ekholm, 2011; Guttman, 2011; Nour, 2010; Anumba et al., 2009; Bedrick, 2008). For the purpose of supporting analysis and facilitating work processes, it requires different information content at different levels for specific application scenarios. For example, cost information is not required in mechanical analysis but needed for estimation, and levels of detail for cost information are different for conceptual design phase and construction document phase. Intuitively, a BOM needs to include as much information as possible at all levels to fulfill any possible application in the whole life cycle of a construction project. Unfortunately, this will make the entire project model too big and slow in operation for most personal computers and workstations.

In order to balance the usefulness and operability, the current practice is that software vendors integrate information content based on the intended use of their products. Manufacturers have to rely on modeling software to create BOMs of their products so that the value of a parameter is hard to be integrated in a BOM if the parameter is not available in the modeling tool. Partially due to the different parameter sets between BIM tools and partially due to the interoperability issue, one can see that BIM content libraries contain many types of models. The real issue in this topic is that there is no single consistent format to define and maintain all parameters of a building object to be re-used on demand by multiple BIM applications.

Table 1: Comparison features of BIM content libraries

Libraries	Public/ Private	Navigation	User Upload	Modeling Guidelines	Content Format	Ranking	BIM Tool Integration
Autodesk Seek	Public	By Revit categories, attribute	Yes	Yes	Revit, AutoCAD	No	Revit, AutoCAD, Inventor
Revit City	Public	By MasterFormat, by object types	Yes	No	Revit	Rating	No
ArchiBase Planet	Public	By object types	Yes	No	ArchiCAD	No	No
CadCells	Private	By model application	No	No	Bentley cells, AutoCAD	No	Some Bentley Products
Google Warehouse	Public	By search tags created by users	Yes	No	SketchUp	Rating	No
Smart BIM Library	Private	By Revit categories, MasterFormat, user-defined tags	No	Yes	Revit	No	Revit, support drag-n-drop
National BIM Library	Private	By object types, manufacturers	No	No	Revit, ArchiCAD, Vectorworks, Tekla, Bentley	No	No
BIM Stop	Public	By object types, manufacturers	Yes	No	Revit, ArchiCAD, Vectorworks, SketchUp, Bentley, IFC	Rating	No
OpenAsset BIM	Private	By Revit categories	Yes	No	Revit, SketchUp	No	Revit, SketchUp
Sweets BIM Collection	Private	By MasterFormat, manufacturers	Yes	No	AutoCAD, Revit	No	No

2.2 Integration of Commercial Data

The information content discussed so far to be integrated in BOMs is all about static technical parameters such as geometry and physical properties. By investigating the current industry practices and extensive review in the literature of both BIM content libraries and electronic product catalogues, it was found that there lacks a kind of integration between the commercial data of building products and their digital models. The main reason is that most commercial data are dynamic and could be updated at any time throughout the life cycle of the product. For example, the price of a product may change between the time of design and the time of construction. Another example is that the replacement of a product may become discontinued in the long run of operation and there may be a substitute option.

Nour (2010) proposed a concept Object Information Pack (OIP) as the way to encapsulate multidisciplinary and continually updated object information about a construction product or a service. Similar to a bar code, an OIP consists of two main parts: the technical identifier that consists of nice digits and the commercial identifier that consists of four digits. This approach used OIPs as a global unique identifier that enables the retrieval of structured data. However, the paper did not discuss what commercial properties are associated with the four-digit commercial identifier and how those commercial properties are organized in terms of their naming convention, value constrains, etc. For example, how does the system handle the in-house commercial properties (such as Cost in Revit) and the same concept in the external database? The issue in this topic is the dynamic commercial data should be linked to BOMs in a way compatible to existing BIM tools and standards.

2.3 Library Navigation System

As summarized in Table 1, there are three types of navigation systems employed by different BIM content libraries. The first type is by the system defined in a certain BIM software application, for example, Revit family classification system. The second type is by some popular classification standards, such as CSI MasterFormat®, UniFormat™, and OmniClass™. The last type is by user tags or object types defined by the library. The issue in this topic is that BIM content libraries need a navigation system which supports multiple classifications to find object models and supports user annotated tags for customization.

2.4 Object Search and Validation

Most BIM content libraries support search function but only by keywords. Some libraries such as BIMStop support refined search by setting conditions on model types or object types. Some libraries provide a 3D preview of a model but some quality and quantity data are not able to be obtained before the model is actually imported into a BIM authoring tool, for example, the size of window frame, the material of a table top, or the luminous Intensity Distribution Curve. It is very desirable to have a strong search function in a BOM library allowing semantic search for each individual parameter, for example windows that have a heat transfer coefficient not greater than 1 W.m-2K-1.

Along with need for parameter-level search, there is also a need for validating a model against parameters before it is accepted and stored in the library. Many BIM content libraries welcome user contributed models but either there is no mechanism to check uploaded models or it depends on manual check to ensure that all necessary parameters are filled and the value is in a reasonable range. The issue related to this topic is that currently BIM content libraries do not support search and validation at parameter level.

2.5 Social Rating and Annotation

More and more websites use social network concept to collect user opinions based on which the website can provide a more accurate service to its users. Currently not many BIM content libraries incorporate social rating and annotation function. For the few libraries where user can participate in rating and annotation, there is no structured way to organize annotations because the comments are submitted as plain text and it is not easy to mine the comment data to find important information. The issue in this topic is that there is a need for structuring and organizing user comments and providing effective feedback to the model author for quality improvement.

3. SCOPE

After reviewing building object models and their libraries, this paper discusses the problems to be addressed in order to achieve an effective approach in organizing BIM content libraries. It is necessary to clarify the scope of the work that has been done to propose an IFC-based semantic framework as described in next two sections. It has been discussed there are generic building objects and manufacturer-specific building objects, and a BIM content library discussed here will not cover generic building objects but only manufacturer-specific ones.

Building component manufactures produce MTS, MTO and ETO products. MTS products are components that are regularly supplied to the market, such as dry-wall panels and studs in standard dimensions. MTO products are components that are only produced when ordered, usually due to commercial reasons (for example high inventory costs), such as windows and doors in some special dimensions. ETO products are components that need some kind of customization to fit a one-time-only need (Eastman et al., 2011). The framework proposed here for BIM content libraries only covers MTS and MTO products, i.e. products normally shown in a manufacturer's catalogue.

4. SOLUTION CONCEPTS

4.1 Building Object Ontology

There is plenty of research discussing the use of ontologies to support semantics in the construction industry (Scherer and Schapke, 2011; Svetel and Pejanovic, 2010; El-Gohary and El-Diraby, 2011). An ontology is the formal conceptualization of knowledge in a certain domain (Zhang and El-Diraby, 2012). As the cornerstone to support semantic web (Web 3.0), ontologies mark up the content to be communicated and thus enable computer programs to understand each other. An ontology-based system also supports reasoning if the axioms are well defined.

This research proposed an ontology to encapsulate knowledge required to define building object models. It is not the first time to use an ontology to represent construction products. Osman and El-Diraby (2006) created an ontological framework to model infrastructure products and related concepts. The proposed Building Object Ontology (BOO) has four components:

- *Classes* to define object types and their sub types. For example, *Door*, *Interior Door*, and *Interior Sliding Door*.
- *Relations* to define object properties and sub properties. For example, *Thermal Property* and *Thermal Resistance*.
- *Instances* to define the value of some properties. For example, the value of *Stock Status*: *In Stock*, *Out of Stock, Back Order, Discontinued*.
- *Axioms* to define behaviours and rules of classes and relations. For example, the value of *Manufacturer* is a string and the value of *Warranty Status* is either *In Warranty* or *Out of Warranty*.

BOO explicitly defines types of BOMs with a hierarchical structure (super/sub class relations) and all properties that could be associated with building components. A single BOM is represented by its name (assigned class), all possible properties (assigned relations), and rules specific to this BOM (assigned axioms). It has been discussed earlier that including all possible properties of an object will significantly increase the size of a project model, however, BOO is the complete definition of a building component, so it has to include all possible properties, although some of optional properties may not be populated in an instance in an actual project designed by BIM tools. It will be addressed in more details later in this paper.

4.2 IFC and IFD Library Compliance

An important issue in the development of BOO is the naming of BOM types and their properties. BOMs are not able to be directly used in many BIM tools if their definitions are not compatible with the definitions of objects in other BIM systems. The objective of this proposed BIM content library framework is to organize BOMs in a way to support the majority of BIM tools, as such using a commonly agreed naming convention for BOO classes and relations is the minimum requirement.

There are some efforts going on to standardize information content of building objects. The most important one is Industry Foundation Classes (IFC) initiated and maintained by buildingSMART (Liebich, 2011). IFC is a neutral and open specification for modeling objects in the construction industry. As a de facto data standard, at the time of writing, IFC is supported by 151 commercial software applications, according to the online database from buildingSMART.

International Framework for Dictionaries (IFD) Library (Grant et al., 2008) is an effort more directly towards a standardized global terminology irrespective of languages for the construction industry. IFD Library concepts are derived from internationally-accepted standards such as ISO 12006-2, ISO 12006-3 and ISO 15926. IFD Library basically defines *Subjects* (concepts being defined) and *Properties* (concepts that define *Subjects*). IFD Library has a more broad coverage than IFC and can be mapped well with IFC object (through Global User ID or GUID) and major classifications systems (such as OmniClass, MasterFormat, and UniFormat).

The proposed BOO used OmniClass Table 21 and Table 22 as the reference for the class hierarchical structure and mapped class name to IFD Library through a property *hasIFDLibraryGUID*, whose value is populated when the IFD Library counterpart (a *Subject*) exists. Similarly, the properties defined in BOO used IFD Library *Properties* as its reference. This approach ensures the consistent mapping between IFC object in a project file, IFD Library GUID, major classification systems at both object level and its property level.

4.3 Integrate Dynamic Commercial Data

All possible properties related to a building component's commercial information are modeled in the BOO – if a property is defined in IFD Library or IFC, it will be mapped to the BOO. For the classes and properties that are not defined in IFD Library or IFC, names will be assigned based on literature reviews and industry surveys and will be updated when the definitions are available in the new release of those reference standards.

IfcPropertySet is used to implement the association of commercial data with BOMs. In order to enable a BIM content library to support parameter expansion and search, BOMs have to be stored at parameter level. This means an IFC file format is preferred for a BOM. The library may also include other file formats, such as Revit format, to facilitate some designers. As a manufacturer normally relies on BIM authoring tools to create a BOM which certainly does not include all properties defined in the BOO. This BOM has to be converted to IFC format and all missing necessary and optional properties, including those commercial properties, will be added to form a final version of this BOM (also in IFC format).

5. PROPOSED FRAMEWORK

The overall contribution of this paper is an IFC-based semantic framework for organizing BIM content libraries. Figure 1 shows the structure of the framework and will be explained in details in this section. This framework effectively addresses the issues discussed in the problem statement section.

- Information to be included in a BOM: A building component defined by BOO will have all possible properties and the instance of this component in the library (a BOM) should have all mandatory properties populated and optional properties may or may not be filled by model author. When a BOM is called by BIM tools, the designer will have a chance to select what properties should be imported into the BIM tools, based on the application scenario. If more properties are required at a later time, they can always be obtained via the link associated with the library.
- Integration with commercial data: A property table will pop up when a new BOM (in .ifc file format) is imported into the BIM content library showing all properties related to commercial information, BOM author then has a chance to fill them or not.
- Library navigation: This proposed framework supports multiple navigation systems. OmniClass structure is the default navigation system, and other systems, such as MasterFormat, UniFormat, Revit families, and user tags, can be achieved by classification mapping or social annotation.

- Object search and validation: A BOM will be validated against its definition in the BOO at the time of upload. Also, IFC format BOMs support semantic search at property/parameter level.
- Social rating and annotation: This proposed framework suggests not annotating BOMs using plain text but a structured method based on the BOO, so that those annotations could be mined and analyzed to provide meaningful feedback to model authors/users.

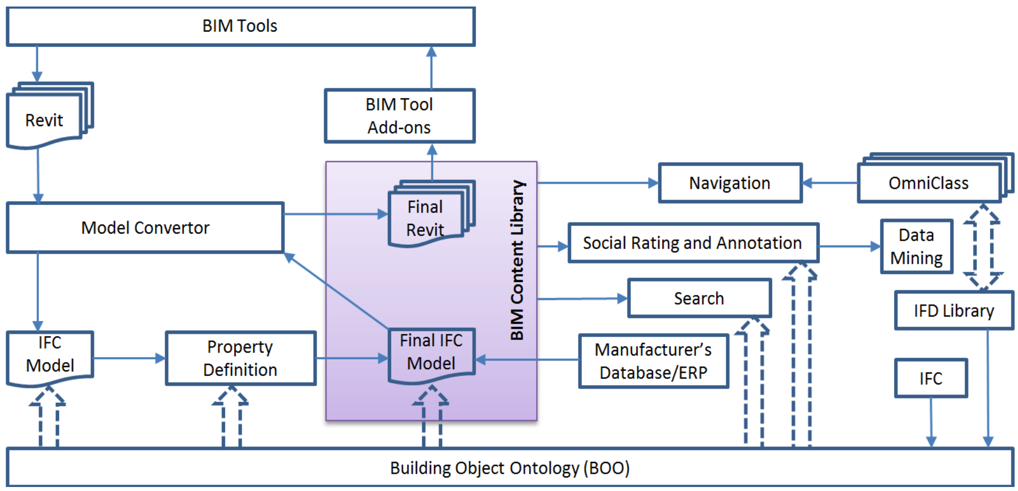

Figure 1: IFC-based semantic framework for BIM content libraries

In Figure 1, an initial BOM is authored using a BIM tool and submitted to the library. The Model Convertor then converts the model from its original format native to the BIM tool (for example, Revit) to IFC format, then the model can be defined in more details based on the properties defined in the BOO. The initial IFC model and the final IFC model will be validated by the system also based on its definition defined in the ontology. The final BOM in IFC format can be linked with manufacturer's database of ERP system to dynamically update values of properties, including both technical and commercial data. This IFC model can also be converted to formats native to some popular BIM authoring tools, which can be linked with BIM tools by software add-ons. Eventually, a building component can have its model in several formats in the library for different applications.

A BIM content library following this framework will perform well in three functions. First, the navigation structure is computable with major classification systems such as OmniClass, MasterFormat, and UniFormat, and can be dynamically mapped with IFD Library. Second, this BOM library supports semantic search at property/parameter level using the BOO as the knowledge model. Third, annotations about BOMs are structured based on the ontology and support data mining to retrieve more meaningful information.

6. CONCLUSION

BOMs are the building blocks of a BIM project model. Although it has been long discussed, there is no standard with respect to what information needs to be included in a BOM and how it should be organized. Furthermore, the organization and utilization of BIM content libraries are seldom studied. This paper proposed a framework for BIM content libraries to (1) define the full spectrum of properties of a building component and flexible integration of required properties on demand, (2) include commercial information of building products which can be dynamically updated from manufacturer's database, (3) support multi-view of navigation structures, including major classification systems and user-generated tags, (4) enable semantic validation and search of models at property/parameter level, and (5) structure annotations related to BOMs based on an ontology to obtain meaningful data from social contribution.

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