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An ontology-based approach for developing data exchange requirements and model views of building information modeling

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ABSTRACT

Each domain industry requires the detailed specifications for sharing and exchanging building information models throughout the design, construction, and operation phases. Industry Foundation Classes (IFC) Model View Definitions (MVDs) specify required information for exchanges of building model data among building project experts. The data involves the identification of model semantics shared by two or more applications. However, since no robust standard for defining building semantics and requirements for data exchange has been agreed upon, information embedded in domain-specific MVDs are generated separately and are vague in scope, which results in a lack of consistency. In addition, the Information Delivery Manual (IDM) that includes exchange specifications needed for each exchange process of a product model is manually defined in a paper-based document. Because there is no clear logical link between the units of information in the exchange requirements of an IDM, and those of MVDs, the mapping that translates requirements of an IDM into ones of an MVD is open to various interpretation, without semantic and logical consistency. Such challenges might result in redundant requirements and rules for data exchange that are not supposed to be handled in the process of MVDs. To ameliorate this situation, this research proposes the new approach of formalizing domain knowledge and defining accurate data modules for model views. To achieve this goal, the authors employed ontological principles for generating an IDM for the precast concrete domain and for linking its MVD with formal information models. The formalized structure of domain knowledge is expected to support defining explicit data modules and developing manageable relationships among entities using semantic reasoning so that domain professionals and software vendors can identify the intents of the requirements of mapped MVDs and keep track of mapping problems. Moreover, to integrate IDM and MVD development processes, the ontology-based IDM is parsed and translated from OWL/XML to mvdXML, which automatically generates MVD documentation in the IfcDoc tool.

1. Introduction

Domain industries have a need of a neutral file format that encompasses its requirements and design information for numerous exchanges supporting full use of a building model. Industry Foundation Classes (IFC), widely used in architectural, engineering, construction, and facility management (AEC–FM) and registered with the International Standardization Organization as ISO 16739, is the standard data schema provided by buildingSMART International (bSI). The objective of this schema is to allow the definitions of explicit and semantic building data for supporting their interoperability. Using this schema, each discipline defines an Model View Definition (MVD) that describes the subsets of the schema required to transmit product and project information supporting the needs of particular data exchanges [25]. In addition, an MVD includes the model specifications of data exchanges so that software vendors and domain professionals can apply the binding process of an MVD to the IFC interface of their software products [12,17]. An MVD consists of modularized concepts with predefined specifications and rule sets to be reused [10,17,19]. A concept depicts required entities, attributes, properties, and relationships using a relational structure and a constraint. A detailed description of these requirements appears in the Information Delivery Manual (IDM), translated into supposedly implementable specifications for software vendors [12]. However, since experts developing an IDM and an MVD have no robust standard that either specifies the requirements of domain knowledge or categorizes the definitions of concept modules, the documentation of an MVD includes redundant and ambiguous specifications and lacks consistency in its implementation. In addition, a

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manually developed IDM in a paper-based document such as an EXCEL table hinders the sharing of information among relevant industries. In particular, this impediment results in a discontinuous and error-prone data interpretation and translation from an IDM to an MVD, which eventually delays the development of an MVD. This procedure does not allow users to confirm the composition or the definitions of an MVD pertaining to the contexts defined in an IDM because no common set of terms and their meaning exists. Furthermore, inconsistent definitions of concept documents often lead to confusion among software vendors developing IFC interfaces on their Building Information Modeling (BIM) tools. For example, while every precast slab can be defined initially as the object of a single building element with attributes associated with a slab object, as it evolves toward fabrication, the slab becomes an assembly made up of structural elements similar to hollow core, reinforcing, and pre-stressed tendons and topping, with their own shapes and attributes. This assembly has a many-to-many mapping between components, with the topping shared among hollow core beams. It is the responsibility of the detailer to validate structural, spatial, and other design equivalences between their representations. Several parts of a product model have multiple representations and attributes and the distinction between these representations must be distinguished to properly exchange the desired data needed by downstream users. To achieve these goals, this paper proposes an approach to developing an ontology-based IDM and MVD that can provide a method of formalizing domain knowledge and integrating the processes of IDM and MVD using ontological principles.

2. Background

The National Building Information Modeling Standard (NBIMS) defines the procedural steps for developing an MVD as shown in Fig. 1. The NBIMS defines standard semantics and processes for building information exchanges, which supports providing interoperable domain contexts [5]. This specified process of MVD development consists of three core steps: an IDM, an MVD, and implementation. Domain professionals in an industry define an information exchange template that contains functional specifications for each exchange process. This template is applied to an IDM that describes required entities and their attributes. This IDM is translated into an MVD using a subset of the IFC schema. An MVD has the set of specifications for data exchange implementation and supports the IFC binding process of the native objects of BIM authoring tools [10,17]. The structure of an MVD consists of reusable concept modules for representing domain knowledge efficiently and consistently [10,17,27]. The concept is a modular-based knowledge unit that helps software vendors properly encode a building model in the IFC translation interfaces of their BIM authoring tools [11]. For example, concepts in a precast concrete domain include global properties such as cardinal line, seam connectors, cambered elements, editable parametric elements, and spatially more complex elements using boundary representation (B-rep). Concepts of a product model are composed iteratively for fulfilling diverse requirements of an MVD so that the exchange requirements of a particular domain can be represented accurately and consistently by a modularized context. In addition, a modular framework encourages the re-usability of existing specifications for the model view development of other disciplines. A concept that describes the required contexts for exchanges of a building model consists of the instructions of implementation, the requirements of attributes, and the shared structure of the IFC schema.

Fig. 2 depicts a diagram and an implementation agreement of a concept pertaining to a precast slab aggregation. This concept shows an aggregation of multiple parts including double tees, hollow core, or precast concrete slabs. The diagram illustrates how entities and their attributes are connected and what values and types are required for them. In other words, this relational data structure in Fig. 2 requires that the aggregation of a precast concrete slab and beam should be represented by IfcRelAggregates using two attributes RelatingObject and RelatedObjects connected to IfcSlab and IfcBeam. The IfcSlab entity has two types of attributes: explicit and those associated through Express's inverse attributes. The explicit attributes such as GlobalId, OwnerHistory, ObjectType, and Representation exist in an IFC instance file called Part 21 physical (P21) file and the inverse attributes such as HasAssociations, IsDecomposedBy, and Decomposes are identified relationally across multiple entities. The binding document also includes implementation agreements that define specific types and values according to the attributes of IfcSlab and IfcRelAggregates entities. These specifications define that an IfcSlab instance of a P21 file must contain GlobalId, OwnerHistory, ObjectType, ObjectPlacement, and Representation: Particularly, ObjectType must be Slab or Precast Slab; ObjectPlacement must be defined by IfcLocalPlacement using the PlacementRelTo attribute, which refers the relative location of a site and a building; and Representation should be Boundary Representation using IfcManifoldSolidBrep as a reference of an Item attribute of IfcShapeRepresentation. With regard to IfcRelAggregates, RelatingObject should refer to a slab entity and RelatedObjects should connect to components in the slab. These specifications are supposed to be used to transform native objects of BIM authoring tools into a P21 file.

3. Problems in current practice

IDM data, generally configured in a spreadsheet in current practice, are too fragmented and vague to define the requirements of an MVD. In particular, IDM developers have no explicit baseline for defining data exchange requirements pertaining to applicability of IDM data to an MVD and a binding process for IFC interfaces. From the initial phase of defining the scope and business rules for specific domain knowledge, more explicit criteria and formal specifications based on the domain knowledge of a field are needed for the development of an IDM and an MVD. Even though we have a buildingSmart International (BSI) IDM process and a NBIM MVD development process, we still lack their base definitions and detailed processes to exchange specifications. One way of considering the issues is to associate baseline model views as derived from the LOD (Level of Development) for each of the exchanged objects. The absence of a standard causes several problems such as inconsistency in developing an IDM and an MVD. Several efforts to define an MVD have been devoted to using a manually defined data table for generating an IDM and an MVD. Table 1 represents an EXCEL sheet for the IDM of the precast concrete domain. The information for precast concrete in the table is categorized into an information group, an information item, an attribute set, an attribute, and availability. The example defines various attributes and their use of slab systems for exchange processes. These slab system data are translated into an MVD to be represented in the IFC schema. However, a current method that collects exchange requirements in an EXCEL table and generates an MVD based on table-based information raises several concerns pertaining to knowledge formalization for IDM and process integration for the development of an IFC MVD. This section illustrates four concerns about a current method for the development of an IDM and an MVD.

3.1. Manually collected information on the table

Industry professionals determine requirements for data exchange and provide sources for their IDM. As shown in Table 1, a manually developed IDM in an EXCEL table may not be