DEVELOPMENT OF THE NATIONAL BIM STANDARD (NBIMS) FOR PRECAST/PRESTRESSED CONCRETE

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ABSTRACT

Part 1 of the National BIM Standard (NBIMS) lays out the generic guidelines for developing specialized model views, defined in terms of Industry Foundation Classes (IFC), for various exchanges. These model views are typically applicable to specific design or construction processes, or specific construction technologies. Various efforts have begun to develop such specialized model views. One of these early projects has completed a model view definition for the planning, design, documentation, construction and fabrication phases of precast/prestressed concrete construction. The project team had to deal with a range of issues stemming from the breadth and depth of the information exchanges. This paper presents the challenges experienced in compiling a BIM standard for precast/prestressed concrete.

We discuss acquiring Exchange Requirements (ERs) from a diverse set of industry participants, rationalizing and formalizing them into an Information Delivery Manual (IDM), and finally developing Model View Definitions (MVDs) with specific IFC implementations that respond to the initial requirements. The model views are defined using information "concepts". Each concept is then detailed with IFC 2x4 entities and relationships, which rigorously define how the concepts are to be implemented in ISO STEP EXPRESS-language functions. We propose several approaches for dealing with the breadth and the depth of information exchanges during the IDM and MVD development that allow for logical breakdown of the processes and the data types. Additionally we examine specific challenges that pertain to the fabrication and construction of precast concrete. We generalize the lessons learned in three different categories according to the NBIMS process phases: requirements development, model view definitions and implementation specifications.

Keywords: National BIM Standard (NBIMS), Industry Foundation Classes (IFC), Model View Definitions (MVD), Information Delivery Manual (IDM), Product Modeling, Process Modeling.

1. INTRODUCTION

The National Building Information Modeling Standard (NBIMS) provides guidelines for the development of information exchange standards for all phases of design, construction and operation of the built environment as well as all disciplines involved during these phases – architecture, engineering, construction, fabrication, and facilities management.

This paper summarizes the challenges stemming from the development of the national BIM standard for precast/prestressed concrete and the lessons learned in the context of the specific project, which could be applied to similar efforts (Carrato and Kreger 2009). The exchanges addressed cover the complete building information flow, which include design, engineering, fabrication, project coordination, material procurement and erection. Interfaces with other building systems are investigated as far as they affect the precast design, engineering and fabrication. The exchanges include those between architect, general contractor, structural and fabrication engineer, plant managers and logistics (Barak et al. 2009).

The standards specification process used follows the National BIM Standard procedures, as supported by buildingSMART, North America. The work reported here was undertaken by a BIM Advisory Committee organized by the Precast/Prestressed Concrete Institute (PCI) in June 2008, sponsored by the Charles Pankow Foundation and the PCI. It included members from 16 precast or precast-related companies, one architectural firm, seven software companies and the five authors serving as a Technical Advisory team.

2. REQUIREMENTS DEVELOPMENT

This project's purpose was to develop the range of model view definitions needed to support full interoperability for precast concrete, using the National BIM Standard (NBIMS) approach. Its primary products were the Information Delivery Manual (IDM), defining the significant information exchanges to be supported and the functional requirements to realize them, and the mapping of the functional requirements for those exchanges into model views, specified in a second product, the Model View Definition. Together these documents from the kernel of the National BIM Standard for Precast Concrete (Eastman et al. 2010). The documents prepared and presented here conform to the standards specification process defined for the National BIM Standard (NBIMS), as supported by buildingSMART, North America and the National Institute of Building Science (NIBS 2008).

The project was preceded by a feasibility study (Eastman et al. 2003) sponsored by the Charles Pankow Foundation to determine the issues of information exchange, focusing on architectural precast (Eastman et al. 2007). Related experimental work examined closely the exchange capabilities for precast concrete previously available in all major BIM design tools (Jeong et al. 2009). This work grew from and expands upon those studies.

Precast concrete includes external cladding, structural elements, and entire building systems fabricated off-site of concrete, then erected to make up various portions of an overall project. Precast as a building system, also interacts with many other aspects of a building. It provides all or part of the external shell or the fundamental building structure; it must transfer its loads to the building foundation. Also, the precast pieces have multiple internal components, including pretension tendons, reinforcing, connection hardware, plus embedded components of other systems. These characteristics of precast result in many needs for coordination and thus information exchanges throughout the design and fabrication process. The IDM incorporates exchanges between architects, engineers (structural, civil, MEP), precast fabricators and general contractors and other subs, such as rebar benders, proprietary embed fabricators, concrete plants and other procurement-oriented exchanges.

It was recognized throughout this Committee's meetings that precast project workflows are not 100% standardized (Weise et al. 2009), but tuned adaptively to reflect what is most appropriate for any given project and stage. The definitions of workflows in the IDM document are tied into an overall process as a typical illustrative schedule, not as a prescriptive process. It is laid out to provide a structure for addressing different use case exchanges. These may be selected to define new processes as needed in practice. It is the exchanges that are the target of this document, not a prescribed process.

The effort reported here is an early undertaking to develop and demonstrate such a standards effort, in this case for the data exchanges dealing with precast concrete. Other structural and building systems are included, in so far as they affect precast concrete engineering and fabrication. The main expected result will be the effective and reliable exchange of information regarding precast concrete. Another benefit will be to serve as a demonstration for other groups likely to undertake similar efforts.

3. WORKGROUP FORMATION

The workgroup formed to participate in and oversee the BIM standards effort was established through the auspices of the Precast/Prestressed Concrete Institute (PCI) in June 2008. The committee included members from 16 precast-related companies, one architectural firm, seven software companies and the five members of the Georgia Tech Advisory team.

This committee has held four physical meetings to date, with numerous conference calls. Two meetings were to define the functional specifications captured and reported in the Information Delivery Manual (IDM), completed in February 2009. Two additional physical meetings and numerous conference calls were held between March and December 2009, resulting in the draft Model View Definitions, uploaded into the IFC Solutions Factory website for review and implementation. Invitation was extended to other vendors in the precast space such as providers of structural analysis software and the standard developed in this project provides specifications for such IFC implementations.

4. PROCESS MAPPING

The Committee broke into four subgroups, each addressing a different aspect of the precast process. Because project delivery methods differ, three different early-stage processes were diagrammed, for precaster as lead contractor, precaster as sub-contractor, and architectural precaster. One backend fabrication process was considered sufficient to complete the three different front end processes (Figure 1). The process maps, activity descriptions and exchange purpose were documented. Four sets of Exchange Models (EMs) were specified by the precast experts: Architectural (A_EM), precaster as prime contractor (P_EM), precaster as subcontractor (S_EM), and the fabrication backend (EM), with a total of 47 distinct exchanges. There were many similar exchanges and they were compiled into an integrated exchange table, allowing comparison and consolidation. The general structure of process maps is shown in Figure 1. All process maps were created using the Business Process Modeling Notation (BPMN) (www.bpmn.org).

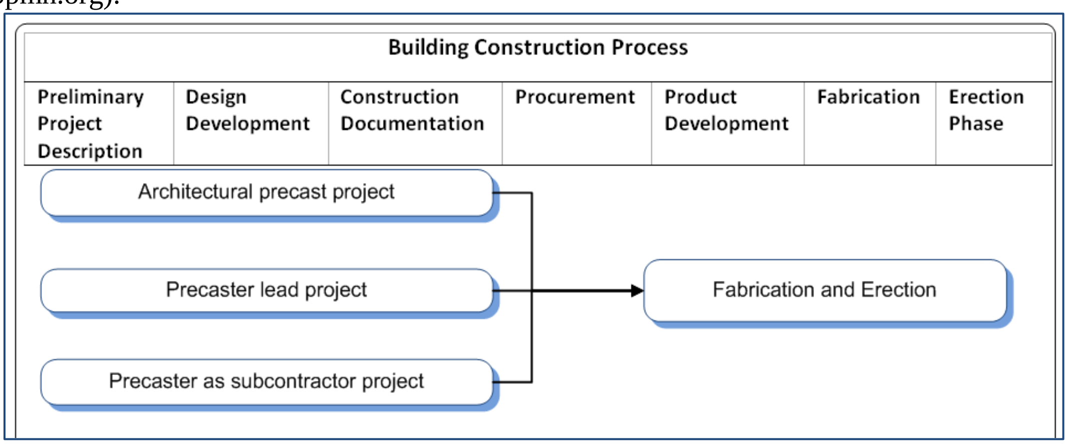

Figure 1: Precast Process Breakdown

The process stages and actors were classified using the new Omniclass classifications, an effort of the U.S. Construction Specifications Institute and the International Framework for Dictionaries effort. Horizontal swim lanes (Figure 2) are used for the major disciplines in the precast process together with the corresponding Omniclass (www.omniclass.org) designation (Table 1):

Major process phases are identified across the top (Figure 2) in the context of their relation to precast construction. Omniclass classification is used to identify their relation to the overall construction process. The horizontal exchange lanes show the transactions between different processes either across phases or between disciplines:

Table 1: Omniclass Designations

Discipline	Omniclass Designation
Architecture	(33-21-11-00)
Engineering	(33-21 31 00)
Building Product Manufacturing	(33-25 41 11 11)
General Contracting	(33-41 11 11)

Project Phase	Omniclass Designation
Preliminary Project Description	31-20-10-00
Design Development	31-20-20-00
Construction Documentation	31-25-00-00
Procurement	31-25-00-00
Product Development	31-40-30-00
Fabrication	31-40-40-14-24
Erection Phase	31-40-40-14-11

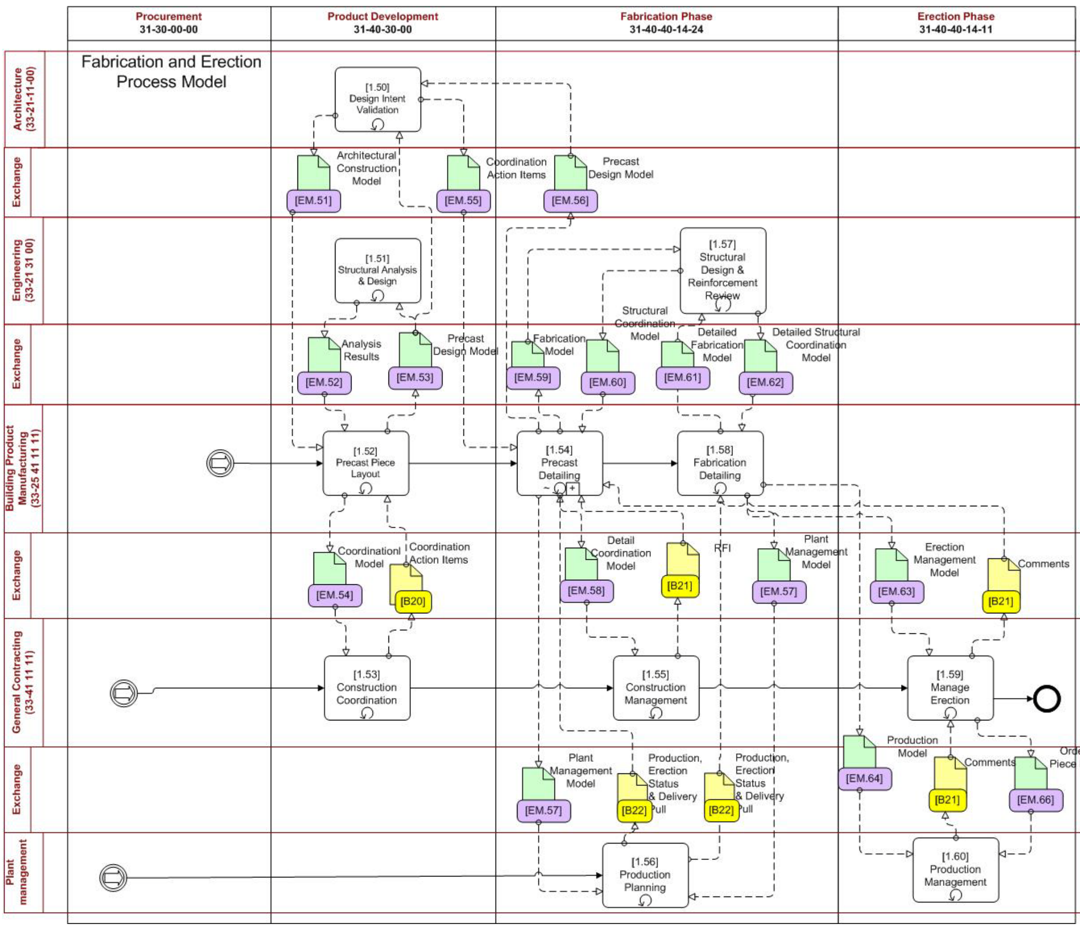

Figure 2: Fabrication and Erection Process Model

5. EXCHANGE REQUIREMENTS AND BUSINESS RULES

5.1 Exchange Requirements

In addition to the standard BPMN notation, the Process Map utilizes notation for information exchanges between activities called Exchange Models (see Figure 3). Each Exchange Model is uniquely identified across the four use cases, as shown in Figure 1, with their names coded according to the process map they are associated with. An EM is the detailed functional specification of the precast data for a specific exchange (or use case). We attempted to identify all the critical variations in information that might be exchanged, so as to result in as detailed and accurate a specification for later implementation.

Exchange Model Notation **Review Comments**

Figure 3: Notation for depicting Exchange Models in the Process Map

To provide clear guidance to the domain experts so as to distinguish the important functional aspects of each exchange, we reviewed the following documents and information:

- precast concrete software applications that were in use and their capabilities
- the IFC current capabilities dealing with geometry, materials, and features
- discussions with the domain experts regarding features and attributes nomenclature in typical day-to-day information exchanges

From these, we identified the possible variations that may be important for a given exchange. This was organized as a checklist of possible functional requirements. Of special concern was geometry, the largest and most complex type of project data. The geometry deformation (camber, twisting), function, accuracy, editability, articulation of features (connections, blockouts) and level of detail were specified for the exchanges. Whether geometry was to be editable or simply visible was identified. Embeds, including reinforcing and tendons, for connections and joints, and also finishes, especially for architectural panels, were addressed. Properties and relations between parts were also specified. Issues dealing with user-selected subsets of objects and defining minimal subsets for effective exchange are also defined.

The Exchange Model specifications are detailed functional descriptions of the information exchanges for the use cases. They are initially identified in the process maps and are then defined in generic text in the Exchange Model Descriptions. Finally, they are specified in terms of the information items they must carry (Figure 4).

	Variables	**Abbreviations**		
Attribute	Required/Optional	R	O	
Geometry Deformations	As Cast/Deformed	A	D	
Geometry Function	Viewable/Referencable/Editable	V	F	E
Geometry Accuracy	Planar/Curved	P	C	
Geometry Level of Detail	Level of Detail High/Medium/Low	H	M	L

Figure 4: EM Variables

Exchange model specification tables (Figure 5) are based on the process maps, activity descriptions and EM descriptions. The variables are used to make individual selections for each attribute and shown in Figure 5.

5.2 Requirements Rationalization

The exchange models were compared to identify opportunities for consolidation of exchange models to reduce their number. A Visual Basic Macro was prepared to scan each field of each EM and compare it to the parallel field of every other EM. The number of differences found was divided by the total number of fields, yielding a percentage degree of difference. The result is shown in Figure 6.

Wherever the degree of difference was less than 10%, the EMs were compared critically with a view to unifying them. The first step required review of the definitions themselves, and in many cases corrections were made. After correction, the degree of difference was recalculated, and, if merging was viable, any additional changes were made and the exchange models were consolidated. The guiding principle of the merge changes was to enhance exchange capability, not to reduce it.

The following table summarizes the EMs that were merged (Figure 6). The details of all changes made, for correction or for merging, are provided in the texts describing each exchange model that appear in the "IDM for Precast Concrete" (Eastman et al. 2009). The final resulting comparison tables are provided and the final proposed EMs are provided in the Consolidated Exchange Models (EM) Table.

Information Group	Information Items	Attribute Set	Attributes		P_EM.1	P_EM.2	P_EM.3
Foundations							
	Grade Beam, Pier Cap, Spread Footing, Slab on Grade, Stem Wall, Retaining Wall, Drilled Pier, Cassion, Pile, Pile Cap	Shape	Geometry	Required?	R	R	R
				Deformations?	A	A	D
				Function?	V	F	E
				Level of	L	M	H
				Accuracy?	P	P	C
			Dimensional Tolerance	Required?	O	O	R
		Type	Structural Type (CIP	Required?	R	R	R
		Supplier	GC/Contractor/Fabricator	Required?	O	O	O
		Material	Material type	Required?	R	R	R
			Quantity	Required?	O	O	R
		Assembly relations	Part of structural system	Required?			R
		Nested relations	Contains	Required?			O
			Contains connection	Required?			O
		Connection relations	.. to Precast	Required?			O
			.. to CIP	Required?			O
			.. to Steel	Required?			O
		Meta Data	Author, Version, Date	Required?			O
			Approval Status, Date	Required?			O

Figure 5: EM Specification Table

Merged Exchange Model	New EM Code	Original EM Codes	Actions taken for merge
Building Concept Exchange Model	BC_EM	A_EM.1, A_EM.2 P_EM.1, P_EM.2 S_EM.1	None
Precast Concept	PC_EM	A_EM.3, A_EM.6	Upgrade geometric accuracy from planar to curved surfaces for A_EM.3 and raise level of detail for precast slab geometry from medium to high.
Architectural/ Structural Contract	ASC_EM	A_EM.4, P_EM.9, P_EM.10	Upgrade geometric accuracy from planar to curved surfaces for A_EM.4 and P_EM.9 and raise level of detail for various piece geometry from medium to high in A_EM.4.
Precast Detailed Coordination	PDC_EM	A_EM.7 and A_EM.10	None
Precast Subcontractor Coordination	PSC_EM	S_EM.8 and S_EM.9	None
Detailed Structural Review	DSR_EM	EM.61 and EM.62	Upgrade viewable to referencable for precast pieces and make dimensional tolerance optional for all cases.

Figure 6: Consolidated EM Table

6. MODEL VIEW DEFINITIONS (MVDs)

The next phase translates the IDM functional specifications into an implementation mapped to a schema that realizes the IDM requirements. This translation is documented in a report called a Model View Definition (MVD). This process has been refined and has evolved over the last few years (Hietanen 2006). Initially, the functional specifications were mapped directly into IFC or similar schema language.

However, it was quickly noted that the contents in different model views, but within similar domains, were often replicated. The BLIS (Building Lifecycle Interoperable Software) group that first proposed the model view approach (Bazjanac 2002) also recognized the redundancy in model views and began to modularize these, calling the modules “Concepts”. These Concepts represent semantic units that map the functional specifications into IFC language bindings that fulfill the IDM requirements.

Concepts are structured hierarchically (Figure 7). At the bottom level are Leaf or Static Concepts that provide the mapping of a Concept to its corresponding IFC Entities. These are then aggregated into higher level Adapter Concepts, allowing the higher level Concepts to be re-used where needed, as along with their static leaves. The top level Concepts are called Variable Concepts. The initial idea was that Variable Concepts may have different bindings, for example IFC or XML. However, we see the high level concepts being defined variously depending upon the purpose of the set of exchanges covered and the semantics of the target schema being used and the bottom-level bindings they target. Thus we do not anticipate that Variable Concepts will support multiple bindings, especially in complex areas such as precast concrete.

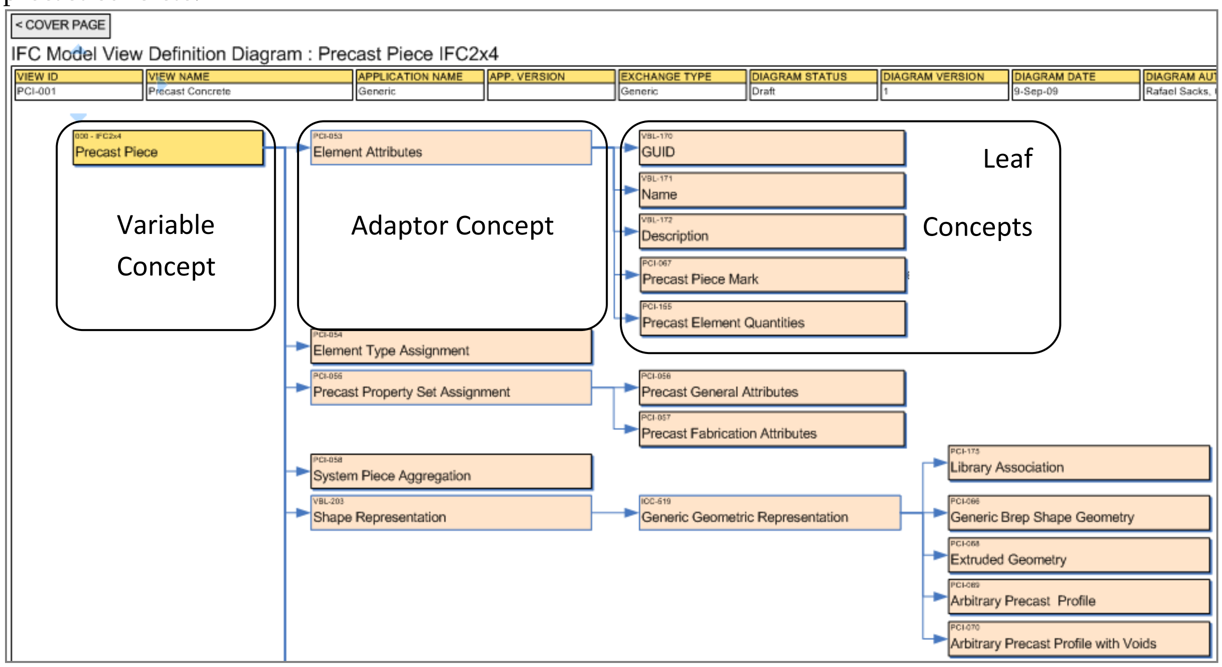

Figure 7: Model View Diagram for the Variable Concept - Precast Piece

The Concept approach has been developed jointly by European and North American groups and is being widely used for implementation. It allows MVD domain-specific groups (CIP concrete, steel, etc.) to re-use concepts that have already been developed and software companies to implement a concept once, then use it again in many MVD exchanges. This approach is supported by a website called the 'IFC Solutions Factory' (http://www.blis-project.org/IAI-MVD), an open and public international website for integrating IFC Model View Definitions, which collects the different MVDs and their bindings in a structured fashion that allows searching and identification of similar concepts across different MVD workgroups. It provides an excellent reference platform for dissemination of the bindings developed to the software companies implementing IFC based exchanges. The 'IFC Solutions Factory’ was developed by 'Digital Alchemy', funded by IAI International, and is maintained by the IAI MVD Coordinator. It is becoming accepted as the standard implementation approach for MVDs, including a variety of European projects, interoperability development sponsored by the General Services Administration (GSA), and other North American initiatives.

The development of Concepts and structuring them is primarily technical work, based on good knowledge of the IFC information model schema and its logical structure (Kiviniemi 2009) and involves translating the functional intent captured in the "IDM for Precast Concrete" (Eastman et al. 2009). Thus, this stage was undertaken primarily by the Technical team, with important input from the two outside consultants. We systematically partitioned high-level piece types defined in the IDM and assigned them to different members of the Technical team, to develop the bindings. Even at this level, a particular functional requirement from the IDM could be mapped and implemented with multiple alternative structures within IFC. These required review of other similar Concepts and often, advice from the IFC implementation advisors. In parallel, we composed and aggregated these Static Concepts into higher level Adapter and Variable Concepts. Each individually developed Concept was reviewed by the full Technical team. The set of Concepts defined address the major part, assembly, embed, connections, finishes, structural analysis, material, fabrication and tracking information specified in the "IDM for Precast Concrete" (Eastman et al. 2009). They include 162 uploaded Concepts, of which 25 are high-level aggregated Concepts, 104 are new IFC binding Static Concepts defined by us, and 33 were re-used from previous or parallel efforts. Figure 8 shows the cover page of the Concepts directory on the IFC Solutions Factory web site, which provides an index to all of the Variable and Static Concepts.

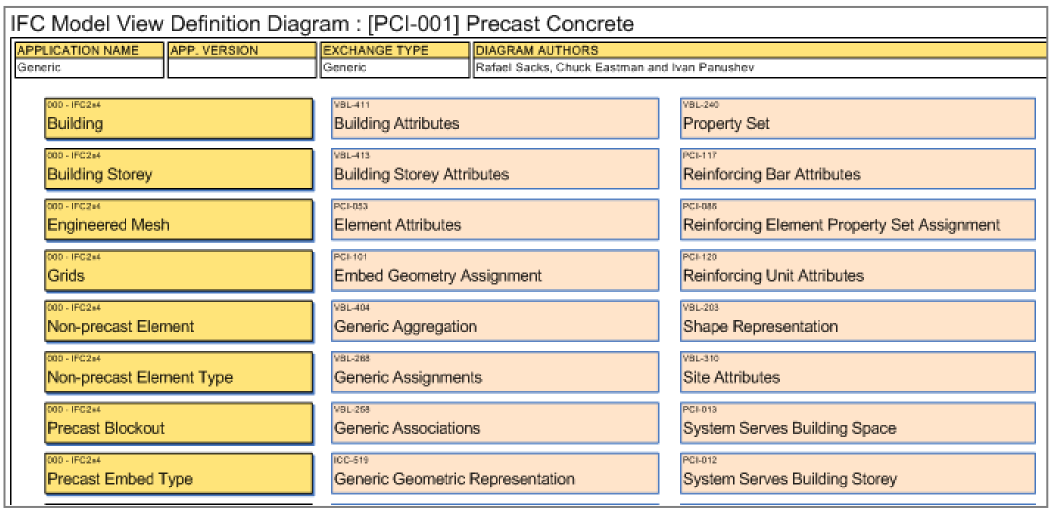

Figure 8: Concepts List Excerpt

7. CONCEPT BINDING TO IFC 2X4

The main specification of the IFC mappings is identified by clicking on "Binding – Diagram" (http://63.249.21.136/IAI-MVD/reporting/browseMVD.php?MVD=PCI-001&BND=IFC2x4&LAYOUT=H). This click brings up a table where the Variable and Static Concepts in the MVD are laid out, as shown in Figure 8.

The left side brighter orange colored Concepts are the twenty-five Variable ones. By clicking on any of the Variable Concept boxes in the table shown in Figure 7, the Adapter Concepts are opened and described as shown in Figure 9. The Variable Concept for Precast Piece is shown in Figure 7. Clicking on the Concepts in Figure 8 leads to lower level Adapter Concepts or to Static (Leaf) Concepts. By clicking on a Static (leaf) Concept (Figure 8), the implementation of that Concept is defined in the right side screen overlapping window (Figure 9). The example for Connection Component Assignment is shown in Figure 9. The Leaf Concepts identify the IFC Entities and their references to each other for different uses. They are still abstracted, in that these diagrams omit IFC Types, including Enumerated Types and Select Types, all important low-level Entities in IFC. However, they are easily resolved in implementation. At the bottom part of each Binding diagram page is a list of the attributes for each entity. They indicate the assignments and any restrictions that might apply in the implementation (these restrictions are also called business rules. They are also used to resolve any ambiguities in the range of attribute assignments or types). Last, a segment of a typical IFC Part-21 instance file is provided for most Concepts to provide a concrete example of how they are to be defined.

This structure is readily available to software companies, for PCI-related work, or to other projects needing to exchange the same or similar information. There is a move to make this website the official buildingSMART repository website.

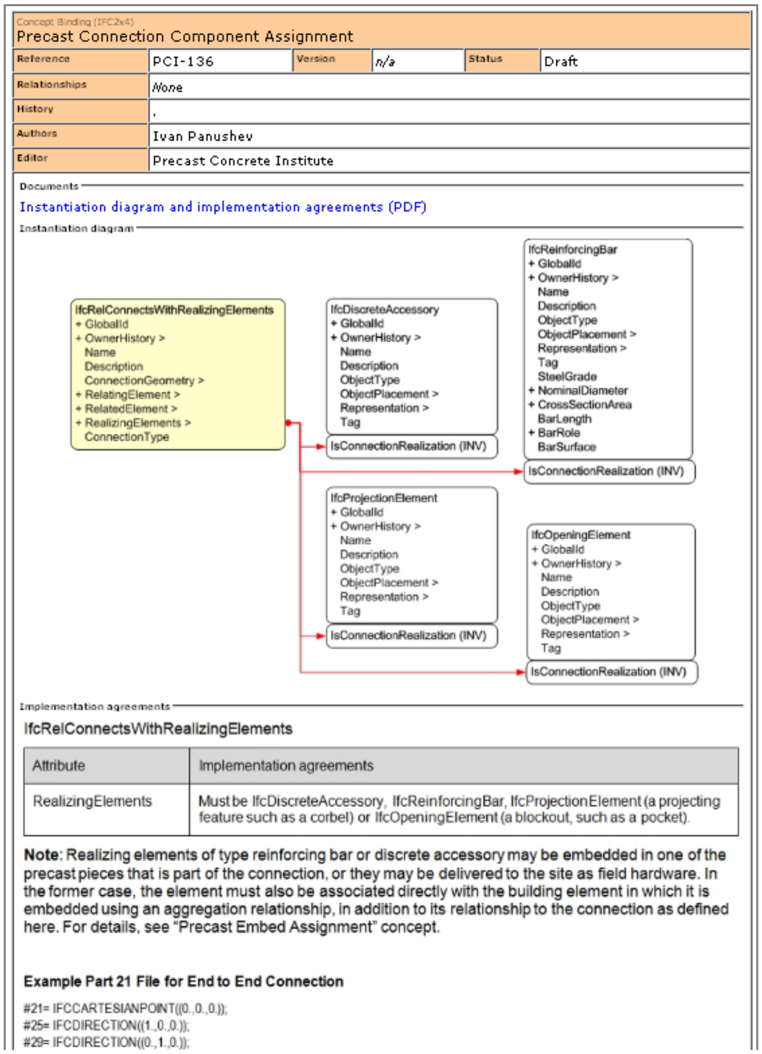

Figure 9: IFC Binding Example

8. IFC EXTENSIONS

The Technical Advisory Team identified several weaknesses of the IFC schema early in development and worked incrementally to add them to IFC Release 2x4, which was in its last phases of completion and closeout. A separate Appendix in the "IDM for Precast Construction" (Eastman et al. 2009) summarizes the extensions proposed, distinguishing those formally approved from those held for further review. These include: parametric hollowcore and doubletee profiles, extended beam types (Inverted tee, L-beam, spandrel), accessories for embeds, corrosion treatments, and precast piece and production attributes, and ACI and general rebar bending patterns. We also proposed concepts to define the spatial relations in assemblies to better support automatic clash detection.

9. CONCLUSIONS

Generating multiple exchange models involves a high level of replication at the schema level: a modular approach is needed to make the development and future conformance testing tractable. The development of the Concepts and bindings addresses this problem. Many of the developed concepts have wide use beyond this project: for example implementations in model exchanges for cast-in-place concrete. The recommended process for generating a National BIM Standard specification and implementation is described in NBIMS, Volume 1, Section 5 (NIBS 2008).

Information modeling for specific industry exchanges is influenced by the established fabrication practices. For example in precast, profiles are defined as part of types, whereas local blockouts are parts of instances. These nuances must be identified during the early stages of IDM development so they are addressed properly during the MVD phases when the mappings between concepts and IFC entities are created.

Additional IFC entities will often be needed for industry specific efforts, but some address generic needs – such as Slabs with Elements, Embedded Components. As more domains complete the exchange standard process, fewer will be needed, thus leading to an Integrated NBIMS Standard (Figure 10).

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