Consolidated Exchange Models for Implementing Precast Concrete Model View Definition

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Abstract –

The US National BIM Standard proposes facilitating information exchanges through Model View Definitions (MVDs). An MVD, defines a subset of the IFC schema that is needed to satisfy one or many exchange requirements of the AEC industry. In the MVD definition for precast concrete domain specified in precast concrete Information Delivery Manual (IDM), four sets of Exchange Models (EMs) have been specified for four different processes i.e. architectural precast, precast lead project, precast detailer as subcontractor, and precast fabrication and erection processes. This approach identifies 47 exchange models for the lifecycle of a precast concrete project. However, there are many similar exchanges among these EMs that can be combined. Two approaches of Exchange Model consolidation has been proposed and this paper identifies the implementation issues of these consolidation strategies. The main objective of this paper is to define the MVD with limited number of EMs that addresses the problems of existing consolidation strategies to facilitate the MVD implementation and execution. This study suggests combining 47 original Exchange Models to twelve EMs by combining them based on two major aspects. First aspect is with regard to the MVD concepts to ensure that the exchange models are being combined based on similar data they include. Second aspect is the phases of the project that the data exchange is happening considering their exchange disciplines to ensure that the consolidated exchange models are related to similar phase/phases of the project with the same exchange purpose.

Keywords –

Exchange Model, MVD, Precast Concrete, IFC, BIM

1 Introduction

The US National BIM Standard [1] proposes facilitating information exchanges through Model View Definitions (MVDs). A Model View Definition that is specific to an Industry Foundation Classes (IFC) release, defines a subset of the IFC schema that is needed to satisfy one or many exchange requirements of the AEC industry [2]. In fact, MVD consists of one or multiple information exchange data and each information exchange is the data that must be provided by one application to support work in one or more other applications. For the IFC work, two types of exchanges can be distinguished: model-based exchanges and all others, non-model exchanges. The unique strength of IFC is its support for model-based exchanges. This paper investigates the model-based exchanges known as Exchange Models (EMs).

IFC MVD provides implementation guidance and agreements for all IFC concepts such as classes, attributes, relationships, property sets, and quantity definitions used within this MVD subset. Therefore, it represents the software requirement specification for the implementation of an IFC interface to satisfy the exchange requirements [3]. In the Information Delivery Manual (IDM) for precast concrete domain [4], four sets of Exchange Models (EMs) have been specified for four different precast business context. These are architectural precast, precast lead project, precast detailer as subcontractor, and precast fabrication and erection processes.

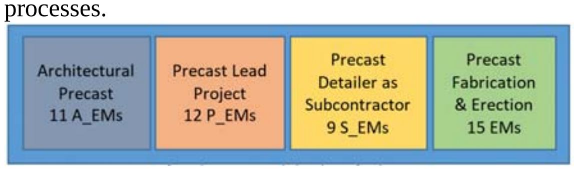

Figure 1 Four sets of Exchange Models identified in precast concrete IDM

As shown in Figure 1, the IDM identified 47 distinct exchange models for the lifecycle of a precast concrete project including 11 exchange models for the architectural precast process (i.e. A_EM), 12 exchange models for precast lead project process (i.e. P_EM), 9 exchange models for precast detailer as subcontractor process (i.e. S_EM), and 15 exchange models for precast fabrication and erection process (i.e. EM) [4, 5].

However, among these EMs there are many similar exchanges [4, 5, 6] such as A_EM.1, P_EM.1, and S_EM.1 that are all identical [4] referring to architectural and engineering concept model. Most importantly, the implementation of precast concrete MVD- either for automated validation of BIM Exchange Models or for implementing in software applications- faces a major challenge when dealing with 47 exchange models. In fact, for implementing precast concrete MVD, limited number of EMs are required to make the software implementation manageable and the functional distinctions between the EMs discernible. Also, consolidation of precast concrete Exchange Models are previously recommended [4, 6]. Therefore, the main objective of this paper is to define the MVD with limited number of EMs in order to facilitate its implementation and execution. This paper, first reviews and compares the existing recommendations to point out the inconsistencies and challenges that exist in current consolidated Exchange Models for precast concrete domain. Then, to address the existing problems, this paper indicates how 47 originally defined exchange models should be combined to address the existing challenges and to facilitate the implementation of precast concrete EMs within a wide range of contexts of an MVD domain.

2 Existing Consolidation Strategies

The percentage degrees of differences between 47 precast exchange models are identified in the IDM for precast concrete [4] and the effort in combining similar Exchange Models have been reviewed in [4] and [6]. Combining Exchange Models in these two efforts is done by reviewing the overlaps, inconsistencies, and redundancies in the exchange models through a detailed analysis. In this analysis all of the exchange models were compared in order to remove inconsistencies and also to identify opportunities for consolidation of exchange models to reduce their number [4, 6]. For this analysis, a Visual Basic Macro was used to scan each field of each EM and compare it to the parallel field of every other EM [4]. Wherever the degree of difference was less than 10%, the EMs were compared critically with a view to unifying them [4, 6]. Table 1 compares the consolidation results in these two efforts as approach “A” [4] and approach “B” [6].

In the first approach [4] (i.e. approach A), some of the similar EMs have not been identified. For instance, A_EM.2, S_EM.2 both define the same exchange in the preliminary project description stage. The exchange description for A_EM.2 and S_EM specifies that each one is related to the engineering concept model which provides information about the structural grid, structural system, major precast connections and issues, interfaces between precast and other structural and curtain wall systems [4]. This similarity is identified in the second approach [6] (i.e. approach B).

Table 1 Comparison of consolidation approach “A” [4] and approach “B” [6]

Consolidated Exchange Model A [4]	Consolidated Exchange Model B [6]	Original Exchange Models A [4]	Original Exchange Models B [6]
BC_EM (Building Concept)	BC_EM (Building Concept)	A_EM.1 P_EM.1 S_EM.1 P_EM.2	A_EM.1, P_EM.1, S_EM.1, P_EM.2, P_EM.3
-	Engineering Concept	-	A_EM.2, S_EM.2, S_EM.3
PC_EM (Precast Concept)	PC_EM (Precast Concrete Concept)	A_EM.5 A_EM.6	A_EM.5, A_EM.6, S_EM.3
-	Engineering design development	-	P_EM.4, P_EM.5, P_EM.6, P_EM.7, P_EM.8
ASC_EM (Architectural/ Structural Contract)	AC_EM (Architectural)	S_EM.4 P_EM.9	A_EM.4, P_EM.9, P_EM.11, S_EM.4, S_EM.6, A_EM.11, EM.51
-	ECO_EM (Engineering Contract)	-	P_EM.10, S_EM.5
PDC_EM (Precast Detailed Coordination)	PDC_EM (Precast Concrete Detailed Coordination)	A_EM.7 A_EM.10	A_EM.7, A_EM.8, A_EM.9, A_EM.10, P_EM.12, S_EM.9, EM.53, EM.54, EM.55, EM.60
-	SRC_EM (Structural review and coordination)	-	S_EM.7, EM.61, EM.62
-	EAR_EM (Engineering analysis results)	-	EM.52, EM.55, EM.56
-	PF_EM (Precast concrete)	-	S_EM.8, EM.58, EM.59
-	PR_EM (Production data)	-	EM.57, EM.64, EM.65

Another similarity that is not identified in approach A is with regard to P_EM.10 and S_EM.5 that both define the same exchange models in the construction documentation phase. Each of these EMs specifies that the exchange model is the engineering contract model focused on the structural design and integrates the structural layout with other building systems. It includes structural elements, connections and details. In this exchange, both the precast and other structural systems are fully designed. The exchange is prepared as a construction drawing set or construction-level model [4]. This similarity has not been identified in approach A but indicated in approach B.

In the second approach [6] (i.e. approach B), while all original EMs are compared then merged into a limited number of EMs i.e. eleven Exchange Models, some issues exist in the consolidation strategy. For instance, as can be seen in Table 2, S_EM3 is duplicated in two exchange models i.e. Engineering Concept and Precast Concrete Concept. Moreover, in approach B although eleven exchange models were defined in the resulting IDM, only six EMs out of eleven have been utilized and further explained.

Another example of the issues of inconsistencies in approach B can be seen in AC_EM which is specified as Architectural Exchange Model. In this exchange, A_EM4 and EM 51 are happening in two different stages of the project with two different purpose. A_EM4 happens in Design Development Phase and EM.51 occurs in Product Development Phase. A_EM4 is specified as the architectural contract model [4] that integrates the building layout of all precast pieces with all other building systems. It includes precast layout of surface finishes, molding, reveals and other decorative features. Other systems interacting with precast are also passed. The pass-off exchange is prepared to support production of a construction level model. EM 51 [4] on the other hand, passes back to the precast fabricator a report of the design intent issues identified by the architect for precast assembly-level piece layout, based on information supplied by the precast fabricator. In this exchange "design constraints of buildings and spaces are indicated, where relevant. Product information that raises issues about the design intent are reported, including layout, shape, material types, geometry and material of finishes of products, both in the piece and assembly level, and assembly relation of the pieces and connections. Openings and opening frames may be identified. Detailed information of different types of products may be included. Facade layout and grid geometry may be designated; slab topping thickness, material and surface treatment may be returned. For load-bearing and non-load bearing pieces, assembly and joint relations may be identified as problems. Characteristics of thermal and acoustic insulation may be referenced Nested relations and details of joints specifications may be referenced. Finally, other building parts affecting precast pieces specifications and systems may be indicated" [4]. A detail analysis of the information groups that A_EM4 and EM 51 include in the IDM for precast concrete [4] shows that A_EM4 includes sets of data that are not included in EM 51 and vice versa. For instance, A_EM4 requires all information groups related to the project and spatial hierarchy data to be provided in the model. However, in EM 51 these information groups are not included except the project name and the unit definition. Also, in A_EM4 all data related to grids such as grid axis assignment and placement relative to grids are required. But in EM 51 these information groups are excluded. In EM 51, the data related to reinforcing bar assignment and aggregation, embeds and joints are required while such data is not included in A_EM4. If these two Exchange Models are combined, the resulting EM will include a lot of information groups that are required in one original EM and not in another.

Given this review, two significant points can be derived. In addition to similarities in exchange description, consolidated set of exchange models should be defined with regard to two major aspects: a) project stage that each exchange is happening considering the exchange disciplines b) detailed specification and information groups each exchange model includes. This ensures that the exchange models are similarly aligned for consolidation.

3 Exchange Requirements and IFC Concepts

In defining the MVD for precast concrete, exchange requirements are combined into a set of information modules [6]. In fact, contents in different exchanges but within similar domains are often replicated. This creates the notion of data exchange modules that could be reused. These reusable modules represent semantic units that map the exchange pieces to an information model schema that is most often an IFC sub-schema [5].

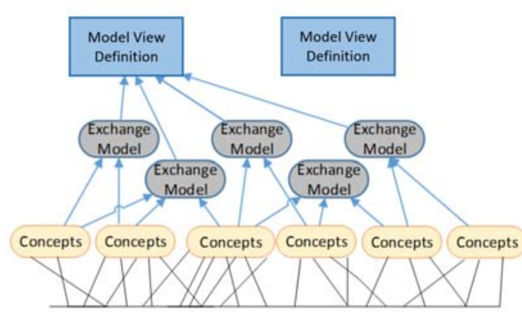

Figure 2 MVD concepts structure

The reusable modules are called MVD concepts or IFC concepts. They are aggregated into Exchange Models that are subsets of MVD concepts specifying the information for a specific workflow exchange. Figure 2 diagrams the concept structure. These concepts are the proposed basis for the Exchange Models representing the semantic and functional knowledge of an industry domain, such as precast concrete [5, 7]. The relationship of IDM requirements and reusable MVD concepts is represented in the work of [8].

The MVD implementation of precast concrete identified 93 reusable concepts while each of the 47 EMs consists of a set of concepts. An example of precast concepts is shown in Figure 3. In this concept, IFC entities are specified to define the data for placement of pieces relative to building elements. Another example of IFC concepts can be the IFC entities that define the geometry definition such as extrusion or B-rep.

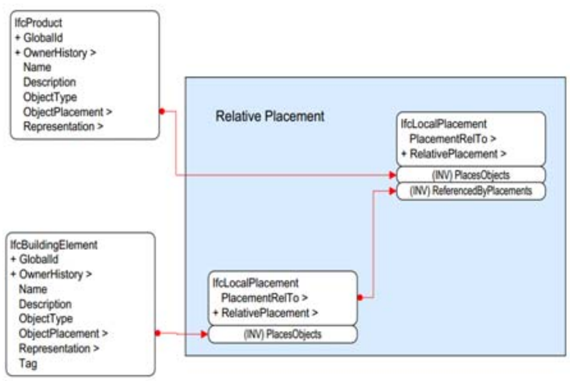

Figure 3 PCI-063 concept for placement of pieces to building element

Comparing original 47 precast concrete EMs with regard to the MVD concepts that each include reveals which Exchange Models have the same set of exchange requirements. Therefore, in this paper the consolidation is mainly based on a detailed review of the MVD concepts in each original Exchange Models. This ensures that the exchange models are being combined with regard to similar exchange data they include. Also, the investigation of the project stages that each exchange is happening (discussed in the next section) is another critical aspect of consolidation to ensure that the consolidated EMs are related to similar phase/phases of the project.

As an example, a detail study on A_EM.1, P_EM.1, S_EM.1, S_EM.2, and A_EM.2 shows that these exchanges are all happening in the preliminary stages of the project [4] with the purpose of architectural concept model or engineering concept model being passed to detailer for further preliminary precast structural and fabrication detailing. In addition, these exchange models all include the same set of IFC concepts such as project and spatial hierarchy, geometry representation as extrusion, metadata including status and approvals concepts. Hence, combining these models ensures that the consolidated model introduces an EM with the same purpose and the same set of concept definition as five original EMs.

Table 2 Precast concrete containment concepts (columns) and the consolidated Exchange Models (rows)

	PCI-040	PCI-042	PCI-043
	Building Element Aggregation	Site Contained in Project	Building Contained in Site
EMPC1	R		R
EMPC2	R		
EMPC3	R	R	R
EMPC4	R	R	R
EMPC5	R	R	R
EMPC6	R	R	R
EMPC7	R	R	R
EMPC8	R	R	R
EMPC9	O		
EMPC10	R	R	R
EMPC11a	R		
EMPC11b	R		

Table 2 shows 12 consolidated Exchange Models developed in this paper associated with some examples of IFC concepts (i.e. PCI-040, PCI-042, and PCI-043). These IFC concepts are defined for addressing containment data in precast concrete National BIM Standard [4]. In this table, if the concept is not included in the exchange it is shown as blank, if the concept is required it is marked with “R”, and if the concept is optional in the exchange it is marked as “O”. Complete table as EMs/Concepts matrix can be accessed on http://dcom.arch.gatech.edu/pci/MVD/Concept-Mapping which associates each of the resulting twelve consolidated Exchange Models with 93 precast concrete IFC concepts.

4 Project Stages and Merging EMs

Seven project stages have been identified in IDM for precast concrete [4] as: Preliminary Project Description, Design Development, Construction Documentation, Procurement, Product Development, Fabrication, and

Erection Phase. Also, the data exchange disciplines are identified as: Architecture, Structural Engineering, Building Product Manufacturing which is the precast detailer, and General Contracting.

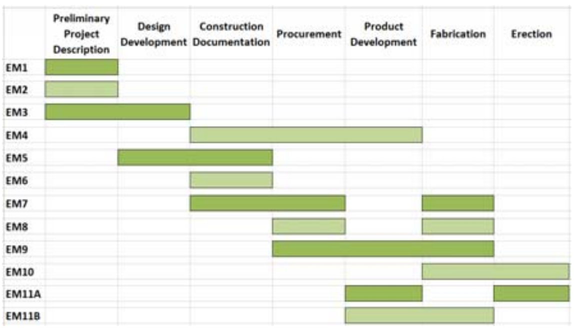

Figure 4 Consolidated Exchange Models (rows) within project stages (columns)

The consolidated Exchange Models developed in this study are illustrated in Figure 4. This figure demonstrates new EMs with regard to the project stages that the exchange is happening. In addition, exchange disciplines and the list of the original EMs are shown in Table 3.

Table 3 Consolidated EMs with associated exchange disciplines and mapping to old EMs

Consolidated Exchange Models	Exchange Disciplines	Original EMs
EMPC1	Architecture	A_EM.1
	Structural Engineering	P_EM.1
	Precast Engineer	S_EM.1
		S_EM.2
		A_EM.2
EMPC2	Architecture	A_EM.3
	Precast Engineer	P_EM.2
EMPC3	Architecture	A_EM.5
	Structural Engineering	A_EM.6
	Precast Engineer	S_EM.3
	General Contractor	P_EM.3
		P_EM.4
		P_EM.5
		P_EM.6
		P_EM.7
		P_EM.8
EMPC4	Architecture	P_EM.12
	Structural Engineering	A_EM.7
	Precast Engineer	A_EM.8
	General Contractor	EM.53
EMPC5	Architecture	A_EM.4
	Structural Engineering	A_EM.11
	Precast Engineer	P_EM.9
	General Contractor	P_EM.11
		S_EM.4
		S_EM.6
EMPC6	Architecture	P_EM.10
	Structural Engineering	S_EM.5
	Precast Engineer	
	General Contractor	
EMPC7	Architecture	A_EM.9
	Structural Engineering	A_EM.10
	Precast Engineer	S_EM.9
	General Contractor	EM.60
EMPC8	Structural Engineering	EM.59
	Precast Engineer	S_EM.8
	Plant Management	EM.57
EMPC9	Structural Engineering	S_EM.7
	Precast Engineer	EM.61
	General Contractor	EM.62
		EM.52
EMPC10	Precast Engineer	EM.64
	General Contractor	EM.58
	Plant Management	
EMPC11A	Precast Engineer	EM.54
	General Contractor	EM.63
	Plant Management	EM.66
EMPC11B	Architecture	EM.51
	Precast Engineer	EM.55
		EM.56

EM11A and EM11B both include the similar sets of concepts but the purpose of the exchanges and the exchange disciplines are different. Thus, they are kept separate from each other. In EM11A the fabricator passes the model of precast pieces and assemblies to the general contractor for coordination and then during the erection phase, the general contractor sends orders for piece delivery to plant manager. EM11B transfers coordination action items to the fabricator from the architect for piece detailing. This exchange passes back to the precast fabricator a report of the design intent issues identified by the architect for precast assembly-level piece layout, based on information supplied by the precast fabricator for the architects' review/approval. Therefore, these EMs are considered as separate exchanges.

5 Precast Concrete Consolidated Exchange Models

Based on the analysis of the exchange description as well as two major aspects described earlier which are: project stages and concept definition for each of the Exchange Models, 47 original EMs defined in precast concrete National BIM Standard are combined to twelve Exchange Models (i.e. EMPCs) listed below. Mapping to original EMs are listed in Table 3.

1. *EMPC1* (Building Concept- BC) consists of concept design layout of precast pieces optionally composed into assemblies. Geometry is nominal, without camber or twisting. It does not include surface or structural detailing. It includes structural- and other grid-controls, if used. It optionally includes major architectural finishes, and site information. It identifies interfaces with other structural elements and curtain wall systems. Extrusion is used as the geometry representation.
2. *EMPC2* (Precast Concept- PC) is the precast detailer's review on Building Concept model from architects and structural engineers. It specifies major architectural/structural precast components. This may deal with precast structural system, panelization, architectural finishes and site logistics. Extrusion is used as the geometry representation.
3. *EMPC3* (Precast Contract Development- PCD) provides precast design intent dealing with both structural and architectural intent. It defines the structural requirements of the building. It may include loads reactions, precast connection designs, precast-to-structural steel connection design, foundation design, and connection element capacities. Precast finishes may be defined and optionally doors, windows, interior wall partitions, and curtain wall systems embedded in or related to the precast. It is passed between different parties for review to ensure the building design intent and the structural adequacy is preserved. It is further refinement of the concept model, providing basis for the precast cost estimate based on early schematic design models. General contractor adds budget, schedule and specifications for the entire building received from several precast detailers/subcontractors to be passed to the owner/architect group to make a go/no-go decision about the project. Main geometry representation in this exchange is extrusion.
4. *EMPC4* (Engineering Design Development- EDD) is the detailed precast design model. It includes high-level description of precast piece detailing and all connection details. It provides assembly and piece layout and panelization for review to the architect and engineer. Architect's response then identifies those aspects and parts of the design where design intent has not been met to ensure consistency between the architectural design and precast detailing models. The general contractor can use this model for bid preparation or for coordination merged with other trade models. Main geometry representation is B-rep.
5. *EMPC5* (Architectural Contract- AC) integrates the building layout of all precast pieces with all other building systems. It identifies the shape and logical connectivity of all precast pieces. It includes the layout of surface finishes, molding, reveals and other decorative features. Other systems interacting with precast are also represented. Based on the architectural and engineering designs, this exchange model is used for coordination of all precast components includes precast slabs, beams, columns, and connections. It conveys detailed model descriptions of all precast structural elements, using B-rep geometry. The model together with the drawings and specifications are also submitted to the general contractor in order to be assembled with other models and used for the bid preparation. Main geometry representation is B-rep.
6. *EMPC6* (Engineering Contract- EC) is prepared as a construction drawing set or construction-level model. It is focused on the structural design and integrates the structural layout with other building systems. The model includes structural elements, connections and details. Both the precast and other structural systems are fully designed. Main geometry representation in this exchange is extrusion.
7. *EMPC7* (Precast Detailed Coordination- PDC) is general purpose multi-workflow exchange model defined by diverse sources for different recipients for detailed coordination. It may be used for the total building cost estimate based on the early schematic design models. It includes descriptions of all connection details, finishes, joints, embeds, reinforcing, tensioning cable layout, pre-tensioned pieces, and lifting hooks for lifting and transporting. Structural design of logical connections are specified. This model also conveys the results of structural design and reinforcement review of the engineer of record to the precast fabricator during the fabrication phase with information about design constraints, design loads and structural design. Main geometry representation is B-rep.
8. *EMPC8* (Structural Review & Coordination- SRC) includes geometry and assembly relations of buildings. Common categories of information for various types of products are included like layout, related shape and material information; both in the piece and assembly level. Connection relations of the pieces except for non-load bearing pieces are specified. Assembly and nested relations except for connections, and non-load bearing pieces are included. Related identification information and concrete mixes are included. Layout and grid geometry of facades, slab toppings, and reinforcement specifications are designated. More low level, detailed information about products is included. Characteristics of thermal and acoustic insulation are defined. Nested relations of both field

applied and plant applied connections are specified. Finally, related specifications of other building parts and systems are included. It includes detailed description of precast piece detailing, descriptions of all connection details, finishes, joints, embeds, reinforcing, tensioning cable layout, pre-tensioned pieces, and lifting hooks for lifting and transporting. Connections, design constraints, design loads and structural design are defined, using B-rep geometry.

9. *EMPC9* (Engineering Analysis Results- EAR) includes all structural precast elements. Slab layout and topping are defined. Assembly, nested and connection relations of load bearing and voided pieces are specified. Assembly and nested relations of logical connections and both field and plant applied connections are defined. Related identification information and concrete mixes are included. Reinforcement specifications and layout are designated. Structural design for load-bearing pieces and design loads for slabs are specified. Important common categories of information are included such as layout, shape, and material types and surface treatment, both in the piece and assembly level. Openings and opening frames are defined. Detailed information for some types of products is included. Layout and grid geometry of facades are designated. For load-bearing, non-load bearing and voided pieces, joint and connection relations are specified too. Logical and physical connections are defined. Lifting devices are indicated. Thermal and acoustic insulation characteristics are defined. Extrusion is used as the geometry representation.
10. *EMPC10* (Final Precast Detailing & Coordination- FPCD) includes fully detailed information about products and their assembled composition in project- layout, shape, geometry and finishes of all precast products. Assembly relations of the pieces and connections are specified. Connections with other systems, including embeds, are included. Openings and opening frames are defined (not opening fillers). Identification and related production information for different pieces are included. Reinforcement specifications are defined. Relevant information for different types of products is provided. Facade layout and grid geometry are defined. Voided pieces, nested, connection and joint relations are specified. Nested relations of both field applied and plant applied connections are specified. Specifications of other related building parts and systems are included. Concrete mixes and finish material types are defined. Lifting devices are included. Surface treatment areas are included. Main geometry representation is B-rep.
11. *EMPC11A* (Production and Erection Data- PED) provides important common categories of information including layout, shape, material types, and information about product finishes both at the piece and assembly level. Also, assembly relations of products except for foundation parts are specified. The piece marks for identification are included. Detailed information for some types of products is included. Layout and grid geometry of facades are designated and slab topping thickness, material and surface treatment are defined. For load-bearing and non-load bearing pieces, assembly, nested, joint and connection relations are specified. Relevant information about reinforcement is included. Nested and assembly relations of both field applied and plant applied connections are specified. Affecting specifications of other building parts and systems like lifting devices are indicated. Main geometry representation is B-rep.
12. *EMPC11B* (Architectural Review and Coordination- ARC) in which design constraints of buildings and spaces are indicated, where relevant. Product information that raises issues about the design intent are reported, including layout, shape, material types, geometry and material of finishes of products, both in the piece and assembly level. Also, assembly and connection relations of pieces are specified. For load-bearing and non-load bearing pieces, assembly and joint relations may be identified. The specifications of joints are defined. Nested and assembly relations of both field applied and plant applied connections are specified. The piece marks for identification are included. Facade layout and grid geometry may be designated. Slab topping thickness, material and surface treatment may be returned. Related specifications of other building parts and systems are indicated. Main geometry representation is B-rep.

These twelve Exchange Models cover the whole lifecycle of the precast concrete project from preliminary design stage to erection phase. They address all the exchange information requirements listed in National BIM Standard for precast concrete projects.

6 Discussion and Conclusion

This paper highlights that while there are many similar exchanges among the EMs defined in the Information Delivery Manual for precast concrete domain [4], the existing recommendations for consolidating 47 originally defined exchange models described in the work of [4] and [6] have not been effective. In the first approach [4], some of the similar EMs have not been identified ending up with too many Exchange Models. In the second approach [6], even though all original EMs are combined to limited number of EMs (i.e. eleven), some issues with its consolidation strategy are analyzed in this study which points out the challenges. This analysis indicates the existence of duplicated EMs and inconsistencies in exchange requirements of the combined EMs. Such problems make the implementation of precast concrete MVD challenging. The MVD requires its Exchange Models to be limited in numbers so that it can be managed within software implementation. Most importantly the MVD should be exhaustive and definite. Exhaustive means every model-based exchange in the lifecycle of the project must belong to an EM, and definitely means each exchange may only belong to one EM. In addition, if two original EMs are supposed to be combined in a resulting EM, the exchange requirements (i.e. the sets of data required in each EM) should be similar, otherwise the consolidation is not practical.

The consolidation methodology proposed in this paper addresses the existing issues. This is with regard to model description as well as IFC concepts that each EM includes, and project stages that each exchange is happening with related exchange disciplines that are involved. A detailed review of the MVD concepts identified the IFC concepts each EM includes and specifies the IFC concepts that similar EMs have in common. This ensures the exchange models are being combined based on similar exchange data they include. In addition, common project phases that similar EMs occur along with relevant exchange disciplines ensures that the consolidated exchange models are related to similar stages of the project. As a result, twelve exchange models are identified as Building Concept, Precast Concept, Precast Contract Development, Engineering Design Development, Architectural Contract, Engineering Contract, Precast Detailed Coordination, Structural Review and Coordination, Engineering Analysis result, Final Precast Detailing and Coordination, Production and Erection Data, and Architectural Review and Coordination.

This methodology describes how to effectively combine what is found to be too many originally defined precast concrete exchange models. Thus, the main contribution of this paper is to make the implementation of precast concrete MVD manageable by introducing a limited number of exchange models in the life cycle of the precast projects. The methodology has been applied in the implementation of the MVD for automated validation of precast concrete IFC instance files [9].

The identification of these new Exchange Models suggests future revision to National BIM Standard for precast concrete Information Delivery Manual. Additionally, the methodology of combining exchange models described in this paper can be utilized in other domains to facilitate the implementation of their MVDs.

7 Acknowledgement

The work presented here was funded by the Prestress/Precast Concrete Institute (PCI). All information presented is that of the authors alone.

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