Integrated BIM Platform for Multi-Story Modular Building Industry

Issa J. Ramaji[1], Ali M. Memari[2], and Ryan L. Solnosky[3]

[1]Ph.D. Candidate, Department of Architectural Engineering, Penn State University, 105 Engineering Unit B, University Park, PA 16802, E-Mail: ramaji@psu.edu
[2]Professor, Department of Architectural Engineering and Department of Civil and Environmental Engineering, Penn State University, 222 Sackett Building, University Park, PA 16802, E-Mail: memari@engr.psu.edu
[3] Research Associate, Department of Architectural Engineering, Pennsylvania State University, University Park, PA, 16802. Email: rls5008@engr.psu.edu

ABSTRACT

Modular construction is known for its economic advantages and high construction quality because of the factory construction environment. Despite the simplicity of the construction of modular single-family dwellings that brings about speedy erection at the job site, the same thing cannot be stated for multi-story modular buildings, especially in design phase. Considering complexities in this industry, more integrated project management is required. Integrated project delivery needs an integrated information management system. Building Information Modeling (BIM) has been used during the past decade to address this need. In this system, different disciplines use an identical BIM model as an input for their analysis and a platform to share their results. Constant information exchanges between BIM models and specialized analysis and design software has to be reliable to have a flawless integrated BIM model. National BIM Standard (NBIMS) is established to address this need and has been used in many different types of construction so far. Using NBIMS for standardization of information exchanges in modular building industry will be very helpful for integrated application of BIM application in modular building projects. In this paper major components of the NBIMS that include Information Delivery Manual (IDM)/Model View Definition (MVD), Industry Foundation Class (IFC), and International Framework for Dictionary (IFD) will be discussed. Next, the methodology for extending the NBIMS will be discussed. Then, for more clarification, the efforts for extending NBIMS in structural analysis/design and precast/prestressed construction areas are reviewed. At the end, the processes for information exchange standardization in modular building industry are discussed

Keywords*:* Modular Buildings, Building Information Modeling (BIM), Information Exchanges, Information Delivery Manual (IDM), Model View Definition (MVD), Industry Foundation Classes (IFC), International Framework Dictionary (IFD), National BIM Standard (NBIMS).

INTRODUCTION

Ever since engineers started using computers for design purposes in 1970s, interoperability was an issue. It started with the translation of geometry, and later expanded to encompass lifecycle information translations. There are two types of information translation: 1) syntactic translation that is the original idea of information translation, where the information is copied from one format to another format; and 2) Mapping information that involves mapping from one type of model to another type with varying semantic; an example is translation of architectural model to structural design model (Eastman 2012).

Advanced features of Building Information Modeling (BIM) have changed the contribution of Information Technology (IT) in the construction industry. This change has evolved from a simple 3D modeling of the construction geometry to an integrated semantic product and process model. Introduction of Industry Foundation Classes (IFC) in 1994 started various efforts to develop an open model standard to address the interoperability issues of the BIM data exchanges in industry (Laasco & Kiviniemi 2012).

Vries (2005) defines a standard in construction as an approved specification of a limited set of solutions to actual or potential matching problems, prepared for the benefits of the party or parties involved, balancing their needs, and intended and expected to be used repeatedly or continuously, during a certain period, by a substantial number of target parties. There are many advantages in using an open standard for interoperability instead of direct translation, one being decreasing the number of required translators. As depicted in Figure 1, by developing an open standard, it's not required to develop a translator between two individual units; we have to just develop a single translator between each unit and the open standard. Other issues with direct translation that can be addressed using an open standard format include handling software changes, access to the proprietary file formats, responsibility in errors in translation and its testing (Laasco & Kiviniemi 2012; Bloor & Owen 1995; Gielingh 2008).

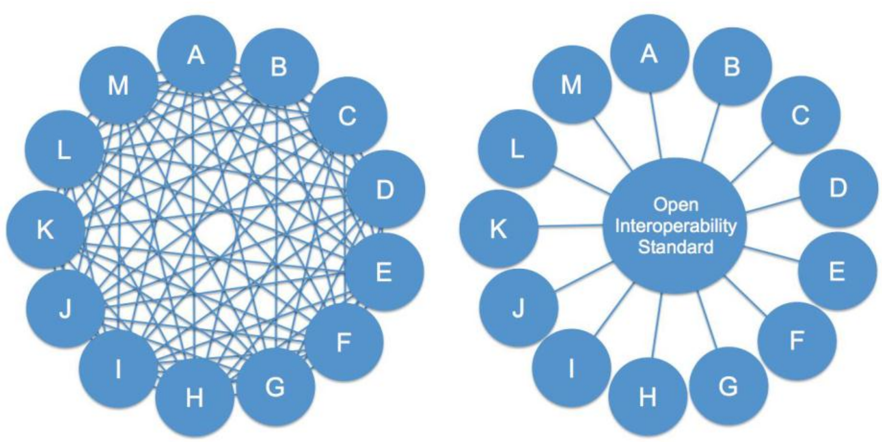

Figure 1: Direct Translators vs. Open Interoperability Standard (Courtesy of: Laasco & Kiviniemi 2012, Bloor & Owen 1995:18, and Gielingh 2008)

There are two different methodologies for data exchanges in IT standards: structuralist (also known as explicit) and minimalistic. The structuralist approach is more comprehensive and complete. The processes of developing the structuralist approach is top down, i.e., first start with high level model, and then add more detail for different parts to complete the model. The minimalist approach is simpler and as a result could be adopted by the user community more easily. The minimalist process is bottom up, i.e., start with a small amount of information and then before adoption, it would be improved based on the experiments, testing, and iterative improvement. Once developed, tested, and adopted, the model would contain more information than what is required (Behrman 2002).

NATIONAL BIM STANDARD

National BIM Standard (NBIMS) was established to standardize semantic and ontologies of information exchanges to support business contexts (Nawari and Sgambelluri 2010). The objective of NBIMS is achieving an improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information, created or gathered, about that facility in a format useable throughout its lifecycle by all (NBIMS 2012).

As depicted in Figure 2, NBIMS has three major parts: 1) Information Delivery Manual (IDM), 2) International Framework for Dictionary (IFD), and 3) Industry Foundation Class (IFC) file format. IDM is a standard for the processes of the work, IFD is a standard for the terminology that is used in the processes, and IFC is a standard format for data management and information exchanges. In the following sections, each of these parts is defined in more detail.

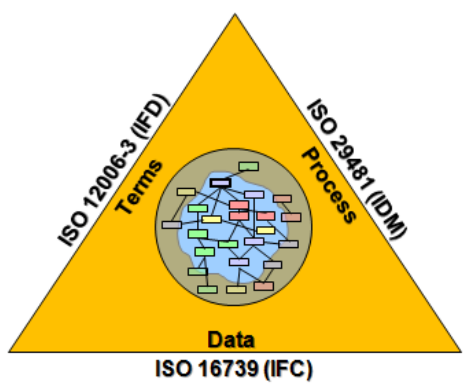

Figure 2, Holistic Diagram of the NBIMS (Courtesy of: buildingsmart-tech.org)

Information Delivery Manual/Model View Definition

IDMs and MVDs are to specify the information exchange requirements and relate these exchange requirements to the IFC file format. They explain the exchange scenario in a human readable format, as well as in a computer interpretable way for software vendors to implement the standard (NBIMS 2012).

An IDM involves identification and documentation of information exchange processes and requirements. These documents are typically expressed in human-readable form (Nawari and Sgambelluri 2010). IDM supports the integrated construction processes by serving the technical implementation needs of the software vendors and provides role—based process workflow for the end user (Laasco & Kiviniemi 2012). IDM is an integrated reference for processes and data required by BIM and specifies where a process fits; why it is relevant; who creates, consumes, and benefits from the information; what is the information; and how should the software solution support this information (Wix 2007; Laasco & Kiviniemi 2012).

An MVD is conceptually the process that integrates Exchange Requirements (ER) coming from one or many IDM processes to the most logical Model Views that will be supported by software applications. Implementation of these components will specify structure and format for data to be exchanged using a specific version of the IFC file format. In other words, it standardizes the way that the information for a certain Model View has to be organized, and then helps to show how the information has to be digitally exchanged using the IFC file format (Nawari and Sgambelluri 2010, NBIMS 2012).

Industry Foundation Class

The IFC file format was developed by International Alliance for Interoperability (IAI) to address the interoperability problems of BIM software. Now it is the standard format of the NBIMS. Using the standard for information management and exchanges can guarantee the sustainable information modeling in the project and prevent missing information during exchanges. IFC is a format for the representation of the object, their attributes, relationships, and inheritance (Nawari and Sgambelluri 2010; Laakso and Kiviniemi 2012).

The IFC files take advantages of both structuralist and minimalistic approaches by using a layered model (Tarandi 1998). As depicted in Figure 3, the structure of the IFC files is divided in four layers, including domain, interoperability, core, and resource. The layers have a restrictive hierarchy and the information in each layer has to be independent of the upper levels. The resource layer holds the resource schema that contains basic definitions intended for describing objects in the higher layers. The core layer consists of the Kernel and extension modules. The Kernel determines the model structure and decomposition, providing basic concepts regarding objects, relationships, type definitions, attributes and roles. Core extensions are specializations of classes defined in the Kernel. The interoperability layer provides the interface for domain models, thus providing an exchange mechanism for enabling interoperability across domains. The domain layer contains domain models for processes in specific AEC domains or types of applications, such as architecture, structural engineering, and HVAC, among others (IAI 1999a; IAI 1999b; IAI 2000, Laasco & Kiviniemi 2012).

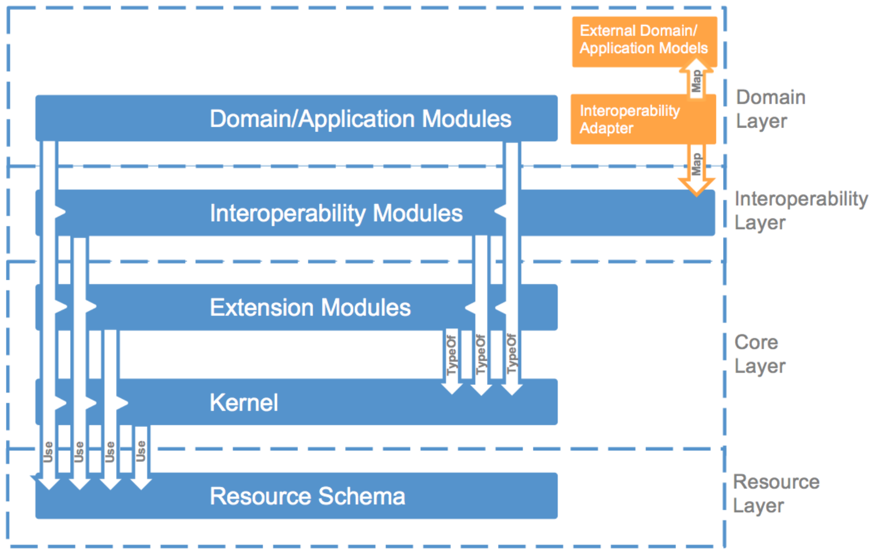

Figure 3, IFC data model structure (Courtesy of: Laasco & Kiviniemi 2012, IAI 1999b, and IAI 2000)

International Framework Dictionary

For any free flow of information, three requirements need to be addressed: a format for information exchanges, a process model, and a standardized description of what the information you exchange actually is. The last requirement has been addressed in the NBIMS by developing the IFD library, which in simple term is a standard for a terminology database (NBIMS 2012; IFD-library.org).

IFD is an open library, where concepts and terms are semantically defined and make it possible to assign a Globally Unique ID (GUID) to each part of the information in the IFC format. As a result, an exact discretion of a component can be correctly understood by the receiving application, as long as the correct GUID is given. For example, the architect can describe the column in a language other than English, and then the structural engineer in the United States will be able to understand the exact description of that column. While textual based information like names and descriptions are exchanged between actors, the underlying GUID is used by the computers. IFD provides a mechanism to develop a dictionary to connect the information from existing database to data model, (NBIMS 2012; Bell and Bejorkhaug 2006; Laasco & Kiviniemi 2012).

Contents within the Data Dictionary can be categorized in two different parts: 1) Subject (Term): something that can be represented by a name, and be distinguished and recognized from other concepts 2) Characteristics (Properties): concepts their meaning cannot be provided except the description and cannot be defined using other concepts; these concepts include: Behavior, Environmental influence, Function, Measure, Property, and Unit. Figure 4 illustrates how a subject (window) can be described using different characteristics and how the IFD library could be used to define different Model Views (NBIMS 2012; IFD-library.org).

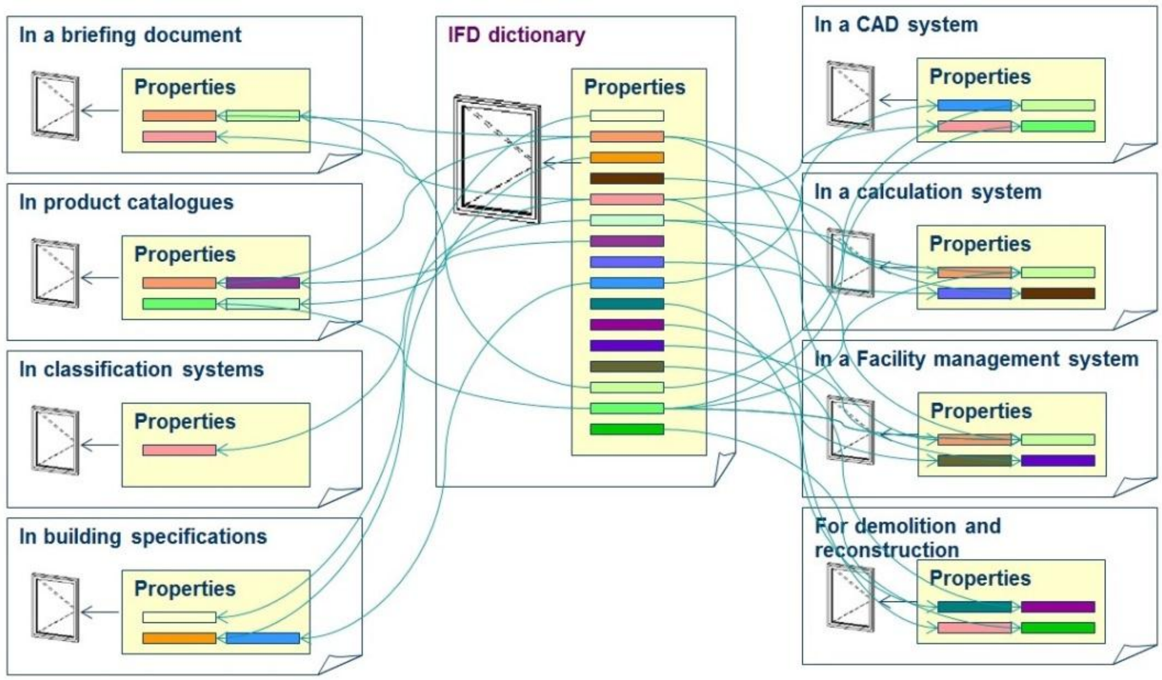

Figure 4, IFD application in BIM models (Courtesy of: IFD-Library.org and Lars Bjørkhaug-Catenda AS)

NBIMS EXTENSION PROCESSES

The NBIMS along with its open standard file format (IFC) is extendable for information modeling and exchanges of any type of construction. For this extension, there are three steps that need to be followed. In the following, these steps are explained.

Developing the Information Delivery Manual (IDM) is the first step. IDM is the user-interfacing phase of NBIMS exchange standard development. First, a lifecycle process map of the BIM model has to be defined. In this step the disciplines that are using the BIM model will be recognized. Then the information exchanges between these disciplines at different phases of the work will be identified. Each of these information packages that are being exchanged is one Exchange Model (EM) (Eastman et al. 2010). Examples of process map and EM definitions are depicted in Figure 5 and Figure 6, respectively, which are developed for precast/prestressed concrete construction (Aram et al. 2010; buildingSMARTAlliance 2011; Venugopal et al. 2012; Panushev et al. 2010).

Afterwards, the Exchange Models would be described. The information included in each of the EMs has to be recognized and defined clearly. The specification of the required information in each of Exchange Models is called Exchange Requirement (ER). An example of EM specification is depicted in Figure 7 (Panushev et al. 2010). The set of the process maps and described EMs is called Information Delivery Manual (IDM).

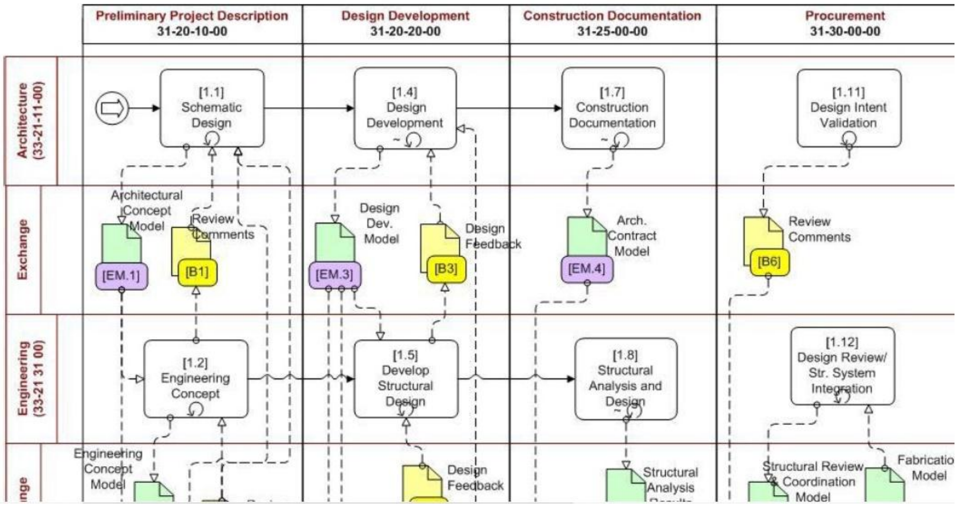

Figure 5: An example of process map (Courtesy of: Panushev et al. 2010)

Project Stage	31-20-10-00 Preliminary Project Description
Exchange Disciplines	(33-21-11-00) Architecture (33-21 31 00) Engineering (33-25 41 11 11) Building Product Manufacturing
Description	Architectural concept model consists of concept layout of precast pieces into simple assemblies, without surface or structural detailing. Building model includes massing models, structural and other grid controls, building program and space layout and use, expected thermal and acoustic functions, if known, It might involve major architectural finishes, structural system selection, structural grid and site analysis.
Related Exchange Models	A_EM.1, P_EM.1, S_EM.1

Figure 6: An example of EM (Courtesy of Aram et al. 2010)

Information Group	Information Items	Attribute Set	Attributes		P_EM.1	P_EM.2	P_EM.3
Foundations							
	Grade Beam,	Shape	Geometry	Required?	R	R	R
	Pier Cap,			Deformations?	A	A	D
	Spread Footing,			Function?	V	F	E
	Slab on Grade,			Level of	L	M	H
	Stem Wall,			Accuracy?	P	P	C
	Retaining Wall,		Dimensional Tolerance	Required?	O	O	R
	Drilled Pier,	Type	Structural Type (CIP	Required?	R	R	R
	Cassion,	Supplier	GC/Contractor/Fabricator	Required?	O	O	O
	Pile,	Material	Material type	Required?	R	R	R
	Pile Cap		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 7: An example for EM specification (Courtesy of: Panushev et al. 2010)

Model Views Definition (MVDs) is the second step. As Nawari & Sgambelluri (2010) define, the Model View Definition (MVD) is the software developer interface of exchange. In this step, the functional specification of the IDM will be translated to a human-readable format that later could be used to store information in a digital format. The MVD is developed using the NBIMS' IFD library. If there is a concept that is not addressed in the IFD library, the developer can define a new concept; but he/she has to use the IFD library concepts as much as possible. In this step, the defined information exchanges in IDM will be organized in IFC specification hierarchy schema to make it possible to map the required information to the IFC predefined concepts. An example of a Model View Definition (MVD) is shown in Figure 8 (Hietanen and Final 2006).

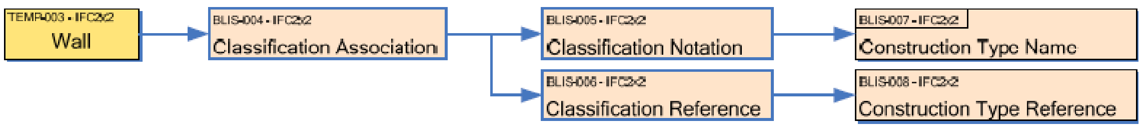

Figure 8: An example of MVD (Courtesy of: Hietanen and Final 2006)

Binding the developed MVD to IFC file format and its implementation is the third step. After preparing the MVDs, each of the concepts in the MVDs will be mapped to their associated IFC format entities. The mapping between MVDs and IFC format is called IFC binding. An example of connection component assignment is depicted in Figure 9. If there is lack of proper entity in the IFC file format, the developers can submit a proposal to the buildingSmart to add the new entities in the next version of the IFC file format.

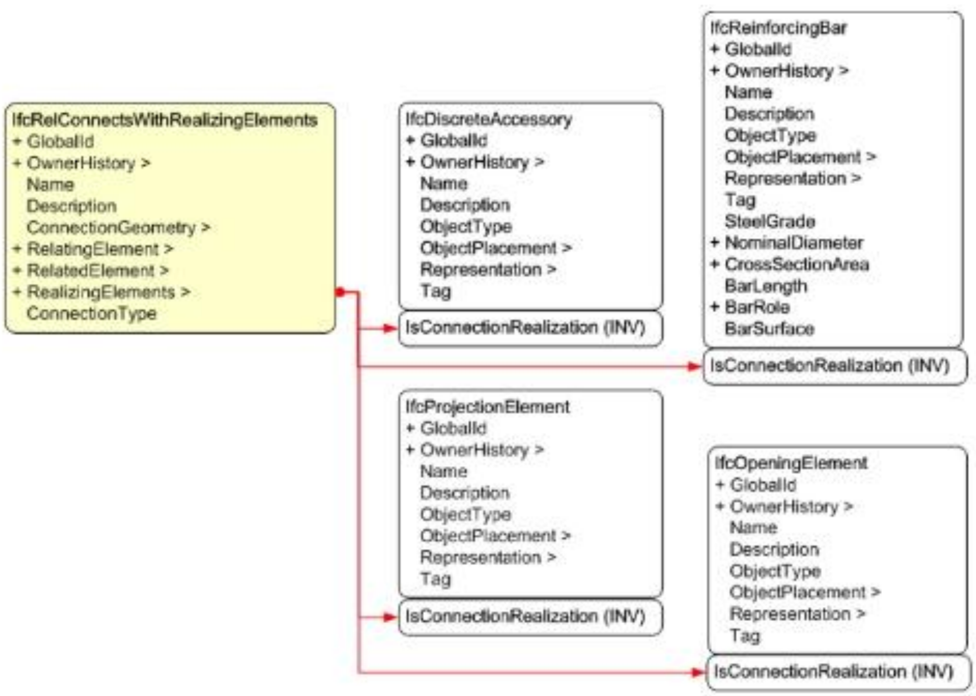

Figure 9: IFC binding example (Courtesy of: Panushev et al. 2010)

The whole developed documents including IDM, MVDs, and IFC bindings have to be sent to NBIMS as a proposal for evaluation. Once accepted, it will be added to the standard and the software vendors would have to adopt and implement the developed MVDs, concepts and entities to be qualified for the buildingSmart IFC certificate. Accomplishing these activities will address the interoperability problem in the area to which we are extending the NBIMS.

MAJOR EFFORTS RELATED TO STRUCTURAL ASPECTS

Many efforts have been done so far to extend the NBIMS to address interoperability issues in different areas. Since software developers are responsible for practical implementations of the standard, the Building Lifecycle Interoperable Software (BLIS) Group was founded in 1999 to fill the gap between publication of the standard and its implementation in software. In 2006, BLIS introduced MVDs as an official element for IFC standardization to show how data exchanges are applied between different types of applications; and by this means benefits the implementers of IFC software (Laasco & Kiviniemi 2012). IFC extension proposals have to be sent to BLIS for evaluation. Figure 10 summarizes the list of the efforts that has been done for NBIMS extension. Not all of these efforts have been completed or evaluated by BLIS; the status column in Figure 10 shows the status of each effort (IFC Solution Factory 2014) that could be Idea, Draft, Proposal, Candidate, or Official, respectively. For more clarification some of these efforts will be discussed in more detail in the sections that follows:

Name	Status	Reference No.	Name	Status	Reference No.
Basic HandOver to Facility Management	Draft	GSC-001	Extended coordination view	Idea	ISG-001
Architectural Design to Building Energy Analysis	Candidate	GSA-003	Extensibility	Idea	VBL-003
Architectural Design to Circulation/Security Analysis	Proposal	GSA-002	Indoor climate simulation to HVAC design	Proposal	HUT_HVAC-001
Architectural Design to Quantity Takeoff for Cost Estimating	Candidate	GSA-004	Landscape design to road design	Idea	CRC_CI-002
Architectural Design to Spatial Program Validation	Candidate	GSA-001	Masonry Structural Design to Structural Analysis	Draft	UF-DCP-001
Concept Design BIM 2010	Official	GSA-005	Precast Concrete Exchanges	Candiate	PCI-001
Design to Code Compliance Checking (ICC 2006)	Proposal	ICC-001	Road design to landscape design	Idea	CRC_CI-001
Early Concept Design to Analysis	Draft	GSA-006	Space Requirements and Targets to Thermal Simulation	Draft	HUT_HVAC-002
Nordic Energy Analysis (subset of CDB-2010)	Candidate	NOW-001	Structural design to structural analysis	Proposal	VBL-001
Architectural design to landscape design	Idea	CRC_CI-003	Structural Design to Structural Detailing (ATC-75)	Draft	ATC-001
Architectural design to structural design	Draft	VBL-002	Wood Structural Design to Structural Analysis	Draft	UF-DCP-002
Architectural design to thermal simulation	Proposal	VBL-007	Architectural design to quantity take-off - level 1	Idea	VBL-004
Architectural Programming to Architectural Design	Draft	BSI-001	Architectural design to quantity take-off - level 2	Draft	GSC-002
Curtain Wall Design to Energy Analysis	Draft	UNSW-001	Architectural design to quantity take-off - level 3	Idea	VBL-006

Figure 10: IFC Solution Factory MVDs (Courtesy of: IFC Solutions Factory)

Structural Design to Structural Detailing (ATC-75):

This project was developed by the Applied Technology Council (ATC) to address the interoperability issue of structural element information between BIM software or between BIM and structural analysis/design software. The methodology that ATC used in this project was the same as that discussed in this article. First, the structural engineering business processes map has been developed. As depicted in Figure 11 (ATC-75 2010), the structural engineers interact with three types of models consisting of: 1) the architectural model, 2) the structural model, and 3) the construction model. The whole processes of the structural design have been divided in four stages consisting of: 1) defining the structural systems, 2) development of the structural model, 3) performing structural analyses for verification, and 4) extracting structural drawings and specifications. Next, the Exchange Requirements (ER) were recognized and based on that, the MVD has been developed and bound to the IFC format (ATC-75 2010).

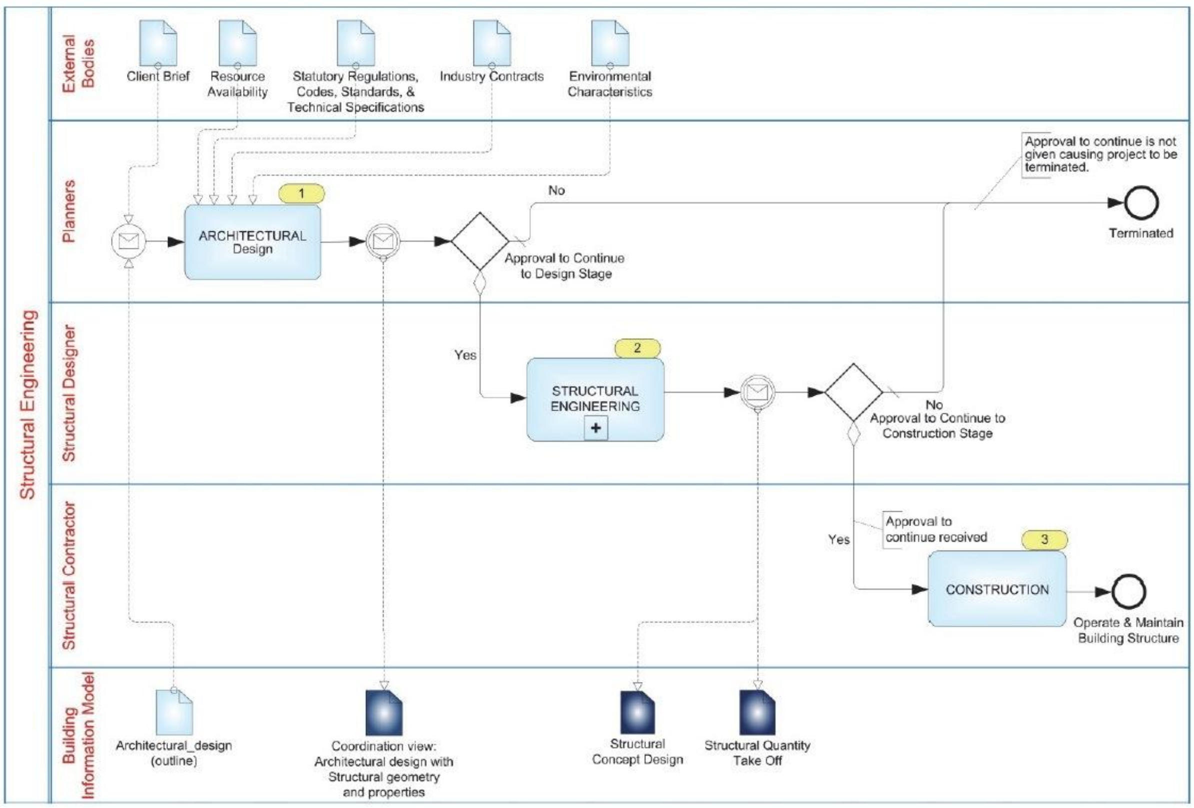

Figure 11: Structural engineering business processes map (Courtesy of: ATC-75 2010)

In this project, a benchmarking test has been done on a variety of BIM and structural design software types to systematically quantify the state of interoperability in a methodical and comprehensive format. This was also done to rate the success of information transfer from one software to another. The criteria for these tests included the following: 1) the accuracy of geometric coordinate transfer, 2) material properties transfer, 3) curved and shaped geometric transfer, and 4) sloped geometric transfer. An identical simple model has been developed for the benchmarking tests. One benchmarking test has been done before developing the IDM, MVD, and IFC binding and one done after. The software vendors modified their software based on feedbacks from the project and the first benchmarking test. The comparison of two benchmarking tests showed a significant improvement in the correct information exchanges among these software. For more clarification, the result of the second benchmarking test on Bentley Structural v8 is shown in Figure 12 (ATC-75 2010).

		DESTINATION									
		CAD / BIM SOFTWARE					STRUCTURAL SOFTWARE				VIEWER
	Software / Version	Bentley Structural v. 8i	AutoCAD MEP 2011 v.E.49.0.0	Revit 2011 20100326_1700	Digital Project v1, r8	Tekla Structures v. 16.0	Sap 2000 11.0.8	Etabs 9.1.6	RISA-3D 7.0.2	Ram Struct System 11.2.1	DDS IfcViewer 6.4
Columns	Geometry	No	No	No	No	No	IFC2x3 Unsupported	IFC2x3 Unsupported	Importer unavailable	Importer unavailable	yes
	Properties	No	No	No	No	No					No
	Sloping	N/A	N/A	N/A	N/A	N/A					N/A
Beams	Geometry	Yes	Yes	Yes	Yes	Yes					Yes
	Properties	No	No	No	No	No					No
	Curved	No	No	No	No	No					No
	Sloping	Yes	Yes	Yes	Yes	Yes					Yes
Braces	Geometry	Yes	Yes	Yes	Yes	Yes					Yes
	Properties	No	No	No	No	No					No
Walls	Geometry	Yes	Yes	No	Yes	Yes					Yes
	Properties	No	No	No	No	No					No
	Curved	Yes	Yes	No	Yes	Yes					Yes
	Sloping	Yes	Yes	Yes	Yes	Yes					Yes
			NA								
Slabs	Geometry	Yes	Yes	Yes	Yes	Yes					Yes
	Properties	No	No	No	No	No					No
	Sloping	Yes	Yes	Yes	Yes	Yes					Yes
Remarks					DP can not display element properties from IFC files. Body name is inherited from Bentley element name.	No import errors. Must import as reference model.					

Figure 12: Second benchmarking test on Bentley Structural v8 (Courtesy of: ATC-75 2010)

Precast/Prestressed Concrete Constructions

This research was done to address the interoperability issues in the precast/prestressed concrete industry. This research also followed the same methodology as discussed previously. First, the IDM was developed for the planning, design, documentation, construction and fabrication phases and their information exchanges (Panushev et al. 2010). Next, five different Model Views were defined and bound to the IFC file format. These five MVDs are supporting the following five use cases:

- Clash detection among different disciplines like MEP, structural or electrical -- In this model view, the boundaries of the elements are important.
- Structural analysis and design purposes -- This model view is in the form of nodes and axes and 3D geometry is not addressed, but the loads and the weight of the elements are concerned.
- Precast fabrication purposes -- In this model view, the boundaries of the precast parts and the hollow cores are addressed.
- Parent assembly representation -- This is developed for the times that is needed to specify the components that the parent assembly is composed of. In this model view, the geometry of the parent assembly is derived from the geometry of individual components
- Production and delivery sequencing -- Geometry is not concerned in this model view, but items like piece counting and erection sequencing is important.

STANDARDIZATION IN MODULAR BUILDING CONSTRUCTION

Proper information exchange and integration of different project phases are the two fundamental needs of the construction industry. Modular building industry is still at relatively early stages of its development, therefore there is no specific code or standard for the modules and the processes of this this type of construction; as a result, integration level of the information in this industry is relatively low (McGraw-Hill 2011). Standardization of information exchanges can significantly increase the information integrity level of the projects in this industry. In the following, the steps that need to be followed to achieve this goal are summarized:

Product Architecture Model (PAM) development: There are many different innovative systems in the modular industry and for developing a standard, these different systems have to recognized, categorized, and documented. In the PAM, different options for the assemblies and subassemblies have to be recognized based on the conventional modular systems; and then aspects such as functionality, aesthetic, geometry, energy efficiency, and sustainability have to be mapped to these options; then, attributes like scopes, limitations, and relations needs to be assigned to the assemblies and subassemblies to come up with the Product Architecture Model.

IDM/MVD development: The processes of the modular building projects are different from the site-built constructions; for example, modular building projects have two additional stages that are manufacturing and transportation. In addition, the design considerations of modular buildings are different as well. Therefore, a special process map along with exchange requirements required to be developed to standardize the information exchanges in this industry. Furthermore, different MVDs need to be defined to ease using the BIM model for different disciplines like structural engineer, architect, manufacturer, logistic manager, etc.

Updating the IFD: Modular buildings contain a lot of assemblies and subassemblies. Each of these assemblies is a concept. A lot of these concepts are new and are not addressed in the concepts developed for site-built constructions (especially assemblies at higher levels); these concepts have to be defined clearly to prevent any confusion. For example, it should be clear what subassemblies are pointed out when we say the module’s light gage steel wall; does it mean the wall including the corner posts of the module; does it mean the wall including the sheathing on the walls. Clear definition of the new concepts will significantly increase the interoperability in this industry.

IFC Binding of the developed MVDs: In order to ease information exchanges between different disciplines and make auto model view generations possible, the developed MVDs needs to be bound to the IFC file. Since there are new concepts defined for the modular assemblies and subassemblies in the IFD, new classes in the IFC file format need to be developed for storing new concepts’ information in the IFC file. For example, if the structural engineer needs the equivalent stiffness and resistance of the walls of modules, an entity needs to be defined in the IFC class of the module’s wall concept to store the values of these parameters.

SUMMARY AND CONCLUSION

In this article, the National BIM Standard (NBIMS) has been reviewed. NBIMS has been established to address information exchange issues in AEC industry. It has three main parts including: Information Delivery Manual (IDM)/Model View Definition (MVD), Industry Foundation Class, and International Framework for Dictionary. IDM/MVD specifies the information exchange requirements and model views; IFC is a file format for digital storing and information exchange purposes; and IFD is like a dictionary for defining concepts from different disciplines into a universally understood language. Next, the methodology for extending the NBIMS for a certain area of the AEC industry was discussed. This extension has three main steps including IDM, MVD and IFC file format binding. Then, efforts and the methodology for extending NBIMS in different construction areas were discussed. One of these efforts is Applied Technology Council's (ATC) research for addressing interoperability issues in structural design to structural detailing processes. The other one is the research for extending NBIMS issue in Precast/Prestressed Concrete Constructions. At last, the steps that this research is seeking to extend the NBIMS for modular building industry are discussed. These steps are: Development of Product Architecture Model (PAM), IDM/MVD development, Updating the IFD, and IFC Binding of the developed MVDs.

NBIMS is still in its infancy. There are many different ongoing researches and projects that are trying to extend it for different types of construction and their different disciplines; and still many more efforts needs to be done. Regarding the framework of the NBIMS, it does not just address the interoperability issues, but it also standardizes the information flow and the construction processes. Standardization of information flow and processes defines the responsibility of different disciplines to each other clearly; and this helps to prevent constant challenges of different disciplines for receiving their required information in a proper format and roper time. It has to be noted that by improvement of the technology, the processes may be changed or some new attributes be added to the product, so the IDMs and MVDs has to be updated constantly for the upcoming changes based the feedbacks from the industry.

On the other hand, the software vendors can play a very important role in practical implementation of different aspects of the NBIMS; the software vendors provide tools for leveraging NBIMS in the projects. So, they have to adopt and implement the extension of the NBIMS to make it possible to use the NBIMS extensions in the projects. Therefore, their participation in the extension projects can speed up the NBIMS evolution and its adoption in the industry; in addition, it will guarantee the feasibility of the full implementation of the NBIMS extensions.

REFFERENCES

Aram, S., Eastman, C. M., Sacks, R., Panushev, I., and Venugopal, M. (2010). Introducing a new methodology to develop the information delivery manual for AEC projects. *Proceedings of the CIB W78 2010: 27th International Conference–Cairo,* Egypt*,* Vol. 49.

Behrman, W. (2002). Best practices for the development and use of XML data interchange standards. *Center for Integrated Facility Engineering Technical Report*, Stanford University, Vol. *131*, pp. 27.

Bell, H., and Bjørkhaug, L. (2006). A buildingSMART ontology. *Proceedings of the 2006 ECPPM Conference,* Valencia, Spain, pp. 185-190.

Bloor, M. and Owen, J. (1995). *Product data exchange*. UCL Press, London, pp. 262.

Vries, H. J. (2005). IT Standards Typology. In: Jakobs K. (Ed.) *Advanced Topics in In- formation Technology Standards and Standardization Research Volume 1*, Hershey, PA, USA, Idea Group Publishing, pp. 11-36.

buildingsmart-tech.org – Homepage. <http://www.buildingsmart-tech.org> (accessed January 2014).

buildingSMARTAlliance (2011). A council of the National Institute of Building Sciences, Develop and promote the National BIM Standard-United States™ and United States National CAD Standard, <www.buildingsmartalliance.org> (accessed January 2011).

Eastman, C. (2012). The evolution of AEC interoperability. unpublished manuscript.

Eastman, C.M., Jeong, Y.-S., Sacks, R., and Kaner, I (2010). Exchange Model and Exchange Object Concepts for Implementation of National BIM Standards. *ASCE Journal of Computing in Civil Engineering*, 24(1), pp. 25-34.

Gielingh, W. (2008). An assessment of the current state of product data technologies. *Computer Aided Design*. Vol. 40 (7), pp. 750-759.

Hietanen, J., and Final, S. (2006). IFC model view definition format. *International Alliance for Interoperability*.

IFC Solutions Factory – The Model View Definition site. <http://www.blis-project.org/IAI-MVD/> (accessed January 2014).

IFD-Library.org. IFD Library White Paper <http://www.ifd-library.org/images/IFD_Library_White_Paper_2008-04-10_I_.pdf> (accessed January 2014).

IAI, (1999a). Specification Development Guide. Ed. Wix J and See R. International Alliance Of Interoperability (IAI). Specification Task Force, pp. 47.

IAI, (1999b). IFC Object Model Architechture Guide. Ed. Liebich T and See R. International Alliance Of Interoperability (IAI). Specification Task Force, pp. 9.

IAI, (2000). IFC Technical Guide - Enabling Interoperability in the AEC/FM Industry. Ed. Liebich T and Wix J. Modeling Support Group. International Alliance Of Interoperability (IAI), pp. 46

Laakso, M., & Kiviniemi, A. O. (2012). The IFC standard: a review of History, development, and standardization, Information Technology. *ITcon*, *17*(9), 134-161.

McGraw-Hill Construction. (2011). Prefabrication and Modularization: Increasing Productivity in the Construction Industry. *Smart Market Report*, McGraw-Hill Construction, New York, NY, USA.

National Institute of Building Sciences (NIBS), (2012). *United States National Building Information Modeling Standard: Version 2*, buildingSMARTAlliance, <http://www.nationalbimstandard.org/> (accessed January 2014).

Nawari, N. O., and Sgambelluri, M. (2010, May). The role of national BIM standard in structural design. *The 2010 Structures Congress joint with the North American Steel Construction Conference in Orlando, Florida,* pp. 1660-1671.

Panushev, I., Eastman, C. M., Sacks, R., Venugopal, M., and Aram, S. (2010). Development of the National BIM Standard (NBIMS) for Precast/Prestressed Concrete. In *Proceedings of the CIB W78 2010: 27th International Conference–Cairo, Egypt,* Vol. 18.

Tarandi, V. (1998). *Neutral Intelligent CAD Communication - Information exchange in construction based upon a minimal schema*, Doctoral Dissertation, Kungliga Tekniska Högskolan, Stockholm, pp. 194.

Venugopal, M., Eastman, C. M., and Sacks, R. (2012). Configurable Model Exchanges for the Precast/Pre-stressed Concrete Industry using Semantic Exchange Modules (SEM). ASCE Journal of *Computing in Civil Engineering,* pp. 269-276.

Wix, J., and Karlshoej, J. (2010). Information Delivery Manual: Guide to Components and Development Methods. *BuildingSMART International*, <http://iug.buildingsmart.org/idms/development/IDMC_004_1_2.pdf> (accessed January 2014).