Bim Standard in the Structural Domain

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Abstract- **The Building Information Modeling (BIM) standard focuses on the challenges of enriching the model of relevant professional domain. It develops standard descriptions for building information exchanges to support essential professional contexts utilizing standard semantics and ontologies. This standard establishes the foundation for correct and effective communication and exchange that are necessary for the construction industry. The standard is still in its early stages and the advancement and development of BIM Standard will be contingent chiefly upon the efforts and involvement of various disciplines contributing to design, construction, and management of a facility. This research centers on advancing standardization of BIM model for structural analysis and design. In particular, the study addresses the Information Delivery Manual (IDM) as it targets to deliver the integrated reference for BIM process and data required by recognizing the discrete processes undertaken within structural design, the information required for their execution and the results of that activity. Furthermore, it will address Model View Definitions (MVDs) for structural design and analysis to create a robust process for seamless, efficient, reproducible exchange of accurate and reliable structural information that is widely and routinely acknowledged by the industry.**

Keywords- Building Information Modeling; BIM Standard; Information Delivery Manual (IDM); Model View Definitions (MVD); Industry Foundation Classes – IFC; Structural Design.

I. INTRODUCTION

The application of Building Information Modeling in Architecture, Engineering and Construction (AEC) industry can only be successful if all relevant data are captured in the BIM model, and successfully be exchanged between various project participants. One of the effective ways of performing this information exchange is through a standardized data exchange mechanism.

The problems of interoperability between engineering software systems have existed since the introduction of computer-aided design (CAD) in the 1970s [18]. The same issues have become critical in the architecture, engineering, and construction industries with the widespread adoption of building information modeling (BIM) in the early 2000s [6, 19]. The cost of inadequate interoperability for the AEC industries in the United States has been estimated at over $15 billion [9]. While parametric modeling of buildings has existed for as long as it existed in manufacturing, efforts to develop a building product model exchange schema based on ISO-STEP technology only began in the mid-1990s and are on-going. This effort is the industry foundation classes [10], promoted by Building SMART previously called the International Alliance for Interoperability (IAI) [11].

The second requirement is that BIM model must contain enough discipline specific information to get trustworthy design and analysis results. To attain these objectives and advance construction productivity, the US National BIM Standard (NBIMS) is founded to offer the digital schema and requirements for proficient BIM application in the AEC industry. The vision for NBIMS is "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". The organization, philosophies, policies, plans, and working methods comprise the NBIMS initiative and the end product will be the National BIM Standard (NBIM Standard or NBIMS) [17], which includes classifications, guides, practice standards, specifications, and consensus standards.

BIM Standard centers on the data exchanges between all of the individual actors in all of the phases of a construction project lifecycle. NBIMS will be an industry-wide standard for organizing the different trades and disciplines, work phases, and facility cycles, where data exchanges are expected and, for each of these exchange zones, stating the components that should be encompassed in the exchange between parties.

Many of the aspects of this predominant objective will be accomplished by a large conglomerate of actors. The part that BIM Standard is focused on is the design of the theory and structure for a new way of thinking about buildings as information models. Specifically, the BIM Standard recognizes that BIM needs a discipline and transparent data structure that supports the following:

- An explicit business case that encompasses an exchange of building information.
- The users' view of data that is essential to service the business case.
- The data exchange instrument for the necessary information interchanges (software interoperability).

This combination of content designated to support user needs and described to provide open digital exchange is the foundation of information exchanges in the US NBIMS. All these efforts must be harmonized for interoperability and this is the emphasis of the NBIMS Initiative. Therefore, in summary the principal drivers for defining requirements for the BIM Standard are industry standard processes and associated information exchange requirements.

In addition, even as the US BIM Standard centers on transparent and interoperable data exchanges, the BIM Standard Initiative addresses all related aspects of the facility lifecycle. BIM Standard is commissioned as a partner and an enabler for all organizations involved in the communication of information throughout the facility lifecycle.

The effectiveness of Building Information Model hinges on is its ability to encapsulate, organize, and transmit information for both users and machine in simple readable format. These associations must be at the detailed levels relating, for example, a window to its wall or even connecting a nut to a bolt, but preserve relationships from a detailed level to a world view. When engaging with as large a universe of materials as exists in the built environment there are many customary vertical integration points that must be traversed and many different "languages" that must be comprehended and associated. Architects and engineers, as well as the real estate appraisers or insurers must be able to communicate using the same semantic and refer to items in the same terms as the first responder in an emergency situation. This also applies to the world view of being able to translate to other global languages in order to support the transnational organizations. In order to standardize these many alternatives and create a comprehensive feasible standard, all AEC establishments have to be represented and asked for input.

One of BIM Standard's principal roles is to set the ontology and related common language that will permit data to be machine readable between parties and eventually offer direction and, add quality control to what is produced and called a BIM model. Eventually, these borders will embrace everyone who interacts with the built and natural environments. In order to achieve this, the actors who share information must be capable of using the same terminology. Common ontologies will facilitate this communication.

The acclaimed process for creating a BIM Standard specification, and implementation is defined in NBIMS, Vol. 1, Section 5 [17]. The main modules of NBIMS (see Fig. 1) include the Information Delivery Manual (IDM), and Model View Definition (MVD) and the IFC. The three core modules are also identically used by building SMART and the EU (European Union) in the IDABC (Interoperable Delivery of European eGovernment Services to public Administrations, Businesses and Citizens).

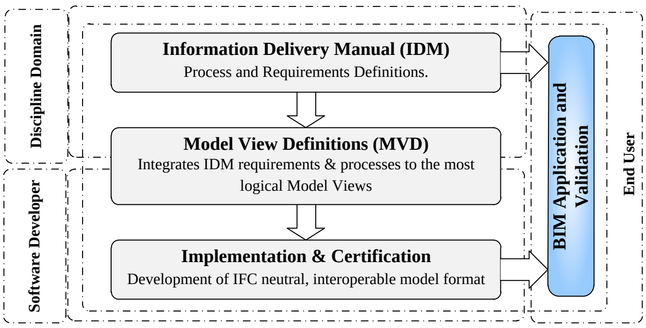

Fig. 1 Core modules of NBIMS.

The Information Delivery Manual (IDM) (also ISO/DIS 29481), is adopted from international practices, to enable identification and documentation of data exchange processes and requirements. IDM is the first step in BIM Standard development with information typically communicated in readable form.

The Model View Definition (MVD) is the software developer interface of NBIMS exchange. MVD is conceptually the development which incorporates Exchange Requirements (ER) stemming from many IDM processes to the most rational Model Views that will be implemented in IFC format by software applications. Implementation of these components will stipulate schema and format for data to be exchanged using a specific version of the industry foundation classes (IFC) standard to produce and endure a BIM application.

The IFC have been developed to provide neutral model data format. They provide an extensive set of generic building object types such as beam, truss, column, pile, wall, slab, etc. with associated attributes and other properties. It provides various form definition methods and means to illustrate relationships between objects. The envisioned role of IFC is to represent all information related to a building, from feasibility and design, through construction and then operation and to support exchanges of this range of information [11].

In summary, for a real effective BIM application the BIM standard requires three fundamental factors to be in place:

- Terminology: A standardized definition of the information exchanged. This is given by the International Framework for Dictionaries (IFD) and in the US it is being managed by the Construction Specifications Institute (CSI) in cooperation with ICC and can be understood as a multilingual framework for mapping objects terminology, classification systems, or ontologies to achieve consistency.

- Process: A specification of which information to exchange to who and when. This is established through the definitions of the IDMs and MVDs.

- Neutral Digital Storage: This is specified by the format for the model information exchange and is provided by the IFC. The data schema of the Industry Foundation Classes (IFC) is generic, and designed to support the full range of model exchanges required in the AEC industry.

Applying these development phases to the structural domain is the main activity for standardization of structural BIM. Fig. 2 depicts the key areas of data exchanges that include structural systems information. Each one of these areas has a number of sub-exchanges that necessitate further development. An initial effort in structural BIM standardization is represented by the Applied Technology Council project ATC-75 [3]. It is only a beginning and only started to define the elementary structural exchange data.

Considering the structural domain, there are virtually countless sets of structural attributes that can be associated with a BIM model which can be exchanged between different disciplines. They range from element ID, geometric and material properties to loads and support conditions, cost and scheduling to supplementary items such as LEED attributes or in fact any other parameter that needs to be shared.

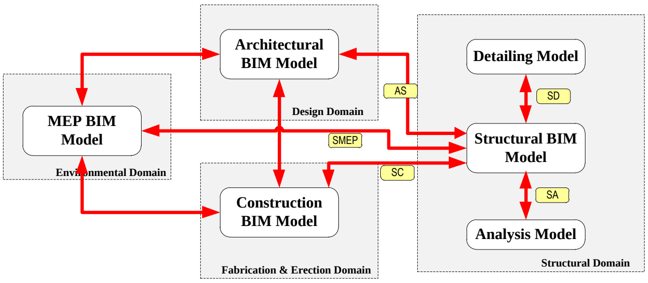

Fig. 2 Main structural information exchanges.

The main attention of ATC-75 project is centered on the following nine structural object categories or elements: Story, Grid, Column, Beam, Brace, Wall, Slab, Footing and Pile. Besides, for each of these objects a related set of attributes were defined [3]. For instance, the Column object attributes entailed: Column Axis, Profile Name, Material Type, Grade, Length, Roll, Cardinal Point, Element ID, Schedule Mark, Base Reference Story, Top Reference Story, Base Off Set and Top Offset. There might obviously be numerous more important attributes and it is anticipated that these will advance over time to include much more.

There is no doubt that structural BIM Standard will add incredible value to structural engineering by enhancing interoperability and efficiency of both design and construction [15, 16]. The next sections examine the key phases of developing standardization in structural modeling.

The establishment of standard transactions also decreases the footprint of commercial applications used to interact with building information. The delivery of open standard deliverables should also result in the elimination of proprietary software specifications. With such standards owners will actually own their data instead of having it locked up in proprietary software formats. When coupled with ubiquitous nature of XML processing tools, the adoption of these standards should span an entire new market in the creation of open-standards applications that could appear on devices such as cellular phones. The provision of formats that allow the consistent capture, without a proprietary software model requirements and project-specific implementations should also have a significant impact upon the types of design reviews that need to be accomplished. With automated reviews of logically organized project- and discipline-specific criteria, reviewers will have more time to evaluate the code conformity, constructability and operability of the each new project.

This study reviews the current state of national BIM standard and how to implement it in the structural domain. It is a part of research projects (UF-DCP-010 and UF-DCP-020 [21], http://www.blis-project.org/IAI-MVD/) funded by the College of Design, Construction and Planning, University of Florida to investigate the development of BIM Standards for masonry and wood construction. The study explores the main methodology of developing standardized BIM models as specified by building SMART [11] and the National Institute of Building Sciences [17]. It covers the principal components of the BIM standard, namely the information delivery manual (IDM), the model view definition (MVD), and the industry foundation classes (IFC) implementation.

II. STRUCTURAL INFROMATION DELIVERY MANUAL (IDM)

Structural systems modeling needs a widespread array of input data, which comprises building orientation, form including the layout and configuration of spaces, construction materials including strength and physical properties of all structural elements, type of joints, foundations and boundary conditions, loading cases, and other MEP related information.

The output results of structural analysis and design could comprise the evaluation of the building's deformation and strength for conformance with building codes, global evaluation of the building safety level, and estimate of the quantities of structural materials used.

The structural IDM refers to the document that defines the procedures and requirements to set up BIM models for structural analysis and design purposes. It centers on the relationship between processes and data. Structural designers are presently confronted with the fact that BIM platforms do not allow for full interoperability with their structural analysis and design applications and furthermore they get upgraded quite often with new features. Until some of these features are added, however, the designer has to use "workarounds" to get the paper documentation to communicate design intent. The critical issue here is to define the level of detail required for the structural modeling process. The structural IDM offers the basis for standardized information exchange. The central objectives of the IDM contain:

(1) Describe the processes within the structural design project lifecycle for which engineers require data exchanges.

(2) Define the results of procedure execution that can be utilized in succeeding processes.

(3) Identify the actors transferring and receiving data within the process.

(4) Make sure that meanings, specifications and descriptions are provided in a way that is valuable and effortlessly understood by the target group.

To develop IDM, there are two main steps: one is the process map that details the end user processes and data exchanges between end users, as shown earlier in Fig. 3. The second phase is the list of exchange requirements. The development of IDM begins with definitions of the information exchange functional necessities and workflow scenarios for exchanges between architects, engineers, manufacturers, erectors, and general contractors employing the 'use case' concept. A use case describes an exchange scenario between two well defined roles for a specific purpose, within a specified phase of a building's life cycle [6]. It is generally composed of more detailed processes and is embedded in a more aggregate process context. Most of the use cases are parts of larger collaborations, where multiple use cases provide a network of collaboration links with other disciplines. Such configuration of use cases is referred to as a process map.

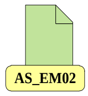

Fig. 3 Exchange model notation.

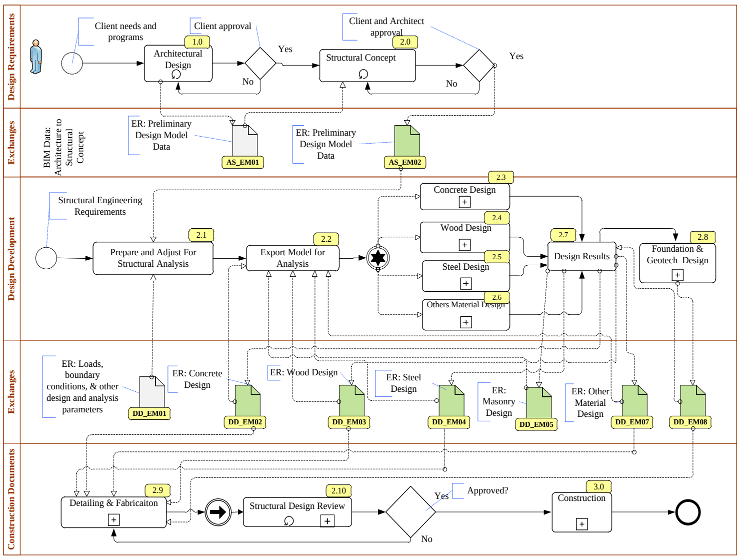

Fig. 4 Process map for structural design.

The process map was generated using the Business Process Modeling Notation (BPMN) (www.bpmn.org), since the notation has been accepted by building SMART and the National Institute of Building Sciences (NIBS). Horizontal swim lanes are utilized for the major processes. Main activity phases of typical structural analysis and design are identified along with their relationship to sub-processes (Fig. 4). In addition to the standard BPMN notation, the IDM employs symbolization for data exchanges between activities termed Exchange Models (EM) (see Fig. 3). The exchange model requirement denotes a link between process and data. It applies the pertinent information defined within an information model to fulfill the requirements of an information exchange between two processes at a particular stage of the project. Every exchange model is distinctively recognized across all use cases and in addition to its designation caries abbreviated description of the use case it belongs to:

- AS_EM01 - Architectural, Structural Concept use case exchange models.
- AS_EM02 - Structural concept, Structural Analysis use case exchange models.
- DD_EM01 - Preliminary Structural Analysis use case exchange models.
- DD_EM02 - Structural Analysis, Reinforced Concrete Design use case exchange models.
- DD_EM03 - Structural Analysis, Structural Steel Design use case exchange models.
- DD_EM04 - Structural Analysis, Structural Wood Design use case exchange models
- DD_EM05- Structural Analysis, Structural Masonry Design use case exchange models
- DD_EM06- Structural Analysis, Cold Formed Steel Design use case exchange models
- DD_EM07 - Structural Analysis, Other Structural Design use case exchange models.
- DD_EM08 - Structural Analysis, Foundation and Geotechnical Design use case exchanges
- DC_EM01 – Structural Design Review, Detailing and Fabrication use case exchange models

In order to standardize the expressions utilized in NBIMS use cases and to deliver consistent classification schemes for other information related to building models, it is recommended to employ the Omniclass tables and codes that are described by the Construction Specifications Institute CSI for cross referencing among IDM specifications [6] and [13]. Descriptions of some of the major tasks on the process map shown in Fig. 4 are depicted in the following tables (Tables 1a and 1b):

The scope of the exchange requirement is the exchange of information about structural elements and systems. Each of the exchange models described above contains a wide range of exchange requirements to support the coordination of structural analysis and design requirements with general architectural form and spacing requirements. For instance, the exchange mode AS_EM02 will include exchange requirements for structural wall as depicted in Table II 2 below [3]:

For instance, the exchange mode AS_EM01 represents, data exchange requirement between architect and engineer during the preliminary design could include the following data: (a) Type, color and geometrical properties of masonry units: brick, veneer, concrete, hollow, solid, ….etc. (b) Type of mortar and mortar joint type and size, (c) No. of Wythe, (d) Cavity size, type and properties, (e) Bonding patterns, (f)

Grouted or ungrouted, (g) Exterior and interior finish, and (h) Structural usage. Furthermore, the exchange model DD-EM05 specifies more details about the data exchange requirements for the structural analysis and design of masonry structures. This exchange model can include additional information referencing the strength and deformation properties, steel reinforcement, openings for windows and doors, etc. (see Fig. 5). Table III 3 depicts an example of data exchange requirement for DD-EM05.

TABLE 1A PROCESS SPECIFICATION IN PROCESS MAP

Structural Concept	
Type	Task
Name	Structural Concept
Omniclass Code	31-20-10-00 Preliminary Project Description
Documentation	Engineer uses concept model from architect to provide feedback on the structural grid, structural system, major structural connections issues, interfaces between materials and other structural elements, curtain wall systems, and foundation.

TABLE 1B PROCESS SPECIFICATION IN PROCESS MAP

Structural Design Development	
Type	Task
Name	Structural Requirements
Omniclass Code	31-20-20-00 Design Development
Documentation	Structural engineers review architects' models and define the structural requirements on the building. This may include load calculations, boundary conditions and supports, bracing members, type of connection design, diaphragm types, soil and foundation aspects, and other structural framing requirements.

TABLE 2 EXAMPLE OF MODEL EXCHANGE REQUIREMENTS FOR A WALL

Object	**Priority**	**Attribute Name**	**Explanation**
Wall			
	1	Thickness	Dimensional thickness of the wall, applicable to standard wall, having a unique, not-changing thickness along the wall axis. *Note: Typically, structural engineering packages doesn't support multiple layers for wall objects. We would define two walls separately.*
	1	Material	Name of the material of the wall. It should be an indicator of the type of material (steel, concrete, timber) and not any specific material name ("lightweight concrete type ABC"). Only the material name should be exchanged, not the material properties, like Density, Specific Weight, etc.
	1	Grade	Grade is a futher classifier for particular material. It often refers to items from external standards such as ASTM e.g. ASTM 36.
	1	Wall Axis	Definition of the wall axis, used e.g. for determining the Alignment and as a first assumption for the linear structural member representing the wall for structural analysis.
	1	Alignment	Alignment of the wall body relative to the wall axis.
	2	Base Reference	*Base location, reference to the story where the start point of the wall resists. Base story is where the wall axis resists.*
	2	Top Reference	*Top location, reference to the story where the end point of the wall resists. End point is the upper point of the wall axis.*
	2	Base Offset	*Offset from base level*
	2	Top Offset	*Offset from top level*
	2	Load Bearing	*Attribute associated to the wall as a disciplinary setting, indicates that the wall is designed to be load bearing.*

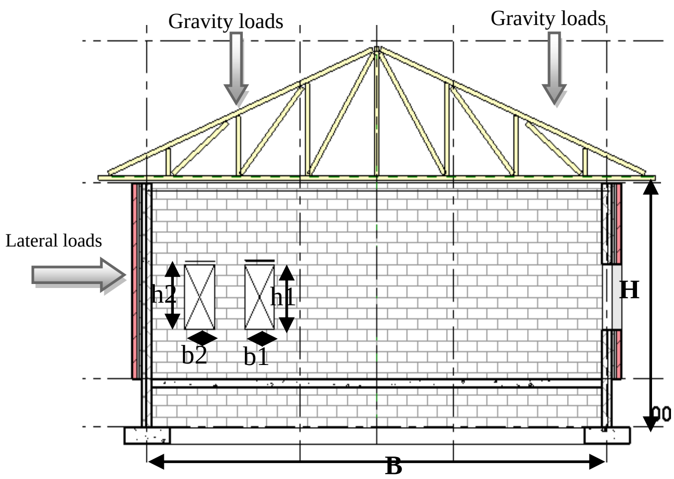

Fig. 5 Masonry wall.

TABLE 3 A SEGMENT OF INFORMATION EXCHANGE REQUIREMENTS DD_EM05.

Type of data	Information needed	Required	Optional	Data type	Units
Masonry units					
	Type	X		String	n/a
	Manufacturer		X	String	n/a
	Size	X		Decimal	in (mm)
	Color		X	String	n/a
	Grade	X		String	n/a
Grout	Type, application procedure	X		String	n/a
Mortar	Type	X		String	n/a
	bed joint	X		String	n/a
Wythe	Number of Wythe	X		Integer	n/a
Bonding	Pattern	X		String	n/a
Cavity	Type	X		String	n/a
	Size	X		Decimal	in (mm)
	Filling	X		String	n/a
Structural usage	Bearing, non-bearing	X		String	n/a
Compressive Strength	f'_m	X		Decimal	psi, ksi, (Pa, kPa)
Modulus of Elasticity	E_m	X		Decimal	psi, ksi, (Pa, kPa)
Joints	Control, expansion	X		Decimal	in (mm)
Connectors	Type	X		String	n/a
	Size	X		Decimal	in (mm)
	Location	X			
Wall Height	H	X		Decimal	ft (m)
Wall Width	B	X		Decimal	ft (m)
Steel Tensile Strength	f_y	X		Decimal	psi, ksi, (Pa, kPa)
Steel Modulus of Elasticity	E_s	X		Decimal	psi, ksi, (Pa, kPa)
Door opening	b, h	X		Decimal	ft (m)
Header type for doors	Masonry, Steel, Concrete, …etc.	X		String	n/a
Window opening	b, h	X		Decimal	ft (m)
Header type for windows	Masonry, Steel, Concrete, …etc.	X		String	n/a
Other openings	size	X		Decimal	ft (m)
In-plane loadings	DL, LL, WL, SL, RL, EL, … etc.	X		Decimal	psi, ksi, (Pa, kPa)
Out-of-plane loadings	DL, LL, WL, SL, RL, EL, … etc.	X		Decimal	psi, ksi, (Pa, kPa)

III. MODEL VIEW DEFINITION (MVD)

The main goal of MVD is to provide high quality IFC-based technical solution that satisfies a given set of data exchange requirements. The MVD format should further satisfy the following requirements [11]:

- Enable industry specific disciplines to communicate their data exchange requirements to software developers. It is important to note that the MVD development process does not cover the definition of data exchange requirements, but relies on other processes that develop such requirements (e.g. IDM). The MVD process may however refine and merge data exchange requirements into packages that are meaningful from the viewpoint of software implementation.

- Provide a way for software developers to implement meaningful IFC support in software applications without wasting resources. Implementing an MVD should be the easiest way to implement IFC support in software.

- Certification must provide useful information about the capabilities and limitations of IFC based data exchange. It is important that industry professionals understand this information.

The model view for the use-case defines the minimum useful subset of the objects from the BIM's model, and the business rules governing their content, that should be exchanged between architectural design and structural design and analysis applications. The model view definitions provide the framework that the software developers use to define the IFC exchange format. It focuses on the relationship of application and data. The process of developing the MVDs begins as indicated earlier with defining the IDM and its exchange requirements by specifically identifying the object attributes to be exchange and how they will be used, both in terms of the users and developers. For instance, in the case of AS_EM01 and AS_EM02, the list of entities includes Story, Grid, Column, Beam, Brace, Wall, Slab, Footing and Pile Foundation.

The IFC schema contains a wide range of datasets as it covers the whole lifecycle of a building and its environment. Software products should only deal with a subset of the full IFC schema to void processing overwhelming amount of data. Therefore a model view definition focuses on defining model subsets that are relevant for the data exchange between specific application types. The goal is that software implementers only need to focus on the parts of the IFC schema relevant to specific domain.

The definition of MVD has two main steps:

- IFC independent (blue color in Fig. 6a). The IFC independent part describes the view on a generic level without making any reference to the IFC model. The audiences for this part are end users of software, professionals and decision makers in software companies, i.e. those who have no knowledge of IFCs or software implementation.
- IFC release specific (orange color in Fig. 6b). The IFC dependent part is done separately for each supported IFC release and it describes how the generic definition is implemented using a specific IFC release. The audiences for this part are developers in software companies and organizers of IFC certification.

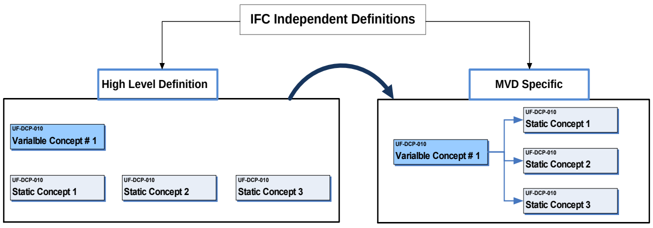

Fig. 6a Format structure for MVD Diagrams.

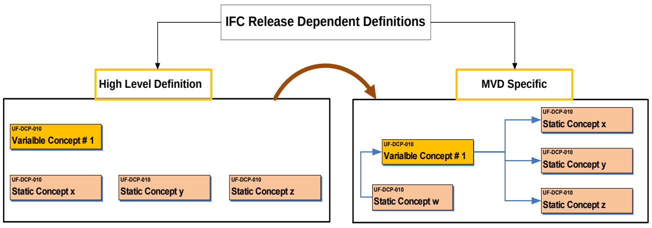

Fig. 6b Format structure for MVD Diagrams

The MVD can be defined using two types of documentation: high level definitions and MVD specific. Concepts are used for capturing re-usable data exchange capabilities, e.g. the possibility to exchange classification references. In the MVD specific section an 'MVD overview' describes the scope of a single MVD. The concept diagrams define which of the re-usable concepts are used in a specific MVD, and the relationships of the concepts that are used. A diagram may for example define that walls can have a classification reference.

The IFC independent part defines the concepts that are used in the data exchange in generic terms. It may even be used for defining concepts that are not exchanged through IFCs. For instance, Fig. 7 below illustrates a model view definition for the design and analysis of a masonry wall. This MVD relies on the IDM development described in the previous section.

The IFC release dependent part defines the binding of the IFC independent concepts into a specific IFC release. It defines how the IFC Model Specification is used for exchanging the required information, e.g. that a classification reference is exchanged using the IFC Classification Notation object. Each supported IFC release will have its own binding documentation, because the details of how the same data is captured may change between IFC releases.

The IFC-based MVD structure consists of a number of levels. At the first level is a list of entities that are relevant for the data exchange. Each entity is listed under a group such as "Spatial Structure" or "Architectural Systems". At the second level is a list of concepts associated with a particular entity. These concepts include basic information such as the name and description of the entity as well as specific characterization related to the entity. Fig. 8 below demonstrates an IFC-based MVD for the building storey entity depicting some of its associated concepts, which include spatial composition s, placement and geometric representation. Fig. 9 expands the wall entity to illustrate further details about the wall exchange requirements.

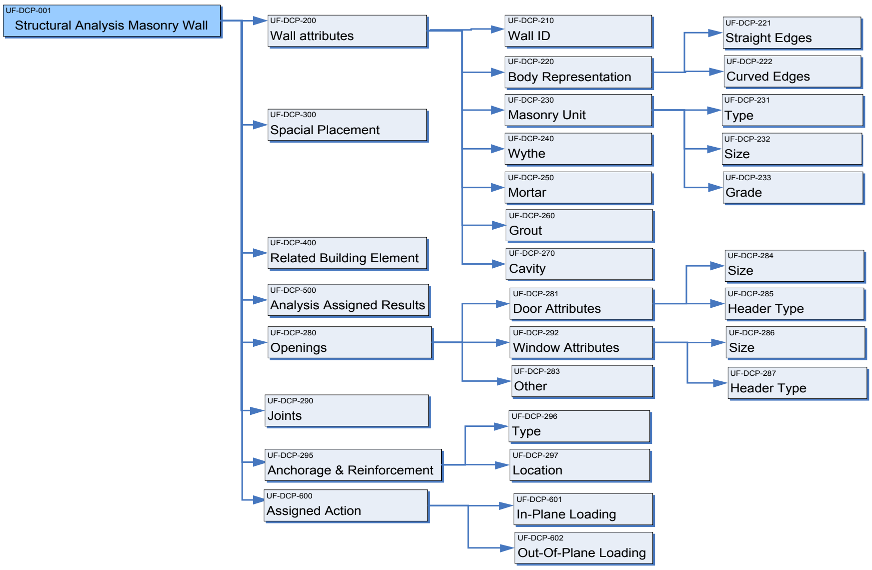

Fig. 7 Model view definition for masonry wall analysis and design (UF-DCP-001).

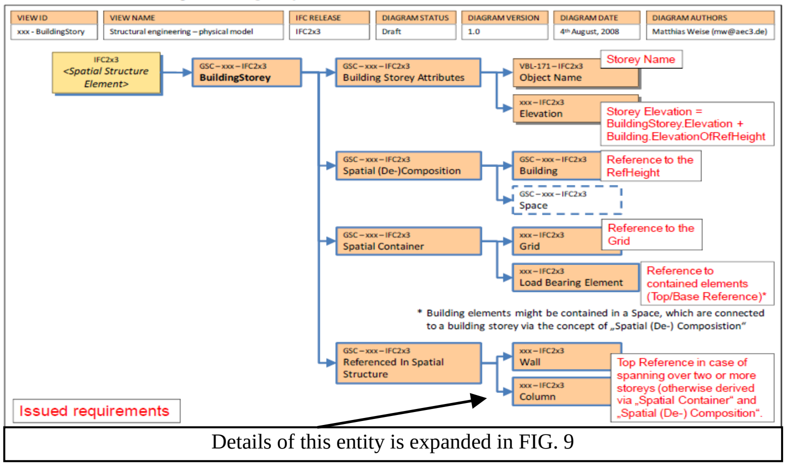

Fig. 8 ATC-75 MDV for building storey exchange parameters.

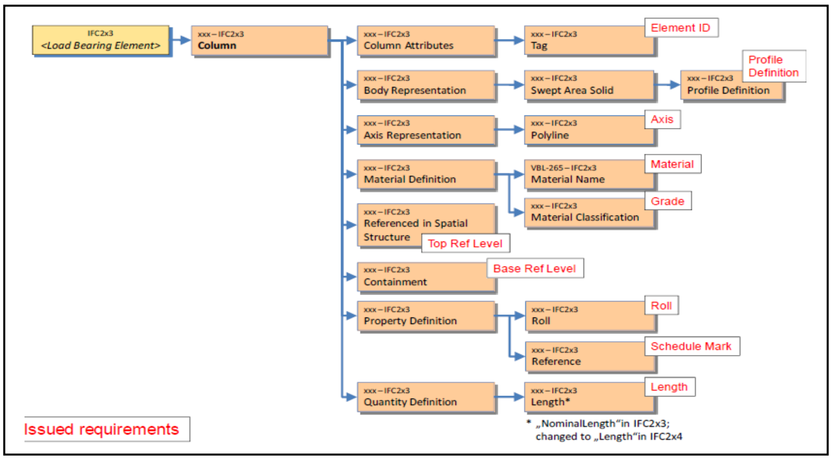

Fig. 9 ATC-75 MDV for structural column exchange parameters.

Finally at the last level is a list of implementer's agreements associated with a particular concept. Since IFC does not provide detailed information about how it should be used in specific cases because of its wide scope and inclusive nature, making such decisions about the use of IFC has been left to IFC implementers. These decisions are called implementer's agreements and they are documented as part of MVDs. Implementation agreements provide the specification that must be followed when implementing IFC support in software. Certification checks that this specification has been followed. Table 4 displays an example of the implementer's agreements for the concept "column", which is related to the load bearing entity [3].

TABLE 4 IMPLEMENTATION AGREEMENTS

IfcColumn	
Attribute	*Implementation agreements*
GlobalId	Must be provided
OwnerHistory	Must be provided, but may contain (reusable) dummy value
Name	Optional, is not required to be unique for the column occurrence
Description	Optional
Object Type	Reserved, should be omitted for now.
Object Placement	Must be provided; relative local placement shall be used
Representation	Must be provided

The translation from MVD to IFC as described above seems to be problematic and tends to be error prone [12, 22]. Venugopal et al. [12] reviewed current difficulties with this procedure and suggested a solution based upon Model Level of Details (LOD). Adding LOD metric to the MVD can improve the applicability to legal/contractual terms, thereby making sure the deliverable at each stage between partners are evidently specified (Bedrick 2008). MVDs need to satisfy specific level of details requirement for each phase of the project. These provide guidelines for commercial/contractual documents between parties to construction projects where BIM is used. Certainly, LOD contributes positively to a better understanding of model views by providing a concise, more manageable object standardized view of the data exchange.

Table 5 provides an illustration of LOD requirements for masonry structural model exchanges. LOD can be a guide to MVD developers in defining the details of the exchanges. Moreover, in contracting, defining the LOD and the exchanges will support partial definition of milestones. However, LOD requires a level of checking not supported by an MVD. For example, suppose that all columns are required at a given LOD to include reinforcing due to bot in-plane and out-of-plane loading. Testing this requires that IfcWall, ifcStucturalLoad and IfcReinforcingElement entities are in the exchange. But this is not always sufficient. Suppose that all masonry walls in an exchange have carried rebar due to both loadings, except for two or three walls. The IfcRelAggregate relation between IfcWall and IfcReinforcingElement must actually be additionally examined on an instance-by-instance basis.

TABLE 5 LEVEL OF DETAIL (LOD) EXAMPLE FOR MASONRY STRUCTURAL MODEL EXCHANGES (ADAPTED FROM [1])

LOD	Design Phase	Explanation
100	Conceptual	Little geometric data and model content; some structural description
200	Preliminary	Generic objects are modeled, including purpose, loadings, materials, and approximate geometry as well as maximum and minimum sizes.
300	Detailed	Specific element modeling, exact geometric data and model content
400	Fabrication	Shop drawings for fabrication, manufacturer and purchase
500	Construction	As-built, actual, handover, operation and maintenance.

Element Type	Attributes	Relations	LOD
Site arrangement and building type		Spatial hierarchy	100
Structural grid arrangements.		Spatial hierarchy	200
Masonry walls	Body representation, structural usage, unit type, unit size, grade, mortar, grout, openings, loadings.	Spatial hierarchy, assembly relations	200
Masonry walls	LOD 200 attributes plus: steel reinforcement and anchors, cavity details, control and expansion joints,	Spatial hierarchy, assembly relations	300
Masonry walls	LOD 300 attributes plus: back up details, insulation details, lintels, foundation and at grade details, Flas`hing and weepholes details, dampproofing and moisture barrier, air barrier.	Spatial hierarchy, assembly relations	400

IV. TESTINNG AND VALIDATION

Testing and verification must be performed after the implementation of the IDM and MVD to validate achieving the baseline for gauging structural information modeling and exchange capabilities. The process includes creating test cases along with a definition of test criteria against which results are validated, a realization of the same test model in (at minimum) two structural modeling applications, a set of IFC export files with well documented export options, a set of success/failure descriptions for external neutral test tools (e.g. IFC syntax checker, IFC validation tools, IFC viewer), and matrix of success/failure descriptions for import/export into other software tools. These subjects and similar that deals with forming industry test cases and direction for compliance testing and interoperability analysis will be addressed in the next phase of the research.

V. CONCLUSIONS

By design the NBIMS is, a standard of standards, i.e. it hinges on other standards, chiefly, IAI, IFC, and Omniclass. The NBIMS aims to found IFC building data model that delivers the foundation for attaining complete interoperability within and across different AEC trades.

This research presents preliminary efforts to standardize structural BIM using NBIMS generic process. NBIMS describes a minimum standard providing a reference line against which additional information exchange requirements may be layered. At the time of writing this paper, no concluded content volumes of the NBIMS had been published and the applicability of the generic approach was thus not entirely verified. The paper provides exhaustive guidelines for the development of structural BIM standards following the generic NBIMS process.

The process for developing structural BIM begins with the development of functional provisions or exchange requirements defined by end users in an IDM. These are then mapped to MVD using both IFC-independent and IFC-specific methodologies to create a neutral IFC data model structure. In theory, a direct mapping should occur between the IDM, the MVD, and the IFC schema where the IDM offers a list of information that must appear in the IFC schema and the MVD provides the guideline postulating how the information must be presented in the IFC data schema. The IDM and the MVD are commonly complementary to each other. The study presented examples illustrating these steps for the structural masonry domain.

The research endeavored to advance structural BIM standard and bridged NBIMS implementation from theory into practice in a manner that provides goals for the optimum process to manage structural information in a proficient integrated approach.

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