ITcon
www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

DETAILS OF THE MAPPING BETWEEN THE CIS/2 AND IFC PRODUCT DATA MODELS FOR STRUCTURAL STEEL

PUBLISHED: January 2009 at http://www.itcon.org/2009/01
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SUMMARY: *A mapping between the CIMsteel Integration Standards (CIS/2) and the Industry Foundation Classes (IFC) product data models for structural steel has been developed. The development of the mapping takes a pragmatic approach through a manual inspection of both schemas to see which entities and attributes correspond to each other. In some cases there is a direct one-to-one mapping between CIS/2 and IFC entities and concepts, while in other cases there is a one-to-many or one-to-none mapping. The mapping has been implemented as a translator from CIS/2 to IFC files. Many examples are shown of partial CIS/2 files and the corresponding mapped IFC entities generated by the translator. The mapping examples and IFC test files generated by the translator have identified several deficiencies in the IFC schema for modeling structural steel and for general structural analysis models.*

KEYWORDS: *product data model, mapping, CIS/2, IFC, structural steel, interoperability*

REFERENCE: *Lipman R (2009) Details of the mappings between the CIS/2 and IFC product data models for structural steel, Journal of Information Technology in Construction (ITcon), Vol. 14, pg. 1-13, http://www.itcon.org/2009/01*

1. INTRODUCTION

1.1 Background

The CIMsteel Integration Standards (CIS/2) (Crowley and Watson, 2000, Eastman et al, 2005) are the product model and electronic data exchange format for structural steel project information. CIS/2 is intended to create a seamless and integrated flow of information among all parties of the steel supply chain involved in the construction of steel framed structures. The Industry Foundation Classes (IFC) (Liebich et al, 2006) are the product model developed by the International Alliance for Interoperability to facilitate interoperability in the building industry. While the CIS/2 and IFC product models have different views of modeling structural steel, a useful mapping from the CIS/2 product model to the IFC product model has been developed. The mapping permits structural steel models from CIS/2-aware design, structural analysis, detailing and fabrication software packages to be imported into IFC-aware software packages to perform model coordination between the structural steel and the other parts of the building such as floors, walls, windows, doors, ductwork, and mechanical systems.

Conceptually, the relationship between CIS/2 and IFC is shown in Fig. 1. IFC provides integration of building information across multiple subsystems and ultimately across a building's entire lifecycle. CIS/2 provides vertical integration of structural steel information across design, structural analysis, detailing, and fabrication. Where CIS/2 and IFC intersect in the structural area is where the mapping between CIS/2 and IFC is important.

This paper provides additional details for the paper "Mapping Between the CIMsteel Integration Standards and Industry Foundation Classes Product Data Models for Structural Steel" (Lipman, 2006) that was published in the proceedings of the 11th International Conference on Computing in Civil and Building Engineering held in Montreal, Canada on 14-16 June 2006. That paper is a general overview of the mapping issues between CIS/2 and IFC, however, there are very few detailed examples. For this paper to be more useful, it is helpful if the reader has read the original paper and has some knowledge about the basics of CIS/2 and IFC.

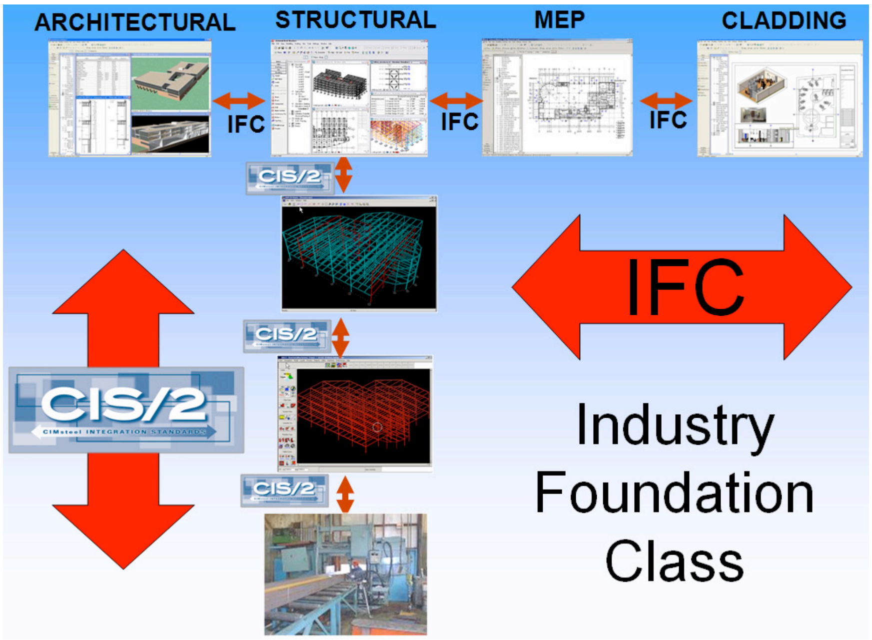

FIG. 1: Conceptual relationship between CIS/2 and IFC (Khemlani, 2007)

1.2 Motivation for the Mapping

The intent in developing of the mapping between CIS/2 (version LPM6) and IFC2x3 was to: (1) provide a practical tool to translate CIS/2 files to IFC files so that structural steel models could be imported to IFC applications that do not import CIS/2 files; (2) to identify deficiencies in the IFC schema for structural steel; and (3) generate IFC test files that use entities that are needed to model structural steel efficiently and that use parts of the IFC schema that have not been commonly implemented. Some of the concepts shown by the IFC test files are detailed in the subsequent IFC examples in the appendices.

The software package that was developed that translates CIS/2 files to IFC files allows structural steel models from design, structural analysis, detailing and fabrication software packages that export CIS/2 files to be imported into computer-aided design (CAD) software packages that support IFC. After the IFC file is imported to the CAD software, model coordination and clash detection can be performed between the structural steel and the other parts of the building such as floors, walls, windows, doors, ductwork, mechanical systems, and concrete structures. Typically CAD software that is used to do model coordination and clash detection import and export only IFC files and not CIS/2 files. Most software specific to structural steel design, structural analysis, detailing, and fabrication only supports CIS/2 file import and/or export and not IFC files.

A typical workflow involves using steel detailing software for detailing the connections between structural steel and the embeds in a concrete structure and then importing the model into CAD software where the concrete structure has already been designed and detailed. The steel model from the detailing software is exported as a CIS/2 file, then converted to IFC format and imported to the CAD software to see if the connection material at the interface between the steel and concrete structures is aligned properly and that there are no interferences. Another workflow involves taking the physical representation of an analysis model used in structural steel analysis software as a CIS/2 file, converting it to an IFC file, and importing the IFC into a CAD package to serve as the basis for a conceptual design.

Traditionally, IFC files have been used to exchange architectural models that contain walls, floors, doors, windows, stairs, beams, and columns. The use of IFC files to exchange structural steel information is a more recent development. The definition of structural steel in CIS/2 is very broad and detailed, whereas its definition in IFC is more generic and not as detailed. In the process of developing the mapping between CIS/2 and IFC, many deficiencies in being able to model structural steel were identified.

For example, CIS/2 can define a pattern or layout of bolts or holes that is located relative to a part or assembly. In IFC2x3, the geometry of the bolts and holes can be modeled by specifying the geometry of each bolt and hole; however, there is no concept of specifying them in a pattern which would be much more efficient.

Another example of a deficiency for modeling structural steel in IFC is the definition of where the longitudinal axis of a part is located relative to its cross section profile. In CIS/2 that location is known as a cardinal point and is typically specified as a point at the corners or mid-sides of the bounding box around the section profile. In IFC2x3, given the cardinal point from CIS/2, the correct geometry of a part and its section profile can be generated; however, there is no way to specify which cardinal point is being used other than deriving it from the cross section geometry placement. An IFC generic property set could be used to specify the cardinal point, however, there is no specification for this definition.

There are also issues related to constructs necessary to efficiently model structural steel in IFC that have not been implemented in some CAD software with IFC import and export capabilities. The most common IFC construct that is not implemented in some CAD software packages is the parametric dimensions of cross section profiles for I-beams, T-beams, channels, angles, and zee sections. The basic dimensions used to define those cross section profiles include depth, width, flange thickness, and web thickness. The CIS/2 to IFC translator, described below, can generate test files that use the parametric definition of cross section profiles which can be used by software vendors to test their IFC implementations of those concepts.

1.3 Mapping Development

The mapping between CIS/2 and IFC was not developed based on any information science research related to the comparison and mapping between different schemas, information domains, or ontologies. The development of the mapping takes a pragmatic approach by a manual inspection of both schemas to see which entities and attributes correspond to each other. The mapping was developed in the context of creating a translator from CIS/2 files to IFC files.

Some of the mappings are obvious such as the CIS/2 entity Cartesian_point mapping to the IFC entity IfcCartesianPoint. Other CIS/2 to IFC mappings are not as direct or have multiple ways of modeling in IFC a single concept from CIS/2. For example, most geometric shape definition is implicitly defined in CIS/2 while in IFC it has to be explicitly defined by extrusions or faceted boundary representations.

There is not necessarily a direct mapping between the semantic meanings of entities in each product model. The name of IFC entities IfcBeam and IfcColumn imply their semantic meaning whereas in CIS/2 the specification of part being a beam or a column is defined by an attribute. Therefore to determine if a CIS/2 part is mapped to an IfcBeam or IfcColumn depends on the orientation of the part or, if available, the attribute. However, the attribute can also indicate that the part is a brace for which there is no corresponding IFC entity. On the other hand, CIS/2 has entities such as Fastener_simple_bolt and Weld_mechanism_fillet whereas in IFC the definition of bolt or weld is an attribute of IfcMechanicalFastener or IfcFastener.

The CIS/2 to IFC mapping detailed by the examples in this paper can also serve as a basis for a reverse mapping between IFC and CIS/2. Independently, as part of a project to harmonize the CIS/2 and IFC product models (Eastman, 2004), a mapping between IFC and CIS/2 was developed for the use cases of structural analysis and steel detailing.

1.3.1 Other Schema Mapping Techniques

The mapping described in this paper has been used at Stanford to develop an information science approach to the mapping between the CIS/2 and IFC product models (Pan, et al 2008). The approach uses statistical semantic similarity techniques that are applied to ontology mappings. The semi-automated techniques used are an attribute-based approach, a corpus-based approach, and a named-based approach. The attribute-based approach looks at the attributes used to define CIS/2 and IFC entities. For example, if an entity from both CIS/2 and IFC reference the same type of attributes such as a cross section and length to define an extrusion, then the entities from each might be similar. The corpus-based approach uses text documents, such as building code documentation, to find similarities between entities names used in each product model. For example if the building code documentation frequently uses the words “beam”, “column”, and “part” in close proximity, then entities names in each product model that use those terms might be related such as IfcBeam and IfcColumn in

IFC and Part_prismatic in CIS/2. The name-based approach looks at the obvious similarity between some entity names in CIS/2 and IFC such as Cartesian_point in CIS/2 and IfcCartesianPoint in IFC. However, that similarity does not guarantee that they refer to the same concept. For all three approaches statistical measures are applied to rank the similarities to determine if they can be used for the mapping. The mapping development described in this paper uses the attribute- and named-based approach based on a manual inspection of CIS/2 and IFC entities.

Other schema mapping techniques have been developed that compare differences between versions of the same schema such as IFC2x2 to IFC2x3. Comparing between different versions of the same schema reduces the scope of the mappings that need to be made. One method categorizes potential differences (identical, renamed, equivalent, modified, added, removed) between IFC schema entities and types and develops an automated system to make the comparison (Amor and Ge, 2002). About 65% of the mappings between different versions of the IFC schema can be generated automatically with this method. Similar research to Amor and Ge extends the classification system and develops a version matching approach that provides significantly better results when compared to manually matching between schema versions (Wang et al, 2006, Wang et al, 2007).

Mapping techniques have also been developed between schemas that have different modeling languages such as XML and EXPRESS. This technique uses domain specific constraints (Wang et al, 2008) in a semi-automated approach to map between IFC2x2 and the AEX (Automating Equipment Exchange, FIATECH 2004) XML schema for HVAC equipment such as fans, pumps, and dampers.

While they do not involve mapping between schemas, techniques have also been developed for automated methods to detect differences between IFC files of the same schema that represent similar structures (Ma, et al 2006, Arthaud and Lombardo 2006).

1.3.2 Mapping Categories

The development of the mapping described in this paper is grouped into five categories: (1) shape and geometry representation; (2) CIS/2 design model, (3) CIS/2 detailed model, (4) CIS/2 structural analysis model, and (5) other concepts. These mappings for categories are described in the following sections 1.4 through 1.8. Examples of partial CIS/2 and IFC files that give the details of the mapping are found in the corresponding appendices A-E.

In a CIS/2 or IFC file, entity names are always in upper case letters such as SECTION_PROFILE or IFCBEAM. To differentiate between entities from each type of file and to improve readability, in the text of the paper (not the figures), CIS/2 entities are written as Section_profile and IFC entities are written as IfcBeam. To save space, similar entities that can be grouped together are written as Ifc{Beam/Column/Member} or Section_profile_{I/T}_type.

1.4 Shape Representation

The shape representation refers to how the geometry of a part is defined. Fig. 2 shows some typical shapes that are used in CIS/2 including I-beams, T-beams, channels, angles, rectangle, circle, and zee sections. Also shown are plates, bent plates, corrugated decking, curved beams, and double sections.

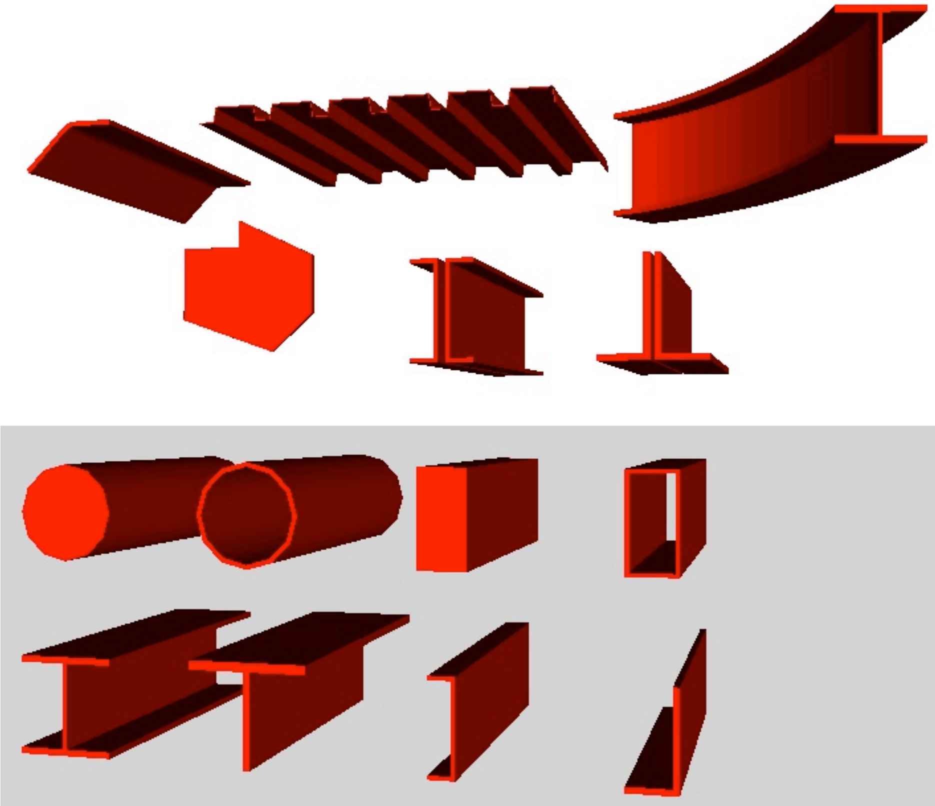

FIG. 2: Typical CIS/2 structural steel shapes

In CIS/2, a long and narrow (prismatic) part is defined by a cross section and length. The cross section is specified by a section designator, cardinal point, and boolean value to indicate if the section is mirrored. The dimensions of the cross section can be implied by the section designator or given explicitly by a section's depth, width, and web and flange thicknesses. If the dimensions are implied by the section designator, then software using the designator must have a lookup table of the section dimensions or parse the dimensions from the designator. The cardinal point defines the location of the origin of the cross section. The most commonly used cardinal points are the center, corners, and mid-sides of a bounding box around the cross section. For example, a cardinal point at the top of the web of an I-beam can be used to position the beam so that the top of the top flange is at a floor level. Mirroring involves flipping the cross section about its vertical axis. Mirroring a cross section is only relevant to sections that are non-symmetric about a vertical axis in the plane of the cross section such as angle, channel, and zee sections. For example, if the angle section in the lower right of Fig. 2 were to be mirrored, then the end of the cross section would appear as the letter 'L'.

Plates in CIS/2 are defined by their thickness and a set of points or line segments that define the edge of the plate. Bent plates and decking are defined their thickness, length, and points that define the profile of the bend or corrugation. Curved parts are defined by a cross section profile and points that define the curve of the part.

For the most part, all geometry in CIS/2 is implicitly defined. The information used to generate the geometry of parts is found on entities related to the definition of a part and not on entities related to the definition of geometry. Conversely, all geometry in IFC is explicitly defined. Information used to generate geometry in IFC is found strictly on entities related to the definition of geometry. Parts, such as beams and columns, must refer to the geometric shape representation entities if they are to have a physical representation.

Several different methods can be used for shape representation in IFC. The most general is a faceted boundary representation. Geometry is defined by points that are used to defined edges. The edges define faces that are used to define a closed set of faces representing the boundary of a geometric shape. With this type of representation any arbitrary geometry can be defined.

The other method to generate shapes in IFC involves extruding a cross section profile along an axis or curve. The profile can be defined by an arbitrary set of closed points or line segments or parametrically defined for an "I" shape, angle, channel, or other similar sections. The parametric values are typically the depth, width, and thickness of the section. The arbitrary closed set of points can also define the edge of a plate. An arbitrary coordinate transformation can be applied to the profile and can be used to mirror the cross section. In IFC2x3 there is no explicit definition of a cardinal point although that information can be implied by the cross section geometry.

Detailed examples of the mapping between CIS/2 and IFC for shape representation are in Appendix A. Generally, the mapping between CIS/2 and IFC for shape representation is straightforward. The most significant issue is the lack of a cardinal point in IFC. The correct geometry can be generated in IFC accounting for a cardinal point, however, there is no IFC2x3 entity to specify what the cardinal point is for design intent.

1.5 Design Model

A CIS/2 design model is characterized by individual parts, defined by the geometric shapes described in the previous section, and associates a position and orientation with them to place them in a steel structure. In practice, details such as assemblies, cutouts, connectivity, connection materials (clip angles, gusset plates), and miscellaneous materials (handrails, steps, floor grating) are not written to most CIS/2 design model files. Also in practice, parts in a design model are not grouped into assemblies. Fig. 3 shows a typical CIS/2 design model. Note the lack of connection material such as clip angles, gusset plate, or bolts and the overlap of beams, columns, and braces.

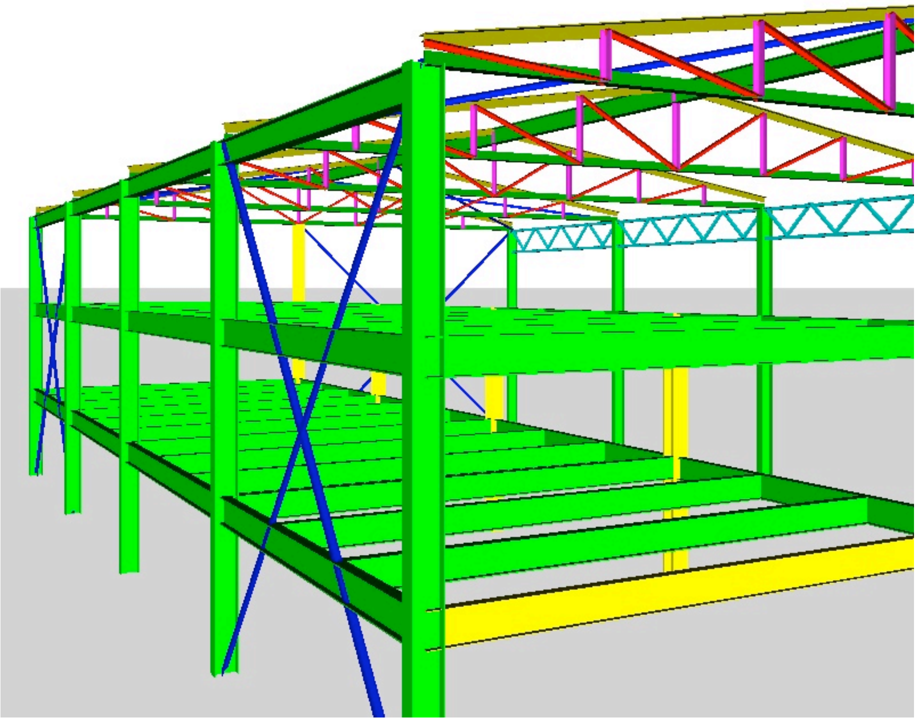

FIG. 3: Typical CIS/2 design model

The location of a design part is specified an origin and two direction vectors. The origin is given by a cartesian point. The orientation of a design part is given by direction vectors that define the longitudinal axis of the part and the orientation of the vertical axis of the part. There are many other features of a CIS/2 design model such as: the type of part (beam, column, brace, cable, cambered, etc.); the type of brace (horizontal, vertical, diagonal, etc.); and internal or external connections. The connections only imply that two or more parts are connected and do not necessarily indicate how they are connected. There can also be mapping between parts in a design model and elements in a structural analysis model (section 1.7). For example, a beam that is subdivided into smaller segments for analysis purposes is physically only one part in the design model.
Detailed examples of the mapping between the CIS/2 design model and IFC are in Appendix B. The mapping for the design model shows how entities such as Ifc{Beam/Column} are used for the design parts in the CIS/2 model. Because entities such as Ifc{Beam/Column/Member/Plate/Railing} have semantic meaning such as their

orientation and function, their use has to be derived from the CIS/2 file. The use of Ifc{Beam/Column/Member} is determined by the orientation of the longitudinal axis of the CIS/2 design part. IfcMember can be used for parts with any orientation such as braces, but also beams and columns. IfcPlate is used depending on the shape of the part and IfcRailing is used when there is information in the CIS/2 indicating the function of the part. Other features of the CIS/2 design model that capture the design intent of the structure generally do not have an IFC equivalent.

1.6 Detailed Model

A detailed model is also known as a physical, manufacturing, or fabrication model. Detailed models are characterized by parts grouped into assemblies that make up the structure. In CIS/2 practice, an assembly is comprised of one main member such as a beam, column, or brace and associated connection material such as clip angles, gusset plates, bolts, holes, and welds. Items such as handrails, stairs, floor gratings, ladders, and surface treatments can be in a detailed model. Parts in a detailed model can have cutouts (copes) such as miter cuts, notches, and chamfers. Cutouts are defined parametrically by their length, width, depth, angle, and the location on the part where they are applied such as the start or end face, left or right side, or the top or bottom.

Fig. 4 shows a typical detailed model and a close-up of a connection. The structure is a braced frame with horizontal and vertical bracing and corrugated decking on the top of the structure. The connections contain bolts, holes, and welds, however, the welds, holes, nuts, and washers are not visible in the figure.

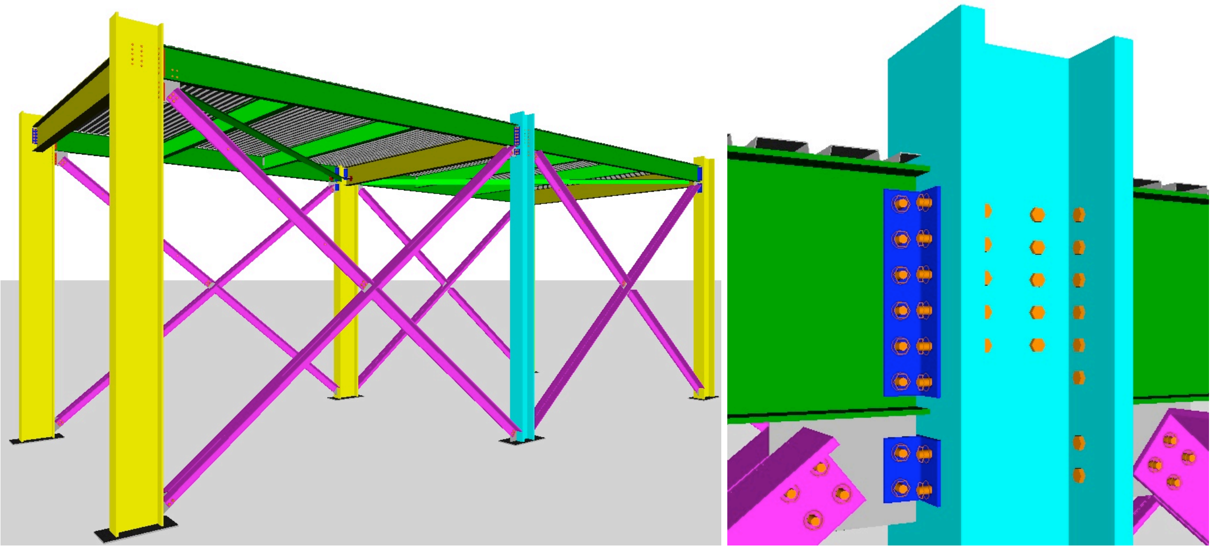

FIG. 4: Typical CIS/2 detailed model and close-up of a connection

In practice, parts in an assembly are located relative to the origin of the assembly while the assembly is located relative to the origin of the structure. Thus all parts in a detailed CIS/2 model are located relative to two nested coordinate systems. However, CIS/2 does allow for an assembly to be located relative to another assembly. Individual bolts and holes are located in a pattern or layout. For example, in Fig. 4, each brace shown in magenta has a 2x2 pattern of bolts and holes on each end. Hole patterns for a part are located relative to the origin of a part and bolt patterns are located relative to the origin of an assembly. Welds can be defined by a weld path and characteristics such as its dimensions and type.

Detailed examples of the mapping between the CIS/2 detailed model and IFC are in Appendix C. The geometry of the parts of detailed CIS/2 models can be represented in a manner similar to design models. However, there are many deficiencies in IFC2x3 that are needed for the efficient modeling of detailed models and to capture the design intent of those features. For example, the geometry of a bolt can be modeled; however, there is no method to specify a pattern of bolts. Each bolt has to be located individually in IFC. The geometry of features such as holes and cutouts that remove material from parts can be modeled in IFC as boolean operations. The boolean operations only facilitate modeling the geometry correctly; however, there are no IFC2x3 entities to describe the parametric dimensions of cutouts or the layout of holes. Parts can be grouped together in assemblies in IFC, however, some of the meaning that parts are located relative to assemblies is lost when mapping from CIS/2 to IFC.

Similar to a design model, several different rules can be applied to determine if IFC detailed parts should be Ifc{Beam/Column/Member/Plate}. Certainly IfcMember can be used for all parts except plates which can use IfcPlate. Ifc{Beam/Column} can be assigned depending on the orientation of the part or assembly. If Ifc{Beam/Column} is assigned based on the orientation of parts, then the dark blue angles in Fig. 4 would be IfcColumn. However, if Ifc{Beam/Column} is assigned based on the orientation of assemblies, then the dark blue angles in Fig. 4 would be IfcBeam because they are part of the assembly with the green beam. CIS/2 can also identify the main part in an assembly which is usually a beam or column. The non-main parts are typically connection material such as clip angles and gusset plates. Therefore IfcMember could be used for all non-main parts in an assembly and Ifc{Beam/Column} for all the main parts.

1.7 Structural Analysis Model

The basic features of a structural analysis model are nodes, elements (linear, planar, and solid) that connect the nodes, loads on elements and nodes, and reactions due to the loading. A structural analysis model is sometimes referred to as a finite element model, wireframe model, or stick model. Fig. 5 shows a typical CIS/2 analysis model. On the left are the wireframe analysis elements and nodes and on the right is the physical representation of the elements.

Detailed examples of the mapping between the CIS/2 structural analysis model and IFC are in Appendix D. The mapping between CIS/2 and IFC for the structural analysis model is straightforward. For most CIS/2 entities there is an equivalent IFC entity for the structural analysis model.

Currently, the IFC structural analysis model has not been widely implemented. The IFC examples in Appendix D are based on a thorough interpretation of the IFC specification. However, the IFC structural analysis examples have not been generally tested by importing them into applications that supports the IFC structural analysis model. The IFC examples have been confirmed that they conform to the IFC schema. Currently, there are also discussions amongst the IFC software developers and model developers to improve some aspects of the IFC structural analysis model for the next version of the IFC specifications.

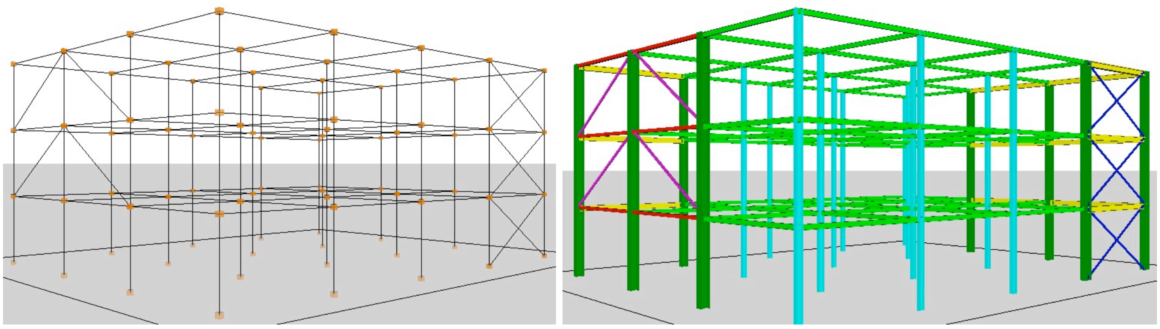

FIG. 5: Typical CIS/2 analysis model (left) and corresponding physical representation (right)

1.8 Other Model Concepts

Detailed examples of the mapping between the CIS/2 and IFC for some other concepts are in Appendix E. Some of those concepts are common to all CIS/2 and IFC models such as units, globally unique identifiers, and material, section, and generic properties. Other CIS/2 concepts such as surface treatments, grid planes and levels, camber, and document references do not necessarily have an IFC equivalent.

1.9 Mapping Implementation

The CIS/2 to IFC mapping has been implemented as a free software program available from NIST at http://cic.nist.gov/vrml/cis2.html. The translator between CIS/2 and IFC was developed as part of the existing CIS/2 to VRML (Virtual Reality Modeling Language) translator (Lipman and Reed, 2003). The translator does not use any software development toolkit to facilitate parsing the CIS/2 files and generating the IFC files based on their associated product model schemas. The translator simply parses the CIS/2 file line-by-line and generates some IFC entities as the CIS/2 file is being read. The bulk of the IFC entities are generated from CIS/2 information that has been stored by the translator in various data structures.

Fig. 6 and Fig. 7 show the user interface from the translator and the options available for generating IFC files. These options allow the generation of IFC files with many of the different representations described in this paper. The CIS/2 to IFC translator has been tested with over 500 different CIS/2 files for most combinations of shape and element representations, using mapped and non-mapped representation, and for the IFC2x3, IFC2x2, and IFC2x schemas. All of the IFC files that are generated by the translator were tested that they conform to the schema. In general, no unexpected errors and warnings resulted from the conformance checking of the IFC files. Some of the IFC files were also tested in a variety of IFC viewers, model checkers, and CAD applications that import IFC files. This served to show the capabilities and limitations of those programs.

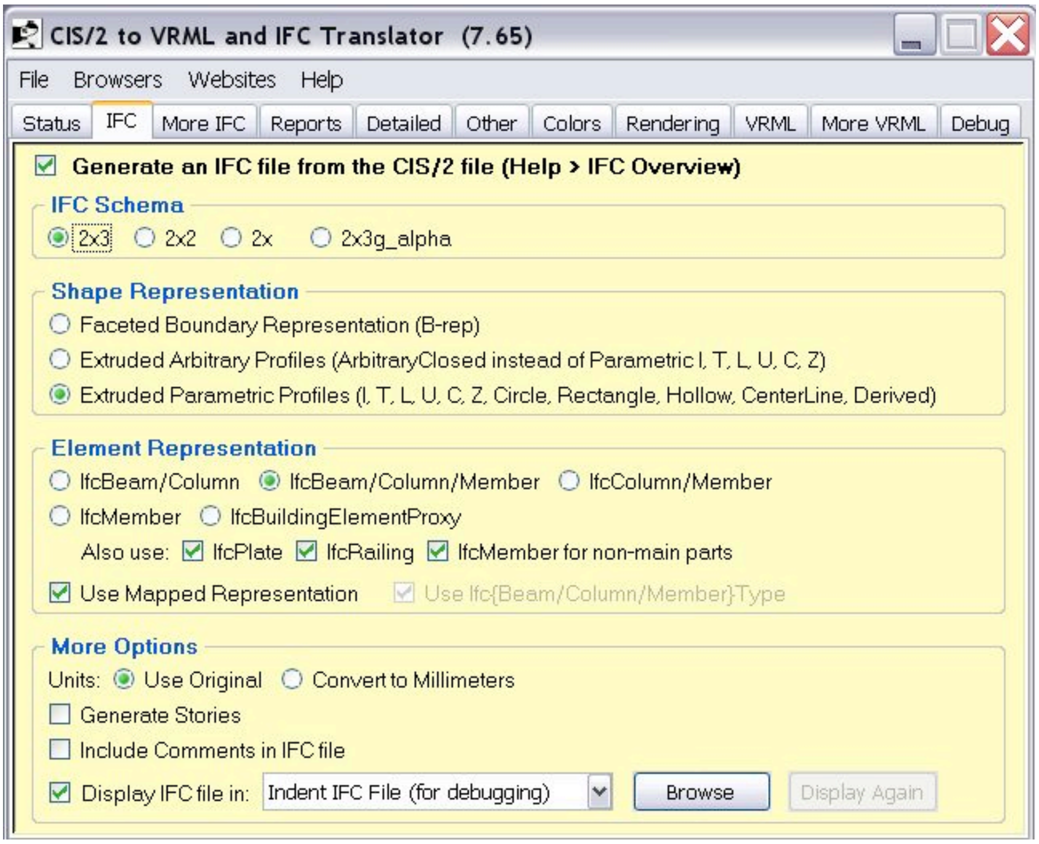

FIG. 6: CIS/2 to IFC translator options

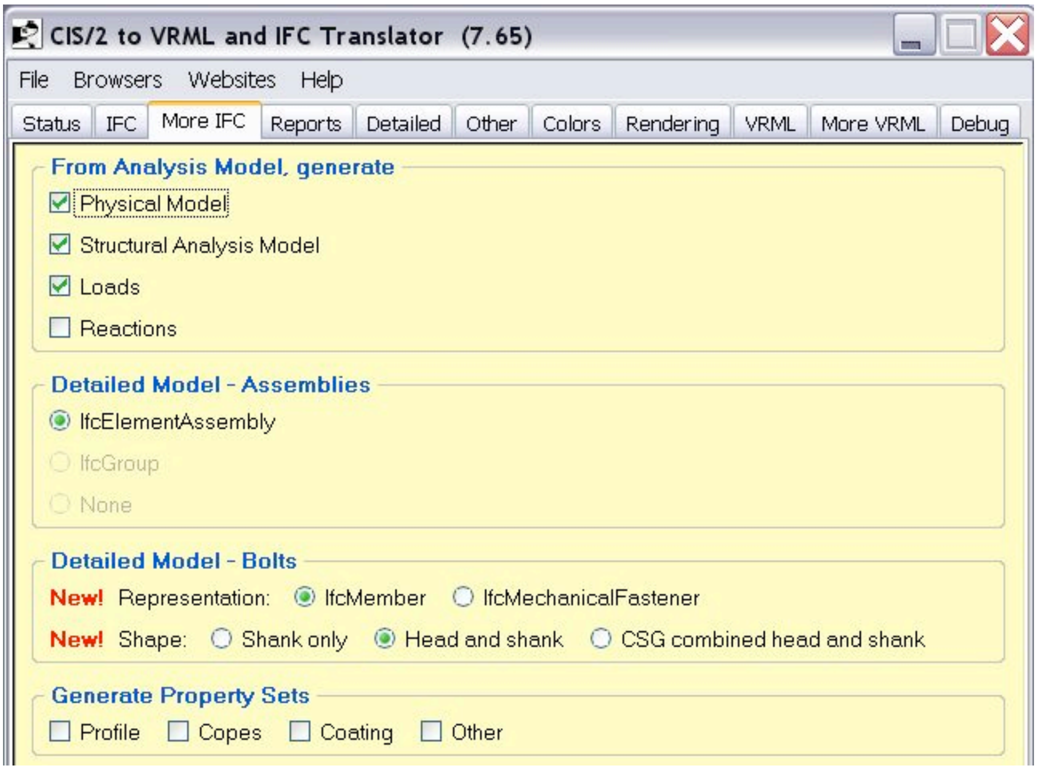

FIG. 7: More CIS/2 to IFC translator options

2. RECOMMENDATIONS

In the course of developing the mapping between CIS/2 and IFC, many insights have emerged into how structural steel should be modeled in IFC. The recommendations fall into two categories: (1) how the existing IFC specifications should be implemented by IFC applications and (2) what improvements to the IFC specifications are needed to model structural steel. Some of the recommendations are very specific relating to particular text strings while other recommendations are more general. With an increased focus on building information models that can be exchanged via IFC it is important to consider these recommendations so that the end-user can have a seamless and accurate exchange of all structural steel model information.

2.1 Implementing the existing IFC specification

- An agreement is needed to specify which text fields are used for steel information such as the section designator (i.e. W14x89) and the part and assembly piecemarks. The section designator would normally go on the entity that defines the section profile. However, if a boundary representation is used for the geometry, then there is not necessarily a section profile definition. In this case, the section designator, along with the piecemark, could go on Ifc{Beam/Column/Member/ElementAssembly}.

- The IFC applications should support several entities that are necessary to maintain the parametric definition (depth, width, thickness, curve, profile) of structural steel. The parametric profiles are Ifc{I/T/L/U/C/Z}ShapeProfileDef. IfcDerivedProfileDef is necessary to mirror non-symmetric parametric profiles. IfcCompositeProfileDef is useful for composite sections such as double angles and channels. IfcCenterLineProfileDef is necessary for bent plates and corrugated decking. IfcSurfaceCurveSweptAreaSolid is necessary for extruded curved parts. IFC applications should export structural steel using the parametric profiles as opposed to using a boundary representation. Applications should also import the parametric profiles, retain the parametric definition in their internal representation, have the parametric definition be accessible to the user, and be able to re-export the parametric definition.

- The IFC applications should support as needed: (1) IfcElementAssembly for element assemblies and preserve the hierarchy between parts and assemblies, (2) IfcFastener and

IfcMechanicalFastener for bolted or welded connections, (3) objects comprising multiple shapes such a bolt with separate geometry for the head and shank, and (4) the structural analysis model.

- An agreement is needed to specify what type of Ifc{Beam/Column/Member} should be used. For example, is a vertically oriented clip angle in a horizontal beam assembly an IfcBeam or an IfcColumn? Is a horizontal brace an IfcBeam or an IfcMember? IfcBeam and IfcColumn are defined in architectural terms as members that are essentially horizontal and vertical, respectively. The orientation of an IfcMember is not relevant to its definition. The use of Ifc{Beam/Column/Member} differs between different CAD applications and whether it is an architectural or structural view.

- An agreement would be useful to indicate which type of structural steel model (design, analysis, detailed) is in an IFC file. This would be particularly useful for detailed and design models which appear very similar in an IFC file.

- There needs to be more implementations of the structural analysis model in CAD applications. The structural analysis model has not been implemented or tested. In developing the CIS/2 to IFC mapping some of the limitations of the IFC structural analysis model became apparent. A better IFC structural analysis model will come about only after software vendors start trying to implement it and end-users start to exchange structural analysis models via IFC.

2.2 Improvements to the IFC specification

Some of the recommendations below are already planned for the next version of IFC, IFC2x4.

- A cardinal point should be able to be associated with a section profile and generate the section with the correct cardinal point offset.

- As seen from some of the examples in the report, some structural steel information can only be specified in IFC with generic property sets. More structural steel information should be predefined with existing property sets, such as PSet_BeamCommon and others, with new property sets, or with specific attributes in other entities.

- The specification needs to have a better implementation of structural steel connections, particularly for specifying layouts or patterns of bolts and holes.

- The specification needs to have parametric definitions of cutouts rather than just being able to create the geometry of a part that has a cutout. At least there should be a specific property set with the parametric definition of a cutout.

- The structural analysis model needs a method to associate analysis results with element connectivity rather than just analysis nodes. This will allow results to be associated with the ends of an analysis element.

3. CONCLUSION

The conceptual scopes of the CIS/2 and IFC specifications overlap sufficiently to allow mapping of information from a CIS/2 (LPM6) representation to an IFC2x3 representation. For basic geometric resources such as coordinate systems, cartesian points, and others there is a one-to-one mapping. There is a one-to-many mapping of geometric shape representations between CIS/2 and IFC because of the multiple methods to explicitly represent geometry in IFC. The basic geometry of CIS/2 design, analysis, and detailed models can be represented in IFC. However, there are areas where the modeling of specific features such as bolts, holes, and welds needs to be improved in the IFC specification. There are also cases where the semantic meaning of a concept in CIS/2, such as detailed model assemblies, is not as strong as in IFC. The lack of robust implementations of the IFC structural analysis model makes it hard to evaluate the details of the mapping from the CIS/2 analysis model.

The mapping examples provide a basis for developing a more rigorous and formal computer science based mapping between CIS/2 and IFC. The examples also provide insight into a possible IFC to CIS/2 mapping. A significant issue for an IFC to CIS/2 mapping is how to determine which members in an IFC model are structural steel as opposed to other parts of a building such as walls, floors, doors, and windows. Other issues include:

mapping from a boundary representation of structural member to a parametric representation; and determining what type of CIS/2 model, either design, analysis, or detailing, the IFC model should be mapped to.

4. REFERENCES

Amor, R.W. and Ge, C.W. (2002). Mapping IFC Versions, *Proceedings of the EC-PPM Conference on eWork and eBusiness in AEC*, Portoroz, Slovenia, 9-11 September 2002, pp. 373-377. http://www.cs.auckland.ac.nz/~trebor/papers/AMOR02A.pdf

Arthaud G. and Lombardo J-C. (2006). Automatic Semantic Comparison of STEP Model Instances, Application to IFC Models, *Proceedings of Design and Decision Support Systems Conference 2006*, Heeze, The Netherlands. http://www.springerlink.com/content/rr27752197800v81/

Crowley A.. and Watson A. (2000). CIMsteel Integration Standards Release 2, SCI-P-268, The Steel Construction Institute, Berkshire, England. http://www.steelbiz.org/Discovery/AllResults.aspx?q=%22P268%22

Eastman C., Wang F., You S.-J., and Yang D. (2005). Deployment of an AEC industry sector product model, *Computer-Aided Design*, Vol. 37-12, October 2005, 1214-1228.

Eastman C. (2004). Harmonization of CIS/2 and IFC, Georgia Institute of Technology. http://www.coa.gatech.edu/~aisc/cisifc/

FIATECH (2004). Automating Equipment Information Exchange (AEX). http://www.fiatech.org/projects/idim/aex.htm

Khemlani L. (2007). BIM Fundemantals Seminar for Structural Engineers http://www.aecbytes.com/buildingthefuture/2007/BIMFundamentalsSeminar.html

Liebich T., Adachi Y., Forester J., Hyvarinen J., Karstila K., Wix J. (2006). IFC 2x Edition 3. International Alliance for Interoperability. http://www.iai-tech.org/.

Lipman R., and Reed K.A., (2003). Visualization of Structural Steel Product Models, *Journal of Information Technology in Construction*, Vol. 8, 51-64, http://www.itcon.org/2003/5

Lipman R. (2006). Mapping Between the CIMsteel Integration Standards and Industry Foundation Classes Product Data Models for Structural Steel, *Proceedings of the International Conference on Computing in Civil and Building Engineering*, Montreal, Canada, June 2006, http://www.fire.nist.gov/bfrlpubs/build06/art025.html

Ma H., Ha K.M.E., Chung C.K., Amor R. (2006). Testing Semantic Interoperability, *Proceedings of the International Conference on Computing in Civil and Building Engineering*, Montreal, Canada, June 2006.

Pan J., Cheng C.-P., Lau G., Law K. (2008). Utilizing Statistical Semantic Similarity Techniques for Ontology Mapping – with Application to AEC Standard Model, *Proceedings of the 12th International Conference on Computing in Civil and Building Engineering (ICCCBE XII)*, Beijing, China, October 16-18, 2008, http://eil.stanford.edu/publications/jack_cheng/icccbe08_ontology_mapping.pdf

Wang H., Akinci B., Garrett J. (2006). A Semi-Automated Schema Matching Approach Based on Automated Detection of Version Differences, *Proceedings of the International Conference on Computing in Civil and Building Engineering*, Montreal, Canada, June 2006.

Wang H., Akinci B., Garrett J. (2007). Formalism for Detecting Version Differences in Data Models, *ASCE Journal of Computing in Civil Engineering*, Vol. 21, No. 5, September 2007.

Wang H., Akinci B., Garrett J., Reed K. (2008). Formalism for Applying Domain Constraints in Domain-Oriented Schema Matching, *ASCE Journal of Computing in Civil Engineering*, Vol. 22, No. 3, May 2008.

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