DEVELOPING COVERAGE ANALYSIS FOR IFC FILES

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ABSTRACT

Conformance and interoperability testing of product data exchange interfaces is essential to delivering reliable software implementations and meeting user's expectations for interoperability between BIM software. For either type of testing, product data model test files, such as IFC files, are required to test the import and export capabilities of IFC interfaces in software applications. However, the extent of information concepts in the IFC schema makes it infeasible to generate a set of test files to provide comprehensive coverage of all concepts and their combinations. Sets of IFC test case files, that have been contributed by multiple industry organizations, are used to test data exchange implementations. While the sets of files are useful for testing IFC software implementations, there are no methods and metrics to measure the coverage of information concepts in the test files. To achieve more effective testing, which could result in better interoperability between software tools, it is essential to be able to measure the coverage of information concepts that are contained in the test files.

The coverage analysis of a set of test files can be based on many metrics. Coverage analysis metrics can be based on concepts that are generic to all files, such as the use of property sets, enumerations, geometric representations, and commonly used attributes. Metrics for coverage analysis can also be based on concepts specific to a particular domain or model view definition such as precast concrete or energy simulation. Software is being developed to implement various metrics related to the coverage analysis concepts and applied to sets of IFC files, such as those used in the past buildingSMART IFC certification process and the current model view definitions developed for IFC implementations. Ultimately, the results of coverage analysis will determine if a set of test files used provides sufficient coverage of all the relevant concepts that need to be tested.

An IFC File Analyzer has been developed to implement various metrics to measure the coverage of information concepts in IFC files.

Keywords: IFC, coverage analysis, software testing, conformance, interoperability

1. INTRODUCTION

The Industry Foundation Classes (IFC) is the product data model developed by buildingSMART International (Liebich 2006) to facilitate interoperability between Building Information Modeling (BIM) software packages about many aspects of buildings throughout their lifecycle. Typically, an end-user will export and import IFC files between various BIM software packages to exchange, for example, a building model developed in a conceptual design application with an application to do detailed design or import a final design into a facilities management system.

Conformance and interoperability testing can be used to improve the quality and reliability of information exchanged between software applications (Kindrick, Sauter, Matthews 1996). Testing for conformance involves either, (1) testing IFC files that are exported from BIM software or (2) testing the results of importing an IFC file into a BIM application. Conformance testing of exported IFC files involves checking them for syntax, structure, and semantics. Syntax checking ("are the attributes of the right type?") and structure checking ("are the relationships between the entities correct?") can be done automatically with software that checks an IFC file against the IFC schema. Most semantic checking is performed by visually checking that the geometry of the structure in the IFC file looks correct and that the attributes assigned to building elements are correct.

Conformance testing of an IFC file imported into BIM software is difficult because each application has its own user interface and how information in an IFC file is mapped to the internal BIM representation is unknown. The types of visual checks used for this type of conformance testing are similar to the semantic checking of an IFC file. Interoperability testing involves comparing the results of importing an IFC file into a BIM package with the original BIM model from which the IFC file was exported. This type of testing is also difficult as there are no automated procedures or agreed upon methodologies and criteria for comparing the first BIM model with the second.

Either type of testing described above requires the use of IFC files. The IFC certification process that occurred in 2007 (http://www.iai.hm.edu/how-to-implement-ifc/certification), used two categories of IFC test files, Step 1 and Step 2, for conformance and interoperability testing. The Step 1 files were divided into several broad categories such as building elements and building service elements. The building elements category had fifteen groups of elements including: walls, beams, columns, slabs, doors, windows, stairs, ramps, railings, roofs, curtain walls, members, plates, piles, and footings. The building services categories had seventeen groups of elements related to flow devices, piping, heating, cooling, ventilation, electrical, and others. Within the groups there could also be other sub-groupings related to the type of geometry, such as boundary representation or extruded profiles, used to model the building elements. Altogether there were 717 Step 1 IFC test files of which 391 were in the building elements category. In general, the Step 1 IFC test files only contained one or several building elements and not complete buildings.

There were 38 Step 2 IFC test files of complete building projects containing hundreds or thousands of building elements. The IFC test files for both Step 1 and Step 2 were generated by the software vendors who were involved with the certification process. Subsequent to the certification process, several studies were done to analyze the IFC test files and the overall process used (Kiviniemi 2007, 2009). The study showed that even though software products were certified, there were still issues related to exchange certain types of building elements in IFC files and that user's expectations were not met regarding the quality of IFC implementations.

However, there has never been a more detailed characterization of, or process to measure, the information concepts found in the IFC test files. A fundamental question that could be asked, specifically about the Step 1 and Step 2 IFC certification test files and IFC test files in general, is: how can the coverage of information concepts, related to the IFC schema, be measured in a single IFC file or in sets of IFC files? Without knowing which information concepts are covered in the IFC test files, it makes the analysis of test results and conformance and interoperability assessment difficult and inefficient. Significant improvements in conformance and interoperability testing could be achieved by knowing which information concepts are covered and which are not.

2. COVERAGE ANALYSIS

Kindrick (1996) discusses how to improve conformance and interoperability testing of product data models and those insights are still applicable today to testing IFC files. In addition to analyzing the syntax, structure, and semantics of the file exchanges between two BIM systems, coverage analysis should be performed to determine the extent to which the IFC schema has been covered during testing by a set of test files. The coverage analysis can also identify parts of the schema that have not been covered by the test files. Of course, it is unlikely that there will ever be a set of test files to cover all 653 entities, 317 property sets, and 164 enumerations in IFC2x3, each with multiple attributes, types, and relationships. However, performing a coverage analysis directed at specific information concepts or for the exchange requirements of particular domains, such as precast concrete, can provide needed metrics for more effective testing.

Coverage analysis can also be used to reduce the number of test files and to develop a more optimal set of files. The 391 Step 1 IFC test files in the building element category contain significant duplication of information concepts that can be tested. Coverage analysis could be used to eliminate redundant test files to a more manageable set, thereby reducing the time required to actually do the conformance and interoperability testing. In addition to reducing the number of test files, coverage analysis can be used to identify specific information concepts in the files. For example, common information concepts might be expected to be found in all test files while other less common concepts might be found in only a few test files.

The software industry uses code coverage analysis (Cornett 2008) which is the process of: (1) finding areas of a program that are not used by a set of test cases, (2) generating more test cases to increase coverage, (3) determining a measure of code coverage which is an indirect measure of quality, and (4) identifying redundant test cases that do not increase coverage. Code coverage analysis is used to assure the quality and utility of a set of test files. Applying the same principles of code coverage analysis to coverage analysis for IFC files, the principles could be stated as:

- Finding which parts of the IFC schema or specific subset is covered by a set of test files and conversely which parts are not covered
- Help guide the generation of IFC test files to ensure a required level of coverage
- Identifying redundant test files that do not increase coverage

Various industry groups are defining subsets of the IFC schema to support interoperability in their application domain. These can be used for coverage analysis that can range from all the IFC entities and attributes necessary to exchange information in an application domain, such as precast concrete or energy analysis, down to the specific usage of the certain attributes of an entity.

The following sections will discuss software that has been developed to perform coverage analysis of IFC files and some examples of its usage. The IFC files used in the examples below were not generated from the most recent versions of BIM software and do not necessarily reflect their current capabilities to generate IFC files.

3. IFC FILE ANALYZER

The IFC File Analyzer (IFA) is a software platform for implementing various metrics to measure the coverage of information concepts in IFC files. It reads single or multiple IFC files and reports the results of the coverage analysis in a spreadsheet application. The IFA is available for free from http://ciks.cbt.nist.gov/cgi-bin/ctv/ifa_request.cgi and uses the IFCsvr ActiveX component (http://tech.groups.yahoo.com/group/ifcsvr-users/) to read and parse information from an IFC file. The software is currently under development.

A spreadsheet generated by the IFA contains one worksheet for each type of entity in the IFC file and a summary worksheet. Figure 1 shows a portion of a summary worksheet. The first column lists all of the entities that were processed. They are grouped together, indicated by color, into several broad categories of types of entities. For example, entities in light green are related to parametric profiles and extrusions and entities in yellow are related to properties. The second column (Count) gives the number of instances of each entity in the file. The remaining columns (Name, Description, ObjectType, Tag, ProfileName) indicate the number of instances where values for those attributes were found for those entities. All five of the attributes are optional. For example, all of the building elements (IfcBeam, IfcColumn, IfcSlab, IfcWall) have values for the Name, Description, and ObjectType attributes, but not the Tag attribute.

The number of times the attributes are used is a simple type of coverage analysis. In this example, since the Tag attribute is never used, this IFC file would not be useful for testing if the Tag attribute could be imported to another application. If the number of attribute values is greater than zero but less than the number of entities, then it indicates that some of the entities are missing an attribute value. Comparing the use of entities and the optional attributes associated with them, between similar models generated by different applications, indicates how those entities and attributes are used in those applications.

Figures 2 and 3 are from the IfcBeam worksheet from a different IFC file than the summary in Figure 1. Figure 2 shows columns A thru E and Figure 3 shows columns F thru I. Each row, 2 thru 11, shows the attribute values for one IfcBeam entity. Column A is the entity ID from the IFC file. The values for GlobalId and OwnerHistory are not shown. Attributes can also refer to other entities. For example, the ObjectPlacement attribute refers to IfcLocalPlacement entities where the number after IfcLocalPlacement in column E is the entity ID. Columns H and I are not values found on the IfcBeam entity, rather they are inverse relationships associated with IfcBeam. In column H, INV-HasAssociations indicates that there is an IfcRelAssociates (supertype of IfcRelAssociatesMaterial) that references IfcBeam and IfcMaterial. In column I, INV-IsDefinedBy shows that there is an IfcRelDefines (supertype of IfcRelDefinesByProperties) that references IfcBeam and multiple

8	Entity	Count	Name	Description	ObjectType	Tag	ProfileName
9	IfcBeam	75	75	75	75	0	
10	IfcColumn	45	45	45	45	0	
11	IfcSlab	3	3	3	3	0	
12	IfcWall	5	5	5	5	0	
13	IfcArbitraryClosedProfileDef	8					8
14	IfcArbitraryProfileDefWithVoids	2					2
15	IfcExtrudedAreaSolid	124					
16	IfcGeneralProfileProperties	128					128
17	IfcIShapeProfileDef	93					0
18	IfcRectangleProfileDef	2					0
19	IfcPropertySet	128	128	0			
20	IfcPropertySingleValue	512	512	512			
21	IfcRelDefinesByProperties	128	128	128			
22	IfcMaterial	12	12				
23	IfcMaterialLayer	8					
24	IfcMaterialLayerSet	8					
25	IfcMaterialLayerSetUsage	8					
26	IfcRelAssociatesMaterial	12	0	0			
27	IfcGeometricRepresentationContext	2					
28	IfcProductDefinitionShape	128	0	0			
29	IfcShapeRepresentation	254					
30	IfcRelAggregates	3	0	0			
31	IfcRelContainedInSpatialStructure	1	0	0			
32	IfcPresentationLayerAssignment	4	4	0			
33	IfcSIUnit	9	9				
34	IfcUnitAssignment	1					
35	IfcApplication	1					
36	IfcBuilding	1	1	0	0		
37	IfcBuildingStorey	1	1	0	0		
38	IfcOrganization	1	1	0			
39	IfcOwnerHistory	1					
40	IfcPerson	1					
41	IfcPersonAndOrganization	1					
42	IfcProject	1	1	1	1		
43	IfcSite	1	1	0	0		

Figure 1: IFC File Analyzer – Summary worksheet

	A	B	C	D	E
1	ID	Name	Description	ObjectType	ObjectPlacement
2	456	Concrete-Rectangular Beam:16 x 32:16 x 32:201801		Concrete-Rectangular Beam:16 x 32:201805	IfcLocalPlacement 443
3	600	Concrete-Rectangular Beam:12 x 24:12 x 24:201823		Concrete-Rectangular Beam:12 x 24:201844	IfcLocalPlacement 590
4	717	#W Shape:W18x35:W18x35:202828		#W Shape:W18x35:202831	IfcLocalPlacement 639
5	851	#W Shape:W18x35:W18x35:202845		#W Shape:W18x35:202848	IfcLocalPlacement 773
6	984	#W Shape:W14x22:W14x22:202868		#W Shape:W14x22:204327	IfcLocalPlacement 906
7	1184	#W Shape:W14x22:W14x22:203280		#W Shape:W14x22:204515	IfcLocalPlacement 1106
8	1315	#W Shape:W14x22:W14x22:204486		#W Shape:W14x22:204488	IfcLocalPlacement 1237
9	1378	Concrete-Rectangular Beam:12 x 24:12 x 24:204496		Concrete-Rectangular Beam:12 x 24:204516	IfcLocalPlacement 1368
10	1503	#Rectangular HSS:HSS6x4x3/8:HSS6x4x3/8:206088		#Rectangular HSS:HSS6x4x3/8:206118	IfcLocalPlacement 1417
11	1645	#Rectangular HSS:HSS6x4x3/8:HSS6x4x3/8:206194		#Rectangular HSS:HSS6x4x3/8:206226	IfcLocalPlacement 1562

Figure 2: IFC File Analyzer – IfcBeam worksheet

F	G	H	I
Representation	Tag	INV-HasAssociations	INV-IsDefinedBy
IfcProductDefinitionShape 455	201801	(1) IfcMaterial 457	(8) IfcPropertySet 540 572 574 576 578 580 582 583
IfcProductDefinitionShape 599	201823	(1) IfcMaterial 457	(8) IfcPropertySet 604 621 623 625 627 629 631 632
IfcProductDefinitionShape 716	202828	(1) IfcMaterial 264	(11) IfcPropertySet 721 750 752 754 756 758 760 762 764 765 766
IfcProductDefinitionShape 850	202845	(1) IfcMaterial 264	(11) IfcPropertySet 855 883 885 887 889 891 893 895 897 898 899
IfcProductDefinitionShape 983	202868	(1) IfcMaterial 264	(11) IfcPropertySet 988 1014 1016 1018 1020 1022 1024 1026 1028 1029 1030
IfcProductDefinitionShape 1183	203280	(1) IfcMaterial 264	(11) IfcPropertySet 1188 1214 1216 1218 1220 1222 1224 1226 1228 1229 1230
IfcProductDefinitionShape 1314	204486	(1) IfcMaterial 264	(11) IfcPropertySet 1319 1345 1347 1349 1351 1353 1355 1357 1359 1360 1361
IfcProductDefinitionShape 1377	204496	(1) IfcMaterial 457	(8) IfcPropertySet 1382 1399 1401 1403 1405 1407 1409 1410
IfcProductDefinitionShape 1502	206088	(1) IfcMaterial 1504	(11) IfcPropertySet 1512 1539 1541 1543 1545 1547 1549 1551 1553 1554 1555
IfcProductDefinitionShape 1644	206194	(1) IfcMaterial 1504	(11) IfcPropertySet 1649 1676 1678 1680 1682 1684 1686 1688 1690 1691 1692

Figure 3: IFC File Analyzer – IfcBeam worksheet (continued)

IfcPropertySet. Multiple IfcPropertySet are indicated by the number in parentheses in column I. The numbers after IfcPropertySet are the IfcPropertySet entity IDs.

Worksheets similar to Figures 2 and 3 are generated for every processed IFC entity in a file. Effectively, manual coverage analysis of entity attribute values can be done since all attribute values for every type of entity can be viewed at once. It is much easier to scroll through the worksheets and visually inspect the attributes than to use an IFC viewer or file browser to drill down to the attributes for a single IfcBeam. In this example, all values for Name, ObjectType, and Tag can be viewed at once on the worksheet. It is easy to see that the ObjectType values are similar to the Name, and the Tag value also appears in the Name. Comparing the use of the attributes from models of similar structures from different software applications can show how some attributes are used. Figure 4 shows the variation of attribute values from four IfcColumn entities from different software applications.

	A	B	C	D
1	**Name**	**Description**	**ObjectType**	**Tag**
2	IDColumn-01			A84C202D-69C2-4CE5-91-87-EEE95CFA654C
3	Steel--Columns	0, steelcolumn.dgn, Default:359	Steel:Columns	
4	W-Wide Flange-Column:W10X49:W10X49:212284		W10X49	212284
5	Column			

Figure 4: IfcColumn attributes from four different software applications

The IFC File Analyzer can also process multiple IFC files at one time. Figure 5 shows part of the summary worksheet from processing five IFC files from different software vendors of a precast concrete structure that was

	A	B	C	D	E	F	G
1	**Entity**	**ArchiCAD**	**Bentley**	**Digital Project**	**Revit Building**	**Total Entities**	**Total Files**
2	IfcBeam	16	9	34	18	77	4
3	IfcBuildingElementPart	3				3	1
4	IfcBuildingElementProxy	19	26		82	127	3
5	IfcColumn	31	4	15	5	55	4
6	IfcColumnType				2	2	1
7	IfcCurtainWall		42		4	46	2
8	IfcDoor	1	1		2	4	3
9	IfcFooting		15			15	1
10	IfcOpeningElement	12	90		8	110	3
11	IfcSlab	7	9	1	10	27	4
12	IfcStair	1	1		1	3	3
13	IfcStairFlight				1	1	1
14	IfcWall	4	3	3	5	15	4
15	IfcWallStandardCase	14			4	18	2
16	IfcWindow	4				4	1
17	IfcArbitraryClosedProfileDef	43	43		16	102	3
18	IfcArbitraryProfileDefWithVoids		7		1	8	2
19	IfcCircleProfileDef		2		2	4	2
20	IfcExtrudedAreaSolid	74	164		33	271	3
21	IfcRectangleProfileDef	31	112		14	157	3
22	IfcComplexProperty	98			60	158	2
23	IfcDoorLiningProperties	1			2	3	2
24	IfcDoorPanelProperties	2			2	4	2
25	IfcDoorStyle	1	1		2	4	3
26	IfcMechanicalConcreteMaterialProperties			1		1	1
27	IfcMechanicalSteelMaterialProperties			1		1	1
28	IfcPropertySet	98	8		362	468	3
29	IfcPropertySingleValue	392	67		1516	1975	3
30	IfcRelDefinesByProperties	98	8		362	468	3
31	IfcWindowLiningProperties	4				4	1
32	IfcWindowPanelProperties	4				4	1
33	IfcWindowStyle	4				4	1
34	IfcMaterial	3	26	2	3	34	4
35	IfcMaterialLayer	22			5	27	2
36	IfcMaterialLayerSet	22			5	27	2
37	IfcMaterialLayerSetUsage	22			6	28	2
38	IfcMaterialList	1				1	1
39	IfcRelAssociatesMaterial	96	26		9	131	3

Figure 5: Summary worksheet from processing five IFC files of a similar precast concrete structure

modeled from the same design specifications. The precast concrete structure was used in the data interoperability benchmark test of the Precast BIM Standard Project (Eastman, et al. 2006). Columns B thru E show the number of instances of each entity in the IFC files. Column F shows the total number of entities in all five files and column G shows the number of files in which an entity type occurs. The summary worksheet shows a wide variation of the type and number of entities to represent the same structure. There are several possible causes of the variations including: how information is mapped from the internal representation in the BIM software to the IFC file, and how the structure was modeled in the BIM software. The summary also shows that several entities (IfcStairFlight, IfcMechanicalConcreteMaterialProperties, IfcMechanicalSteelMaterialProperties) occur only once in one file. Knowing the distribution of entity types is important to help resolve issues related to interoperability between IFC applications.

4. COVERAGE ANALYSIS EXAMPLES

Other than counting occurrences of entities and being able to easily inspect attribute values, the IFC File Analyzer has some specific methods to do other types of coverage analysis.

4.1 Parametric Profile Position

This particular example is very specific and only has limited use for coverage analysis, however, it was implemented to show the need to characterize the information concepts that can be tested by an IFC file. IfcParameterizedProfileDef can be used to parametrically describe the dimensions of section profiles that are typically used in steel construction such as I-beams, T-beams, channels, and angles. The basic dimensions of a profile are its depth, width, and thickness. The origin of the profile is at its geometric centroid. For example, the origin of an I-shaped profile would be at the mid-depth and mid-thickness of the web. The parametric profiles also have a position that can be used to offset the origin. For example, the origin of an I-shaped profile could be offset to the top of the profile so that the longitudinal axis of a beam is at the top of the beam. The values of the offset are specified by an IfcAxis2Placement2D and associated IfcCartesianPoint. Figure 6 shows several profiles where the origin is not at the geometric centroid. It was generated by importing an IFC file with specific profile offsets into two applications. The left side of the figure shows the correct origin of the profiles to the lower right in the top row and to the lower left in the bottom row. The channel and angle are missing in the bottom row. The right side of the figure shows that the profile offsets were incorrectly interpreted by that IFC application.

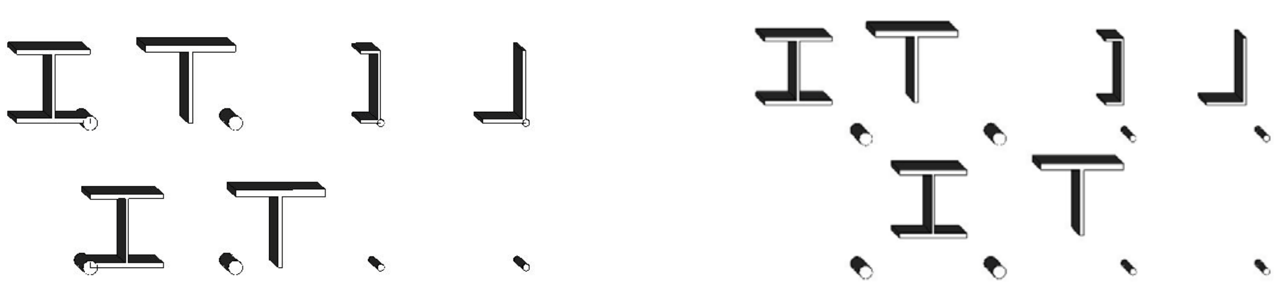

Figure 6: Parametric profiles: left side – correct offset; right side – incorrect offset

The IFC File Analyzer was used to look for profile offsets for these four parametric profiles. Using 98 of the beam, column, and railing IFC test files with parametric profiles, from the Step 1 IFC certification files described above, only three files had profiles with a profile offset. Without doing a coverage analysis for this concept and unless the three files were generated to specifically test profile offset, there would be no way to know that those files test profile offsets. It also shows the need to generate IFC test files to test specific concepts.

4.2 Model View Definition Concepts

Recently, the Information Delivery Manual (IDM) process has been used to develop precise specifications of the information exchange requirements necessary for particular domains. As part of the process, a Model View Definition (MVD) is generated that specifies how the information exchange requirements are implemented using the IFC schema (http://www.buildingsmart.com/content/process). The IDM process starts by defining the information exchange requirements between project participants at different phases of a project. The flow of information between them is documented in a process map. The important aspect of the process map is not to show the process of how a project could be delivered, rather to capture the most common and important information exchanges between project participants, such as architects, engineers, designers, analysts, and fabricators, at different phases of a project. The information that is exchanged between two processes is known as an exchange model. The process map and exchange models are developed with input from domain experts.

An exchange model defines all of the specific information, attributes, and accepted values that need to be exchanged. The exchange models are used to define the MVD concepts which binds the information that is exchanged to how it is represented in IFC. A software developer would use this information to guide the implementation of IFCs to meet the exchange requirements specified in an IDM. An MVD concept can be simple or specific such as (1) a building must be associated with a site or (2) a precast concrete double tee beam has certain required attribute values. The IFC Solutions Factory (http://www.blis-project.org/IAI-MVD/) is the repository for MVD concepts. Some of the MVD concepts include design to energy performance analysis, structural design to structural analysis, and precast concrete.

The IFC File Analyzer has been used to perform preliminary coverage analysis of IFC files for MVD concepts in the precast concrete domain (http://dcom.arch.gatech.edu/pcibim/index.asp). Currently there are over 110 MVD concepts for precast concrete. Each concept is assigned a reference number and name. Some of the names of the concepts are “precast piece mark”, “building contained in site”, “reinforcing bar attributes”, and “precast end-to-end connection geometry”. Each concept is documented by an instantiation diagram and the required attributes and values. Figure 7 shows the instantiation diagram for the concept that a site is contained in a project. This concept shows that IfcSite is associated with IfcProject through IfcRelAggregates.

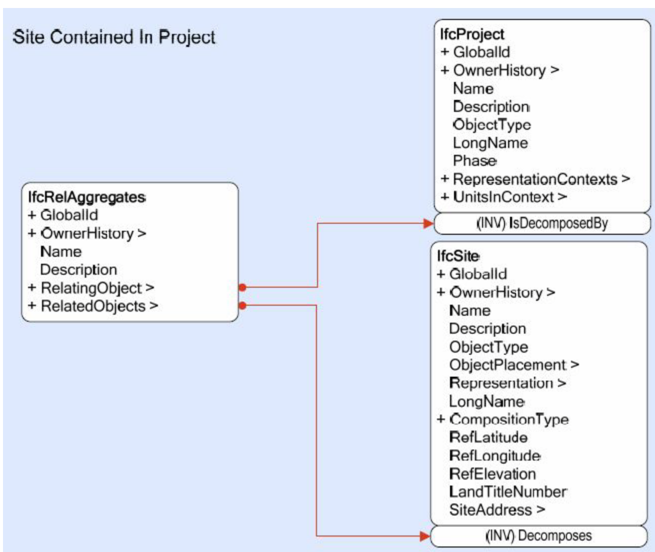

Figure 7: MVD instantiation diagram for “Site Contained in Project”

Analysis of the precast concrete MVD concepts shows that many of the concepts can be classified into at least three categories: relationships, attributes, and attribute values. A relationship concept creates an association between two IFC entities through IFC relationship entities such as IfcRelAggregates, IfcRelAssigns, IfcRelAssociates, IfcRelConnects, IfcRelDefines, and other subtypes of IfcRelationship. An attribute concept indicates that a particular entity attribute must have any value assigned. An attribute value concept is similar to the attribute concept except that a specific value has to be assigned to the attribute. Some concepts might be combinations of relationship, attribute, and attribute value classes. Other classes of concepts have yet to be developed. Approximately 60 of the precast concrete MVD concepts can be assigned to one of the three classes of MVD concepts.

Checking for the coverage of the three classes of MVD concepts has been implemented in the IFC File Analyzer. Figure 8 shows results with a summary of some of the entities whose usage covers some of the precast concrete MVD concepts (PCI) in column G. However, the results in this worksheet do not indicate how many of the entities are associated with an MVD concept. For example, in row 4, there are eight IfcPropertySingleValue entities and some or all might fulfill the MVD concepts PCI-056 and/or PCI-057. The worksheet for IfcPropertySingleValue would show which of the eight entities satisfies either of the MVD concepts.

	A	B	C	D	E	F	G
1	Entity	Count	Name	Description	ObjectType	Tag	MVD-PCI
2	IfcColumn	1	1	1	1	1	PCI-067
3	IfcPropertySet	2	2	2			PCI-056 PCI-057
4	IfcPropertySingleValue	8	8	8			PCI-056 PCI-057
5	IfcRelDefinesByProperties	3	3	3			PCI-055 PCI-155
6	IfcQuantityArea	1	1	0			PCI-155
7	IfcQuantityLength	1	1	0			PCI-155
8	IfcQuantityVolume	1	1	0			PCI-155
9	IfcQuantityWeight	1	1	0			PCI-155
10	IfcRelAssociatesMaterial	1	0	0			PCI-061
11	IfcRelAggregates	3	3	0			PCI-042 PCI-043 PCI-044
12	IfcRelAssignsToActor	1	1	1			PCI-060
13	IfcRelAssociatesApproval	1	1	1			PCI-059
14	IfcRelContainedInSpatialStructure	2	0	0			PCI-049 PCI-062
15	IfcRelDefinesByType	1	0	0			PCI-054

Figure 8: Summary of MVD concept coverage for IFC entities

The IFC File Analyzer also reports the coverage of MVD concepts for a set of IFC files as shown in Figure 9. Column A shows 34 of the MVD precast concrete concepts by their reference number and name. The other columns show which concepts are fulfilled by one of the ten test files. This type of coverage analysis is particularly important when developing IFC test files to ensure that all of the MVD concepts are covered by a sufficient number of files which will help software developers in testing their products for conformance and interoperability.

Improvements are needed for the coverage analysis of MVD concepts. More classes of MVD concepts, beyond the three already identified, need to be implemented in the IFC File Analyzer. A more rigorous coverage analysis is also necessary, in this example, to assure that coverage of MVD concepts is applied only to precast concrete building elements. For example, the coverage analysis of a precast concrete MVD concept that is related to IfcBeam would have to determine if the beam was made of precast concrete and not of steel. This might be done through an IfcBeam attribute or with its association with an IfcMaterial.

The IFC Solutions Factory has over 1000 documented MVD concepts and as more Information Delivery Manuals are developed, that number will increase. Certainly, many basic concepts can be reused across different domains such as the concept that a site must contain a building. However, to aid in the coverage analysis of MVD concepts, they could be expressed in a computer processable form. The processable form, such as XML, could then be read by the IFC File Analyzer or other software. Although, the current definition of the concepts that are checked for coverage in the IFC File Analyzer are hard-coded in the software, the definitions can easily be extracted and defined in an external file. The external file could be extended to check for other MVD concepts related to other Information Delivery Manuals.

3	MVD-PCI	PCI IFC test file 02_mv.ifc	PCI IFC test file 03 BREP.ifc	PCI IFC test file 04.ifc	PCI IFC test file 05.ifc	PCI IFC test file 06_mv.ifc	PCI IFC test file 07_mv.ifc	PCI IFC test file 08_IP.ifc	PCI IFC test file 09.ifc	PCI IFC test file 14_IP_v3.ifc	PCI IFC test file 15_IP_FP_v3.ifc
4	040 Precast Slab Aggregation				X						
5	042 Site Contained in Project	X	X	X	X	X	X	X	X	X	X
6	043 Building Contained in Site	X	X	X	X	X	X	X	X	X	X
7	044 Building Storey Contained in Building	X	X	X	X	X	X	X	X	X	X
8	045 Space Contained in Building										
9	046 Space Contained in Building Storey										
10	047 Grid Name	X									
11	048 Grid Representation										
12	049 Grid Spatial Structure Containment	X									
13	050 Grid Axis Assignment										
14	052 Placement Relative to Grid										
15	053 Element Attributes										
16	054 Element Type Assignment	X	X	X	X	X	X	X	X		X
17	055 Precast Property Set Assignment	X	X			X	X	X			X
18	056 Precast General Attributes	X									
19	057 Precast Fabrication Attributes	X									
20	058 System Piece Aggregation										
21	059 Approval Assignment	X		X	X				X		
22	060 Actor Assignment	X		X	X				X		
23	061 Precast Piece Material Association	X	X	X	X		X		X		X
24	062 Precast Piece Containment	X	X	X	X		X	X	X		X
25	063 Relative Placement										
26	064 Absolute Placement										
27	066 Generic Brep Shape Geometry										
28	067 Precast Piece Mark	X	X	X	X	X	X	X	X	X	X
29	068 Extruded Geometry										
30	069 Arbitrary Precast Profile										
31	070 Arbitrary Precast Profile with Voids										
32	073 Precast Embed Assignment								X		
33	074 Precast Blockout Assignment					X	X	X	X		X
34	077 Precast Design Criteria										
35	080 Precast Piece Type Attributes										
36	081 Piece Type Geometry Assignment										
37	083 Precast Blockout Attributes					X	X	X	X		X

Figure 9: Summary of MVD concepts in 10 precast concrete test files

5. CONCLUSIONS

Preliminary methods have been developed to measure the coverage of selected information concepts in IFC files and have been implemented in the IFC File Analyzer. Coverage analysis is necessary (1) to identify which parts of the IFC schema or specific subsets are covered by a set of test files, (2) to help guide the generation of IFC test files to meet a specified level of coverage, and (3) to identify redundant test files that do not increase coverage. The ability to measure the coverage of information concepts is necessary for improved conformance and interoperability testing which can result in better exchange of information between BIM software.

The IFC File Analyzer has implemented coverage analysis for single IFC files or for sets of IFC files for selected information concepts such as the usage of entities, attributes, and their values. Coverage analysis for simple MVD concepts such as relationships, attributes, attributes values has also been implemented. There are certainly more information concepts that could be tested when doing a coverage analysis. The coverage of enumerations and of property sets and their attributes could be easily implemented in the IFC File Analyzer.

Coverage analysis of concepts related to geometry have yet to be explored. For example, coverage analysis of the geometry and material composition could be performed for different types of walls, including: vertical walls, sloped walls, walls with openings for windows or doors, walls with recesses, walls with multiple material layers, straight walls, curved walls, intersecting walls, etc. Checking for the IFC entities, attributes, and relationships related to all types of walls is more involved than what has already been implemented. The software developers who are implementing IFC in their BIM software, industry organizations involved with testing IFC implementations, and domain experts defining information exchange requirements can help determine what are the most important information concepts that need to be tested for coverage in IFC files. Information concepts that could be expressed in a processable form, such as those defined by model view definitions, are logical choices for inclusion for coverage analysis testing. Processable information concepts could also be used by other types of testing software.

The initial coverage analysis of some sets of IFC files has shown several characteristics of those files. In an ideal world, all BIM software would export the exact same IFC file when the same structure is modeled in each of them. However, we know this is not true. Coverage analysis can help reveal the differences of how similar information is written to an IFC file in different ways using different IFC entities and attributes by different BIM applications. Knowing the differences will help identify and resolve issues related to interoperability and hopefully move the software implementations towards a more standard usage of IFC entities and attributes.

Coverage analysis can also be used to give a more definitive measure of the characteristics of the information concepts in IFC test files that will be generated for use in the upcoming recertification of IFC2x3 software implementations (http://gtds.buildingsmart.com/) and certification of software implementations of future versions of IFC. It is important that these certification processes use a common set of tools and methods for developing sets of IFC test files so that conformance and interoperability testing will be done in an efficient and cost-effective manner.

Coverage analysis and the IFC File Analyzer should be part of a testing methodology for interoperability using IFC files that would include: (1) well-defined models (dimensions, materials, profiles, relationships, etc.) of buildings and building elements that can be modeled in BIM software, (2) a description of the attributes that each model tests, (3) a reference IFC file of the model to compare against the IFC file exported by the BIM software, (4) test criteria to measure the characteristics of IFC files and the result of importing them to BIM software to ensure that they meet the exchange requirements, and (5) a description of how testing tools should be used to measure the test criteria. This methodology has been successfully used for testing of several other product data models (Kline, Palmer 1996; http://www.cax-if.org/).

DISCLAIMER

Any mention of commercial products or trade names does not imply recommendation of endorsement by NIST.

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