EVALUATION OF IFC OPTIMIZATION

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ABSTRACT: Today Industry Foundation Classes (IFC) with considerable number of implementations presents almost "de-facto" standard in the Building Information Modelling (BIM). The idea of architecture, engineering, construction and facility management (AEC-FM) software interoperability may be easy understandable but the current standard implementations performances are not always satisfying. Although various deficiencies can be concluded from evaluation reports and the pilot projects presented research focuses only on model optimization issues. IFC files generated with the most commonly used architectural design applications are as a rule not optimal regarding the record length and as deduced from previous research work several easily resolved optimization procedures could be applied. Presented case study is based on Solibri IFC Optimizer, the only IFC optimization tool available. Several simple and complex models were tested and optimization results have been closely examined. Prospects and constraints of presented optimization are discussed at paper closing.

KEYWORDS: BIM - building information model, IFC - industry foundation classes, interoperability, optimization, solibri IFC optimizer.

1 INTRODUCTION

Several initiatives to implement BIM in the AEC-FM sector with different implementation success can be comprehended from information and communication technology (ICT) history. Currently IFC present most general and most comprehensive BIM ever implemented in the AEC-FM sector software. STEP methodology based product model vision is to contain all vital information about a specific building in its lifecycle to the certain level of accuracy. With its layered structure and possible model expansion through "Extension Projects" the IFC share common complex models destiny: never completed and always under construction.

Freely available IFC specification (IAI, 2007) lists the entities and corresponding attributes which are used to describe BIM. The final result within file exchange is STEP based physical file (ISO 10303-21: Clear Text Encoding of the Exchange Structure) which can be exchanged with other IFC compatible applications. Although AEC-FM community has presented more convenient ways of handling IFC models (model servers) most of every day practice projects is still based on file exchange.

Modern BIM includes enormous set of information which can result in hardly manageable IFC files due to the text based record. Expected contented end users can easily be substituted with frustrated ones as proven with several pilots and real life AEC-FM projects. VTT research project SPADEX (Backas 2001) listed IFC file size as one of seven keystone implementation obstacles and consequently dissuade IFC 1.5.1 release usage. Stanford PM4D report (Fischer & Cam 2002) also exposes IFC file size as a major burden on computer hardware, software and networks, adversely impacting the manipulation and general performance. As concluded from introduced reports the implementation challenges of large file size present motivation for further research in the partial data exchange and in database model servers. As result of first evaluation reports later IFC releases (2.0 forward) use simplified description of certain parts of the model but without any evident success regarding to the file size diminishing. (Bazjanac 2002) gathered experiences from early deployment projects and presented them as "six early lessons learned" (2.0 and 2x release). As assumed the project model exchange file size is one of them. Cited author emphasizes that even a modestly sized building can easily approach limits of manageability. Therefore up-to-date hardware is required for considerable working convenience. When planning investments into the hardware IFC extension projects and more and more detailed modelling has also be taken into the consideration.

Considerable part of "constrains" in recent evaluation reports (Amor & Ma 2006; Dayal 2004; Pazlar & Turk 2006) is still related to the frustrating IFC file managing experiences. Database model servers are still not commonly used in practice and although appreciated BLIS defined partial model exchange (BLIS 2002) can face difficulties when assuring general BIM consistency.

2 MODEL MAPPING

Each AEC-FM software tool has its own internal representation of semantic artefacts. In order to achieve application accordance with IFC standard two schema mapping has to be provided: mapping between internal model and IFC model for export purposes and mapping between IFC model and internal model for import purposes (Ma et al. 2006). Both mappings are not trivial and due to the application specific internal representation perfect semantic mapping cannot be expected.

Due to the various possibilities offered by IFC specification some applications describe the same semantic construct differently than the others. Cube as the most elementary example is geometrically always presented as "Boundary representation" (Foley et al. 1995) but once as an extruded area solid and secondly as a collection of surfaces bounded by loops. Implementers can freely choose the approach which best suit their needs.

3 OPTIMIZATION

Optimization is the process of modifying a system to make some aspect of it work more efficiently or use fewer resources. In general computer science related problem optimization may refer on more rapid execution or on capability of operating within a reduced amount of memory storage, or on improving some other issues. Although the word "optimization" shares the same root as "optimal", it is not common that debated procedure would result in the truly optimal system. As common in computer science, optimization usually refers to more efficient software. In presented research work term optimization represents process of reducing IFC file size without any information loss.

Compression of STEP physical file presents the most simple but also most widely used optimization method which is clearly effective only within model manipulation process (like sending the model as e-mail attachment). Several lossless compression algorithms with different compression ratios are available. ZIP file format using DEFLATE lossless data compression algorithm (combination of the LZ77 algorithm and Huffman coding) has been used in presented research mainly for evaluating effectiveness of tested IFC model optimization.

As already emphasized text based IFC files are pretty verbose. On the contrary, binary files used as native format of almost all modern AEC-FM applications usually present much more compact record. Within IFC standard encoding mechanism is strictly defined and therefore record optimization efforts should focus on the file content.

The need for IFC file content optimization presents just one conclusion from our previous research work (Pazlar & Turk 2006) where round trip testing procedure has been used in evaluation of the most commonly used IFC compatible architectural design applications. The duplicated entities were easily noticeable imperfection produced by all interfaces in the cited research. Although stated conclusions have been proven only with architectural models, similar conclusions would certainly occur when testing the other implemented parts of IFC specification.

There was no need to spare a lot of effort in developing the IFC file optimizer. Solibri Inc. (Solibri 2007) introduced their vision of optimization just recently with Solibri IFC Optimizer that performs similar eliminations as suggested in (Pazlar & Turk 2006): redundant lines of Part 21 ASCII file are removed and corresponding references are updated. Presented research therefore aims to confirm if optimization procedure results in semantically equal but more compact IFC physical file.

4 CASE STUDY

4.1 *Simple test cases*

Simple test cases present reasonable origin point to evaluate optimization since the content of IFC files can easily be examined with simple text editors. Simple test cases have been created separately in most commonly used IFC 2x compatible architectural design applications: Autodesk Architectural Desktop 2005 with INOPSO IFC interface, Nemetschek AllPlan Architecture 2005 and Graphisoft Archicad 9.

Although describing the same BIM (concrete wall originated in the world coordinate system) generated file sizes differs up to 100%. Different mapping and description approaches between native and IFC artefacts are evident.

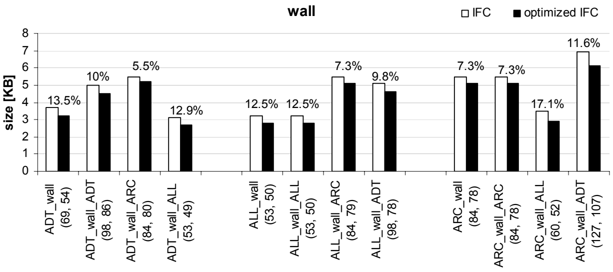

Figure 1. Concrete wall. Original and optimized file size and corresponding optimization ratio. Number of entities (total, total optimized).

Complete IFC 2x specification lists 370 diversified entities, but only 35, 36 or 37 are used to describe tested BIM (exact number depends on specific model and testing procedure). The following redundant entities have been eliminated in the optimization process: IfcAxis2Placement3D (location and orientation in 3D space), IfcCartesianPoint (point in space) and IfcDirection (general direction vector). Additionally ADT and ALL interfaces produce duplicated IfcPropertySingleValue (RGB components) and consequently IfcComplexProperty (colour) entities which were also removed. All end user important tangible entities (IfcProject, IfcBuilding, IfcBuildingStory, etc.) stay intact and corresponding attributes are updated.

Optimization ratios are test case specific (5.5-17.5%) and regardless to stated differences total number of entities and consequently file sizes still differ up to 100%. Detailed IFC file content analysis reveals different modelling approaches: ADT interface in the re-export procedure replaces the solid representation of wall (IfcExtrudedAreaSolid) with the six surfaces bounded by loops (IfcFace). Consequently IfcWallStandardCase (with "SweptSolid" as only possible body representation) is replaced with more general IfcWall entity (“SweptSolid”, “Clipping”, “Brep”, “SurfaceMode” and “BoundingBox” as possible body representations). Although all three applications within the first export process use solids as geometric representation of wall, the attribute presenting swept area of IfcExtrudedAreaSolid differs. Semantically the IfcArbitraryClosedProfileDef and IfcRectangularProfileDef entities present the same surface to be extruded but there is an important difference in record length. Different approaches in geometry modelling can also be observed with the other geometric representation contexts. When wall is circumscribed as an axis (IfcLine), IfcTrimmedCurve (ADT, ALL) or IfcPolyline (ADT) is used. Different modelling approaches and number of reiterated entities can be evaluated from Table 1. According to presented results Allplan and Archicad interfaces generate much more compact record then ADT. Omitting the IfcBoundingBox geometry representation extrusion of rectangular planar surface presents the most optimal geometric representation of regular forms. Three times more entities are required to describe the same geometry with surface boundary representation.

Table 1. IfcWall – IfcProductDefinitionShapeAttribute. Detailed analysis of body representation – number of different entities (optimized BIM).

Entity name	ADT(N)	ADT*	ARC	ALL	ALL(N)	ALL*	ARC	ADT	ARC(N)	ARC*	ADT	ALL
IfcShapeRepresentation	Axis-curve 2D	Axis-curve 2D	Axis-curve 2D	Axis-curve 2D	Axis-curve 2D	Axis-curve 2D	Axis-curve 2D	Axis-curve 2D	Axis-curve 2D	Axis-curve 2D	Axis-curve 2D	Axis-curve 2D
	Body-Solid	Body-Brep	Body-Solid	Body-Solid	Body-Solid	Body-Solid	Body-Solid	Body-Brep	Body-Solid	Body-Solid	Body-Brep	Body-Solid
	Bound. Box	Bound. Box	Bound. Box				Bound. Box	Bound. Box	Bound. Box	Bound. Box	Bound. Box	
IfcGeometricRepresentationContext	1	1	1	1	1	1	1	1	1	1	1	1
IfcAxis2Placement3D	1	1	1	1	1	1	1	1	1	1	1	1
IfcAxis2Placement2D				1	1	1						1
IfcCartesianPoint	5	9	5	2	2	2	5	9	5	5	9	2
IfcDirection	3	2	3	3	3	3	3	2	3	3	2	3
IfcExtrudedAreaSolid	1		1	1	1	1	1		1	1		1
IfcArbitraryClosedProfilDef	1		1				1		1	1		
IfcPolyline	1		1				1		1	1		
IfcFacedBrep		1						1			1	
IfcClosedShell		1						1			1	
IfcFace		6						6			6	
IfcFaceOuterBonund		6						6			6	
IfcPolyLoop		6						6			6	
IfcRectangleProfileDef				1	1	1						1
Total number	13	33	13	10	10	10	13	33	13	13	33	10

Global estimation of optimization ratios on presented models is not grounded. Simple models do not contain enough geometry artefacts which present the main source of reiterated entities in IFC files. IFC and native application format file size comparisons are also not credible on simple BIMs (wall model: ADT 116kB, ARC 496kB, ALL 48kB, wall – door – window model: ADT 125kB, ARC 517kB, ALL 64kB). The advantages of more compact binary record become evident with complex models.

When adding additional semantic artefacts in the model (door, window) the number of reiterating entities does not distinctively change: only IfcAxisPlacement2D (location and orientation in 2D space) is added on the reiteration entities list. Almost all global optimization ratios are negligibility reduced if compared with the first test case (Allplan generated files present exception).

Allplan interface again generates most compact IFC files. Beside optimization ratio IFC file size and consequently modelling approach has to be taken into the consideration when evaluating the IFC interfaces and optimization prospects. Allplan for example generates the most compact IFC file but these files also have the highest optimization ratio.

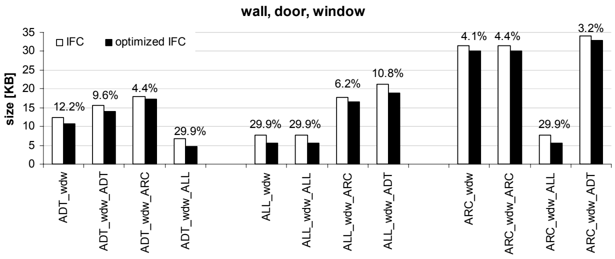

Figure 2. Concrete wall with door and window. Original IFC and optimized IFC file size and corresponding optimization ratio.

Table 2. Wall with door and window. Detailed analysis of reiterated entities.

Entity name	ADT(N)	ADT*	ARC	ALL	ALL(N)	ALL*	ARC	ADT	ARC(N)	ARC*	ALL	ADT
IfcAxis2Placement2D	2/1	2/1		3/3				2/1				2/1
IfcAxis2Placement3D	10/7	9/8	10/6	8/6	10/7	10/7	10/7	10/8	10/6	10/6	10/7	10/8
IfcCartesianPoint	56/42	74/61		13/10	15/11	15/11	14/12	112/100			15/11	112/99
IfcDirection	26/5	23/5	9/6	20/4	24/5	24/5	10/6	25/6	10/6	10/6	24/5	25/6
IfcComplexProperty		5/4		3/1	3/1	3/1	8/7	6/2	8/7	8/7	3/1	9/8
IfcPropertySingleValue		20/17	129/127	12/4	12/4	12/4	26/21	24/11	26/21	26/21	12/4	24/12
Total (only reiterated entities)	94/55	133/96	148/139	59/28	64/28	64/28	68/53	179/128	54/40	54/40	64/28	182/134

Although there is a huge difference in IFC file sizes (max ratio 4.7) the average values have been determined. The average native IFC file size is 17.7kB which is with the optimization process reduced by 14.5% (to 16.0kB). If both files are compressed using “7-zip” file data compression utility corresponding figures are: 5.0kB, 4.7kB and 6.59%. When summarizing stated figures optimized and zipped IFC file is reduced to only 28% of native IFC file size.

Besides automatic zipping of optimized files Solibri IFC Optimizer allows “floating point rounding”. This option just eliminates zero decimal values and in such manner contributes to the optimization. Evidently such contribution is very limited when analyzing small models (below 0.5%), but increases with complex models. Using this option up to 2% optimization improvement can be achieved. However it is not acceptable and understandably why “floating point rounding” with some models alternates numerical values: In the ADT based models for example attributes in IfcCartesianPoint entities are unreasonably changed (form (0.0,-12.5,0.0) to (0.,-12.499998,0.)).

As expected native and corresponding optimized file have the same number of diversified entities. When analyzing the frequency of reiterated entities (Table 2), IfcCartesianPoint and IfcDirection presents majority of reiterating entitles (more than 50%) if IFC file is generated by ADT or ALL. Corresponding entities within Archicad generated files are IfcPropertySingleValue and IfcComplexProperty.

Archicad also enables exporting semantically richer model with “Extended properties” option. This term marks additional properties which dynamically expand the IFC model range through the IfcPropertySet entity. Extending the attainment of the model may seem as valuable contribution to the BIM, but model population also has some negative effects: file size increases several times

(120% in presented test case). Such models may also seem semantically richer since several hundred IfcProperySingleValue have been added. But as analysis revealed many newly included characteristic (fire rating of door panel, heat transfer coefficient, facility management inventory number, etc.) are not defined. Regardless to their origin entities without defined attributes should also be eliminated in the debated optimization process.

4.2 *Complex test cases*

"Complex test case" term marks IFC models that could actually present real life BIM. Models were obtained from the web and after establishing the origin application BIMs had been optimised and furthermore compressed. Almost one hundred BIM originated from different applications using different IFC standard release (mainly 2x and 2x2) and level of accuracy (complete, architectural, structural, etc.) were tested.

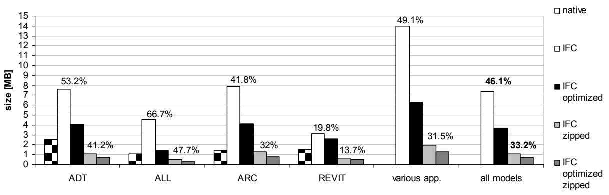

Figure 3. Complex model testing. Average original, optimized, original zipped and optimized zipped file size and corresponding optimization ratios.

Table 3. Complex test cases. Reiterated entities and corresponding optimization ratio.

Optimization ratio [%]	Entity name
90 – 99.9	IfcColourRgb, IfcCurveStyle, IfcPresentationStyleAssignment, IfcCircleHollowProfileDef, IfcArbitraryProfileDefWithVoids, IfcCartesianTransformationOperator3D
80 – 90	IfcDirection, IfcComplexProperty, IfcPropertySingleValue, IfcApplication
70 – 80	IfcCircleProfileDef, IfcPropertyEnumeratedValue, IfcMaterial, IfcMappedItem, IfcMaterialLayer
60 - 70	IfcQuantityArea, IfcMaterialLayerSetUsage, IfcMaterialLayerSet, IfcQuantityVolume, IfcPropertyBoundedValue, IfcAxis2Placement2D, IfcCartesianTransformationOperator3DnonUniform, IfcRectangleProfileDef
50 - 60	IfcCompositeCurve, IfcVector, IfcCompositeCurveSegment, IfcAxis2Placement3D, IfcCartesianPoint, IfcPropertyListValue, IfcQuantityLength
40 - 50	IfcCircle, IfcTrimmedCurve, IfcLine, Ifc2DCompositeCurve, IfcGeometricRepresentationContext, IfcConnectedFaceSet, IfcOrganization, IfcPlane, IfcPerson, IfcPersonAndOrganization, IfcBoundingBox
30 – 40	IfcExtrudedAreaSolid, IfcFaceBasedSurfaceModel, IfcArbitraryClosedProfileDef, IfcPolyline, IfcAnnotationSurfaceOccurrence, IfcProductRepresentation, IfcStyledRepresentation, IfcPolygonalBoundedHalfSpace, IfcShellBasedSurfaceModel
20 – 30	IfcConnectionCurveGeometry, IfcFaceBound, IfcConnectionSurfaceGeometry, IfcHalfSpaceSolid, IfcCurveBoundedPlane, IfcOpenShell, IfcFacetedBrep, IfcClosedShell, IfcPolyLoop, IfcFaceOuterBound, IfcFace, IfcRepresentationMap
10 – 20	IfcLocalPlacement, IfcGeometricSet, IfcShapeRepresentation
0.1 - 10	IfcArbitraryOpenProfileDef, IfcBooleanClippingResult

Several conclusions can easily be observed form Figure 3. As anticipated STEP physical file size can compete to the binary record length only to the certain file size (1-2MB, depending on origin application). If model is more comprehensive then IFC file size soon reaches the "manageability" limits. The average optimization ratios within complex model analysis are as expected much higher than within simple model testing. Complex BIMs contain immense number of geometric artefacts which presents the main source of reiterating entities. Achieved ratios are interfaces specific and depend on how much redundancy the original file has. REVIT IFC interface with average 19.8% optimization ratio seems to be the most improved application. Corresponding ratios achieved with other applications are more than twice as larger: ARC (41.8%) ADT (53.2%) and ALL (66.7%).

All tested files have also been zipped. Data compression utility reduces file sizes much more efficiently than optimization with reiterated entities elimination. If native IFC files are compressed the average reduction percentage is 83.2%. Maximum possible IFC file size reduction is achieved with combination of optimization and compression. Due to involvement of optimization this percentage depends on origin design application. The average compressed and zipped IFC based BIM is commonly in 82% to 93% percentage range (the average ratio is 89.3%).

Most of redundant entities listed in Table 3 are geometry related in terms of describing geometry artefacts (points, directions, surfaces extruded solids, etc.) and corresponding operations (transformations, Boolean operations). Material and single value properties supplement the reiteration lists. Reiterated entities are sorted in ten groups regarding to the optimisation ratio. Entities with the lowest optimization ratio can be just duplicated, but within the highest optimization percentage figures can reach up to 99.3% (IfcColourRgb, IfcCurveStyle and IfcPresentationStyleAssignment). Following example clarifies high optimization percentage: Within optimization process the number of IfcColourRgb entities in the MunkerudBS IFC model is reduced from 1618 to only 7.

Absence of tangible end user important entities (project, building, walls, doors, windows, etc.) in the reiteration list (Table 3) somehow confirms object mapping regularity form native application to the IFC model. After optimization BIMs were visually checked compared with original models: no differences could be noticed.

Regretfully optimization is not to be fully trusted although it may seem easy understandable and theoretically well grounded. Solibri IFC Optimizer does not report any errors within optimization process but when analyzing the content of optimized IFC files with IfcObjCounter (FZH 2007) approximately 3% of models could not be analyzed due to the run time error. Log record created by used IFC file content analyzer as a rule refers to "incompatible assignment" or "set element is not unique" as the crash cause.

Most common reasons for discordance with IFC specification are irregular use of IfcPolyline and IfcPolyLoop entity where end point coincides with start point (the last attribute should be different than the first one). Additionally with IfcPolyLoop some entity points as attributes can refer to the same instance as the first point (loop is represented as a line). However stated errors are most likely the result of numerical errors where more than one IfcCartesianPoint entity is used to describe the same point in space.

Surprisingly regardless to IFC schema non-compliance some majority of IFC compatible applications imports the model without any error reported.

5 DISCUSSION

Hardly manageable files have been noticeable imperfection of IFC specification from its first release. Although almost all evaluation reports emphasize stated deficiency it cannot be easily understood why the first optimizer appeared just recently. Since some optimization proposals were already suggested in our previous research work (Pazlar & Turk, 2006), Solibri IFC Optimizer presents unique opportunity to prove stated recommendations.

Although simple tests cases confirmed fulfilling of the Solibri IFC Optimizer main goal, corresponding optimization ratios are not the most credible indicator. The ratio of "obligatory" and "model specific" entities evidently differ when comparing simple and complex IFC models. However some optimization aspects are more evident with simple models. STEP based geometry description offers various possibilities in describing model geometry. If there are no specific requirements the use of solids instead of surfaces can significantly optimize the length of file record (up to three times) and therefore should present the preferred choice wherever such approach can be used.

The second part of presented research work confirms Solibri IFC Optimizer advertised benefits: 1) Suitable model size, 2) Shorter loading times in IFC applications (not exactly measured but evident), 3) Smaller memory consumption in IFC application, and 4) Lower data storage costs. However testing results figures slightly differ from the promised ones: pure ZIP compression should reduce typical file size to 15-30% and with Solibri IFC Optimizer the optimized and compressed file size reduces to only 6% of the original. Corresponding research established percentage figures are a bit lower (16.8% and 10.7%) but still encouraging. Different optimization ratios ascertained for each interface indicate that some IFC developers (REVIT) invest much more efforts in optimization aspects than the others. Within the mapping process BIM semantics can be preserved even if using more compact record.

As proved with this research and also with every day practice work the usage of IFC exchange format is not very economic since the average size of BIM easily exceeds few tens or hundreds of megabytes. The problem will intensify in the future: IFC model is not complete, more detailed modelling is required and some issues are still not properly solved (provenance data for example).

Regretfully introduced optimization is not always reliable. As established from some optimized models numerical inaccuracy can cause discordance with IFC schema. This could be avoided if optimization aspects would be taken into the consideration by IFC interfaces developers regardless to the technology used (the file based exchange or model servers). Such approach would also allow the simplest inclusion of other optimization aspects (like selecting the most optimal geometry description from various possibilities offered).

CONCLUSION

The aim of this paper is to point out the deficiencies of presented IFC interfaces and suggest possible improvements in the meaning of the optimization. Solibri IFC Optimizer performance has been evaluated on various models. Although simple model testing confirmed fulfilling the optimiser's main goal, difficulties experienced within complex models optimization indicate some scepticism about using this optimizer in practice. But hopefully optimizer motivation discussed in previous section will affect to the IFC interface developers and increase their product quality in terms of optimization.

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