DEVELOPMENT OF A TWO DIMENSIONAL MODEL SPACE EXTENSION FOR IAI/IFC2.X2ND MODEL

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EDITOR: Väino Tarandi

Inhan Kim, Associate Professor
Kyung-Hee University, Korea
email: ihkim@khu.ac.kr, http://italab.khu.ac.kr

Thomas Liebich, President
AEC3, Germany
email: thomas.liebich@aec3.com

Seong-Sig Kim, Senior Researcher
KICT, Korea
email: sskim@kict.re.kr

SUMMARY: *IFC is getting popular as a standard product data model. However, IFC is currently a 3D focused building model with detailed semantics. The current IFC2x model does not include 2D presentation entities (like line types, hatches and dimensions) which are essential to represent 2D drawings. Having drawing information connected to the building model is beneficial for data sharing within the life cycle, as still much information is covered in a drawing-based approach. Therefore, the IFC2x model should be extended with 2D representation capabilities to achieve this aim. The work is executed within the XM-4 project of IAI. The objective of the XM-4 project is to add the capabilities for 2D data exchange of representations of the virtual building model, including annotations, which is mostly adopted from ISO10303/STEP, to the current IFC structure. Therefore in the developed model, the presentations of element geometry and general annotation capabilities have been extended by enhancing the 2D geometric representation capabilities. In the paper, the methodology of relating the two different models, IFC and STEP, has been investigated and the methodology of dividing model and view is examined. Following such approach, the gap between model and view can be systemically sealed and IT systems for the Construction industry can be beneficial from the developed data model.*

KEYWORDS: *IFC2x, Drafting Model, representation, 2D*

1. BACKGROUND

1.1 Rationale

IFC is getting popular as a standard product data model. However, IFC is currently a 3D focused building model with detailed semantics. Its purpose is to have interoperability between similar and dissimilar IT systems for the construction industry covering all life cycle phases using the model-based construction approach. The current IFC2x model does not include 2D presentation entities (like line types, hatches and dimensions) which are essential to represent 2D drawings. Having drawing information connected to the building model is beneficial for data sharing within the life cycle, as still much information is covered in a drawing-based approach. Therefore, the IFC2x model should be extended with 2D representation and presentation capabilities to achieve this aim.

The current IFC2x model does only accept geometric representation of objects, since it strictly follows the model-based approach. However current practise in the building and construction industry shows that a mixed approach (using model-based information for major building elements, but completing this information by using line based drawings) will still be followed by the majority of practitioners for a longer time.

Therefore the new IFC release, IFC2x 2nd edition, should enable the exchange and sharing of drawing information in addition to the building model. The aim of XM-4 project is to combine the essential 2D annotations attached to the building model, since users today work with a combined 2D/3D approach. Additional details or other 2D attachment can be handled by the IFC model already as linked external files trough the external document reference capabilities.

1.2 Representation in IFC2X

Currently, IFC2x does not have the capabilities for the drawing based information although it aims to accommodate the virtual building model. Therefore it is desirable to have the capabilities for 2D data exchange of representations beside the 3D based virtual building model representation, including annotations, within the current IFC structure. In this study, the presentation of element geometry and general annotation capabilities to the current IFC2x have been extended by enhancing the 2D geometric representation capabilities. However, any geometric capabilities, which are beyond current IFC geometry capabilities, are excluded in the extension. For instance, B-spline curves, other then Bezier curves, non-planar surface curves, non-planar surfaces, such as hyperbolic or parabolic surfaces, non-faceted boundary representations, such as NURBS, etc are not in scope of this extension.

1.2.1 Introduction to the current IFC representation model

In the current IFC representation model, each representation is included (or encapsulated – following the object-oriented principles) within the definition of an individual semantic object – being either a product occurrence, i.e. subtypes of *IfcProduct*), or a product type (or block) then a subtype of *IfcTypeProduct*. Each geometric representation (*IfcShapeRepresentation*) is defined in its own object coordinate system, in the case of product occurrences, the object coordinate system is placed through a local placement (*IfcObjectPlacement*) either directly into the world coordinate system, or through some intermediate object placements. Each semantic object can have zero, one or many geometric representations, each being contained in a separate instance of *IfcShapeRepresentation*, but all are placed by a single instance of *IfcObjectPlacement*.

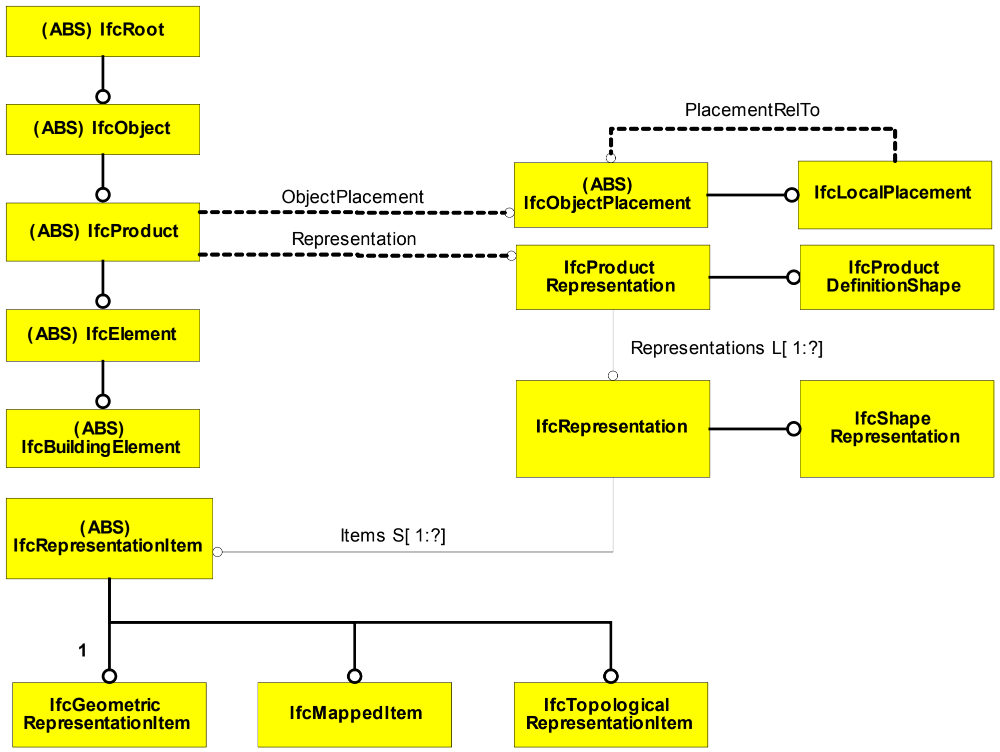

FIG 1: Representation structure in IFC2x

Concentrating on product occurrences it can be summarized that:

Any product defined as subtype of IfcProduct in IFC can have one or more geometric representations (e.g. a simple representation as a bounding box, and/or a complex representation as a boundary representation model).

All of the geometric representations of the same object are defined within the same object coordinate system. This object coordinate system is given by the reference IfcProduct.ObjectPlacement to IfcObjectPlacement.

FIG 1 shows the definition of placement and geometric representation within the context of a semantic object.

The following IFC file shows the use of multiple geometric representations of a single semantic object, a wall. This wall is described by 1) a wall axis, 2) a 3D extrusion body, 3) a simplified bounding box.

```
DATA;
#1=IFCWALLSTANDARDCASE('abcdefghijklmnopqrst01', #2, $, $, $, #3, #4, $);
#3=IFCLOCALPLACEMENT($, #10);
#10=IFCAXIS2PLACEMENT3D(#16, $, $);
#16=IFCCARTESIANPOINT((2.,1.,0.));
#4=IFCPRODUCTDEFINITIONSHAPE($, $, (#11,#13,#211));

/* first representation - wall axis */
#11=IFCSHAPEREPRESENTATION(#110, 'Axis', 'Curve2D', (#18));
#18=IFCTRIMMEDCURVE(#19, (#20), (#21), .T., .CARTESIAN.);
#19=IFCLINE(#30, #31);
#20=IFCCARTESIANPOINT((0.,0.));
#21=IFCCARTESIANPOINT((2.8,0.));
#30=IFCCARTESIANPOINT((0.,0.));
#31=IFCVECTOR(#32, 2.8);
#32=IFCDIRECTION((1.,0.));

/* second representation - wall extrusion of a profile */
#13=IFCSHAPEREPRESENTATION(#111, 'Body', 'SweptSolid', (#22));
#22=IFCEXTRUDEDAREASOLID(#23, #26, #29, 2.8);
#23=IFCARBITRARYCLOSEDPROFILEDEF(.AREA., $, #40);
#26=IFCAXIS2PLACEMENT3D(#28, $, $);
#28=IFCCARTESIANPOINT((0.,0.,0.));
#29=IFCDIRECTION((0.,0.,1.));
#40=IFCPOLYLINE((#41,#42,#43,#44,#41));
#41=IFCCARTESIANPOINT((0.,0.1));
#42=IFCCARTESIANPOINT((2.8,0.1));
#43=IFCCARTESIANPOINT((2.8,-0.1));
#44=IFCCARTESIANPOINT((0.,-0.1));

/* third representation - bounding box */
#211=IFCSHAPEREPRESENTATION(#112, 'Outline', 'BoundingBox', (#218));
#218=IFCBOUNDINGBOX(#230, 2.8, 0.2, 2.8);
#230=IFCCARTESIANPOINT((0.,-0.1));

/* different representation contexts for multiple representations */
#110=IFCGEOMETRICREPRESENTATIONCONTEXT('Plan', 'Sketch', 3, $, #114, $);
#111=IFCGEOMETRICREPRESENTATIONCONTEXT('Model', 'Design', 3, $, #114, $);
#112=IFCGEOMETRICREPRESENTATIONCONTEXT('Model', 'Sketch', 3, $, #114, $);
#114=IFCAXIS2PLACEMENT3D(#115, $, $);
#115=IFCCARTESIANPOINT((0.,0.,0.));

#231=IFCMATERIALLAYERSETUSAGE(#232, .AXIS2., .POSITIVE., -0.1);
#232=IFCMATERIALLAYERSET((#233), 'Single Layer Concrete');
#233=IFCMATERIALLAYER($, 0.2, $);
#234=IFCRELASSOCIATESMATERIAL('abcdefghijklmnopqrst81', #2, $, $, (#1), #231);
```

```
#2=IFCOWNERHISTORY(#6, #7, .READWRITE., .NOCHANGE., $, $, $, 978921854);
#6=IFCPERSONANDORGANIZATION(#8, #9, $);
#7=IFCAPPLICATION(#9, '1', 'IFC2x Text Program', 'IFC2x Test');
#8=IFCPERSON($, 'Miller', 'Frank', $, $, $, $, $);
#9=IFCORGANIZATION($, 'IAI', 'International Alliance for Interoperability', $, $);
ENDSEC;
```

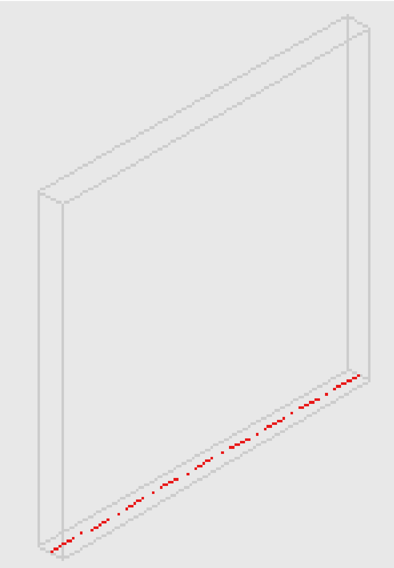

FIG 2: Representation of the example

The FIG 2 shows a potential representation of the given IFC example. The selection of the shape representation to be displayed, the color and line type, etc. is done by the receiving system depending on its system style settings. On one hand it has the advantage that the building model can be displayed by different views with a minimum of exchange information, on the other hand presentation information of the originating system is lost. The XM4 project should provide a solution to exchange the original presentation information.

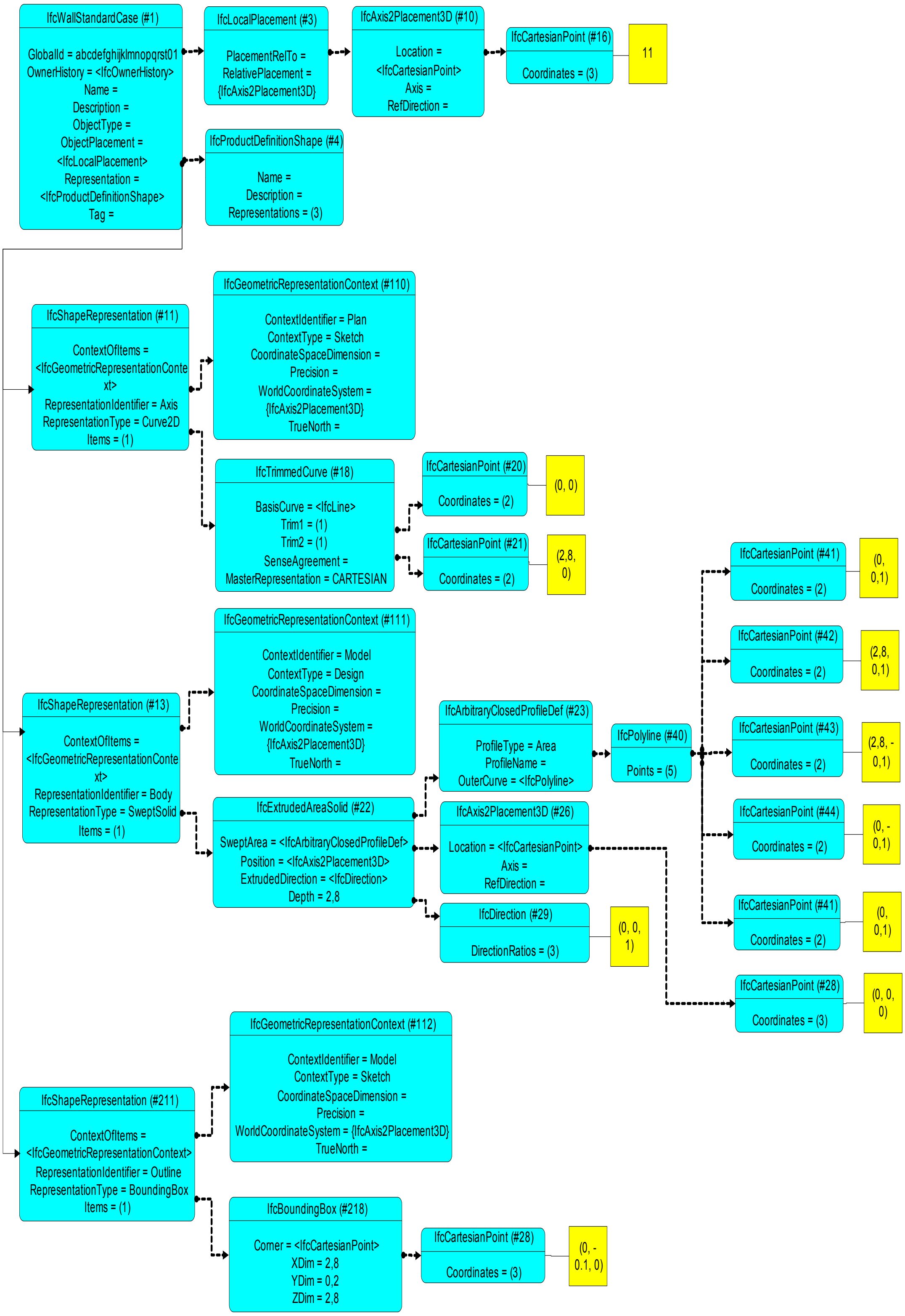

FIG 3: Instance diagram of a multiple representation of a wall

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FIG *3* shows an instance diagram of the content of the IFC file. It also highlights the fact, that all geometric representations are included within the object definition, and geometric representations are only available for building objects, but not independently in the building plan.

The goal of the XM4 project within the IAI is it to overcome these limitations by allowing 1.) to have independent geometric representations within the model-space of the building model, and 2.) to have presentation capabilities (like line colour or line types) being applied to the geometric representations. The necessary extensions to the IFC2x model have mainly been adapted from the ISO 10303 series of standards (STEP). The major sources had been ISO 10303-46 Visualisation, and ISO 10303-202 Associative Draughting.

The example also demonstrates that the inclusion of the 2D drafting capabilities from AP202 has to follow some adoptions (and an additional mapping to the original AP202). The next section describes the principle strategy to include the presentation capabilities in a backward compatible fashion in order to guarantee the platform stability of the IFC2x platform.

1.2.2 Comparison of current IFC2x and ISO 10303 drafting

Although the IFC model uses the same basic geometric and topological representation items from ISO 10303-42 as the drafting models based on ISO 10303-202 (such as STEP-CDS, SCADEC and KOSDIC) there are a few differences:

1) The definitions from ISO 10303-42 had been adopted for the use within IFC2x, mainly following the rules from the IFC architecture. In particular:

- adoption of the IFC naming convention (inner majuscules and Ifc prefix),
- adaptation of the ISO 10303-42 entities, where multiple inheritance or non-exclusive inheritance (i.e. AND or ANDOR subtype constraints) are used[1],
- selection of a subset of ISO 10303-42, using subtype and select pruning,
- dimensionality of geometric representation items defined at each item (not through the representation context),
- omission of p-curves, use of simple 2D curves for the generation of swept surfaces,
- omission of the name attribute at the representation item,
- using profile definitions instead of curve bounded surface for the swept surface of swept area solid, this includes parameterization of basic profile geometries,
- restriction of the manifold solid brep to support faceted breps only,
- additional subtype of half space solid added,
- additional constraining subtype of Boolean result added,
- additional subtypes for Cartesian transformation operator added;

2) The link between the geometric representations to the product definitions is different by following the IFC architecture, whereas in ISO 10303-46 the link between the product definitions and features is done by a link between the content of the drawing and the product data definitions (using presented item representation), all geometry representations in IFC are contained in the product definitions (using the *IfcProduct.Representation* link).

3) The presentation representation items are placed within the drawing coordinates in ISO 10303-46 and there is a hierarchical structure of presentation views, areas and sets. In contrary in IFC all presentation representations are defined within the containing product and are places within the object coordinate system established by the product (using the *IfcProduct.ObjectPlacement* link). Those object placements can be cascading placement.

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[1] These entities have not been incorporated 1:1 into IFC. They had been subjected to an additional transformation process to achieve a similar structure avoiding the multiple and non-exclusive inheritance (e.g., by introducing additional subtypes that resolve the concept of complex entity instances).

1.3 2D Representation requirement in IFC2X

The objective of the XM-4 project is to add the capabilities for 2D data exchange of representations of the virtual building model, including annotations, to the current IFC structure. Therefore in this paper, the presentation of element geometry and general annotation capabilities have been extended by enhancing the 2D geometric representation capabilities.

The XM-4 project extends the existing capabilities within the IFC geometry and representation resources. It replaces the current presentation resource (which is aligned to VRML) by a presentation resource, based on ISO 10303-46 (STEP presentation structures). The definitions from ISO 10303-46 should be used as much as possible. The proposal additionally aims at using the appropriate conformance class of ISO/STEP 10303-202 and 10303-214 as the source definitions for defining the IFC drafting extension. This should enable a basic harmonisation with ongoing national developments for 2D drafting exchange, like KOSDIC, SCADEC and CDS.

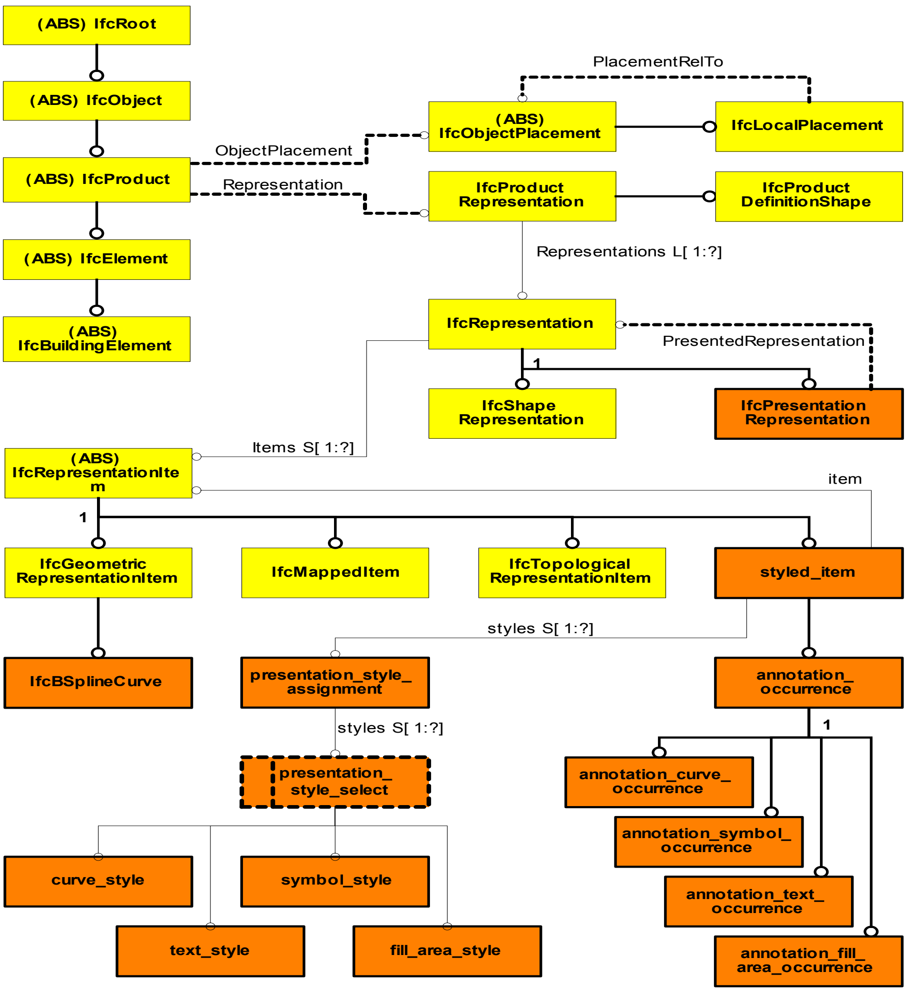

FIG 4: Inclusion of the presentation capabilities

1.3.1 Including 2D representation capabilities in IFC2X

Two major concepts from ISO 10303-46 are the keys for including the presentation capabilities, the presentation_representation and the styled_item. The first groups all presentation information for a particular shape representation (adapted for IFC usage), the second applies the presentation information (like color, line type, text format, etc.) to a geometric representation item, which is (potentially) grouped under a shape representation.

FIG 4 shows the addition of the new concepts (compare with *FIG 1*).

2. RESEARCH MOTHODOLOGY AND PROJECT SCOPE

2.1 Research Methodology

The scope of XM-4 is considerably big, therefore a phased development approach is proposed. This should allow for a better use of the resources available for model development, documentation and maintenance as well as for implementation. It should also allow for faster use of intermediate results already within the timeframe of the IFC2x platform.

There has been two development phases:

- first phase – IFC2x second edition
- second phase – next major release of IFC

There are a few differences between the IFC representation items and ISO10303-42 representation items, although, many ISO10303-42 definitions had been adopted for use within IFC2x.

From the point of visual presentation, the representation mechanism, the linking between the geometric representation to the product definition, between IFC and ISO 10303-46 is inherently different. Therefore, those two models has different representation and presentation organization structures. In ISO 10303-46, the presentation representation items are placed within the drawing coordinates with a hierarchical structure of presentation views, whereas in IFC all presentation representations are defined within the containing product and are placed within the object coordinate system established by the product. In the scope of the XM4 project phase 1, the drawing window approached is not included. The drawing window approach, as a geometric transformation of the 2D or 3D model into a paper space (or presentation area) will be included in phase 2 of the project.

In STEP the representation entities are located inside a representation context, which contains the whole representation model. In case of a drafting model, this whole representation model can be geometrically transformed into a 2D presentation area. In IFC, each representation entity is contained within the object coordinate system of the product, it represents. Each product has a transformation matrix, which is often given relatively, e.g. the window is positioned inside the opening, which is positioned inside the wall which is positioned inside the building storey which is positioned to the world coordinate system. That usage of object coordinate systems is different to STEP.

2.2 Scope of the XM-4 project

The overall scope of the XM-4 project is to add the capabilities for 2D data exchange of representations of the virtual building model, including annotations, to the current IFC structure. The following is **in scope** of the XM-4 project to support for the presentation of element geometry and general annotation capabilities within the IFC model:

- enhancements of the 2D geometric representation capabilities
- addition of curve style presentations (line types, colors, etc.)
- addition of surface style presentations (fill area, surface color)
- addition of symbolic representations (symbols, markers, etc.)
- addition of general annotations (text, text blocks, dimensions, leaders, etc.)
- addition of layer assignments, drawing sheets, etc.
- addition of specific types of b-spline (Bezier curves)
- viewing pipeline (following the basic principles of ISO 10303)

The following should be **out of scope** of the XM-4 project:

- Any geometric capabilities which are beyond current IFC geometry capabilities
- exceptions are the addition of b-spline curves (and subtypes) and potentially other forms of elementary surfaces, than planar surfaces

2.2.1 Relationship to Existing IFC Developments

The XM-4 project extends the existing capabilities within the IFC geometry and representation resources. It will replace the current presentation resource (which is aligned to VRML) by a presentation resource, based on ISO 10303-46 (STEP presentation structures).

2.2.2 Relationship to external standard developments

The definitions from ISO 10303-46 should be used as much as possible. The proposal additionally aims at using the appropriate conformance class of ISO/STEP 10303-202 and 10303-214 as the source definitions for defining the IFC drafting extension. This should enable a basic harmonisation with ongoing national developments for 2D drafting exchange, like KOSDIC, SCADEC and CDS This approach should be followed as far as possible within the existing framework of IFC architecture and modelling rules. The resulting IFC drafting model should be harmonized with ISO/STEP 10303-202, by retaining the current IFC2x architecture and object model.

2.2.3 Phased development

Due to the vast scope of the XM-4 project, a phased development has been adopted. This should allow for a better use of the resources available for model development, documentation and maintenance as well as for implementation. It should also allow for faster use of intermediate results already within the timeframe of the IFC2x platform.

2.2.4 Phase 1 development scope

The phase 1 development should be driven by the following principle to achieve the desired exchange scenario goal - after the first phase the exchange of 2D geometry and annotations should be enabled at the level of "model space", i.e. the not scaled, not projected product and geometry model of the virtual building.

Therefore the following should be **in scope** for phase 1:

- layering information
- curve styles
- text and text styles
- symbol and symbol styles
- filled (or hatched) areas and filled area styles
- surface styles[2]
- dimensioning (non-associative)
- Bezier curves (as a b-spline curve)

In contrary the following should be **out of scope** for phase 1:

- "paper space", i.e. single or multiple representation views and areas
- viewing pipeline, i.e. no mapping of model space onto views or areas
- complex presentation capabilities

The resulting additions to the IFC model, that are required to provide the requested functionality, should be

- backward compatible with IFC2x platform
- comply with the IFC2x architecture and modelling rules, including the restrictions to the use of EXPRESS as postulated within the IFC2x modelling guidelines (e.g. restricting the inheritance structure to single inheritance and mutually exclusive subtyping).
- based within the product definition and representation framework of IFC
- limited additions to the current IFC2x resources for presentation organization, definition, appearance and baseline information

3. 2D EXTENDED ITEMS TO IFC2X

The following proposed new entities and types describe the minimum scope to extend the current IFC2x to obtain the capability to exchange model space drafting. The following sequence is declared in order to adapt solutions from ISO 10303:

- the target definition should be taken from ISO 10303-46
- if not available, the target definition should be taken from ISO 10303-202
- if not available, then extension should be defined based on the closest definition from 10303-46

[2] The definition of surface styles is part of STEP part 46 but not of AP202, focusing on presentation of 2D drafting. However since IFC includes 3D representation of element shapes, using surface models, a provision of basic presentation information for 3D surfaces, at least a surface color, is urgently needed.

According to the scope of the first phase of the XM4 project the 2D drafting capabilities of IFC2x have been enhances by adding curve types (allowing for line colour and line style information), by adding text (text literals and styles in terms of colour, alignment, size and font), and by adding symbol styles and hatching (for hatches and tiles, including colour and other appearance information). In addition to the definitions from ISO 10303-46 the surface style presentations to be included in IFC2x are more elaborated, including surface lighting properties and texture maps, both currently not available in STEP. Also the lighting information to be incorporated in IFC2x expands from the basic support given in 10303-46. All these specifications had been adapted to comply with the overall IFC model architecture rules that restrict the complexity of the underlying data model in favour of its implementability.

4. RESULT AND FUTURE DEVELOPMENT

The approach adopted in the XM-4 project has been followed is within the existing framework of IFC architecture and modelling rules. The resulting IFC drafting model is harmonized with ISO/STEP 10303-202, by retaining the current IFC2x architecture and object model. Harmonization should enable the ability to exchange information with KOSDIC, SCADEC and CDS aware application, possibly by using additional toolbox or mapping capabilities. The scope for phase 2 is not dealt with in this paper. The phase 2 will deal with the level of "paper space", and includes additional items such as general annotations(leader), drawing sheet and viewing pipeline (following the basic principles of ISO 10303).

Harmonization with the STEP AP202 related standards should be seen in the context of an integration architecture, as provided by the IIDEAS project, also being a standard under ISO TC184/SC4. It describes the correspondence between standards that are comparable in content but differs in structure. The following fig. 5 shows an overview of the integration approach.

It is worth to mention about the the file sizes when all the 2D presentation information is added for the extended model. Currently various file size tests have shown, that an IFC file (for the 3D model) has approximately the same size as the native format (like DWG, DGN, etc.). However since the IFC file is an ASCII format, it can be compressed to about 20% of its size. Adding all 2D information, it will certainly increases the file sizes, however a zipped IFC file is still to be estimated to have smaller size than a native file. In addition the IFC interfaces may allow a selection to include/exclude 2D content, so that it can only be sent if needed.

The paper shows part of the result of an international project (IFC 2D extension project: XM-4) which links and relate the IFC model and appropriate presentation capabilities adopted from the relevant STEP parts. The full project report can be downloaded from the URL http://italab.khu.ac.kr/xm-4. Following such approach, the gap between model and view can be systemically sealed and IT systems for the construction industry can be beneficial from the developed data model as current advanced practice in the construction industry is the upcoming use of 3D building models, which are annotated and supplemented with 2D and drawing information, the data exchange standard should combine both, an exchange of the semantic and 3D building model, together with the 2D annotations. This has been achieved with the incorporation of XM4 into IFC2x2.

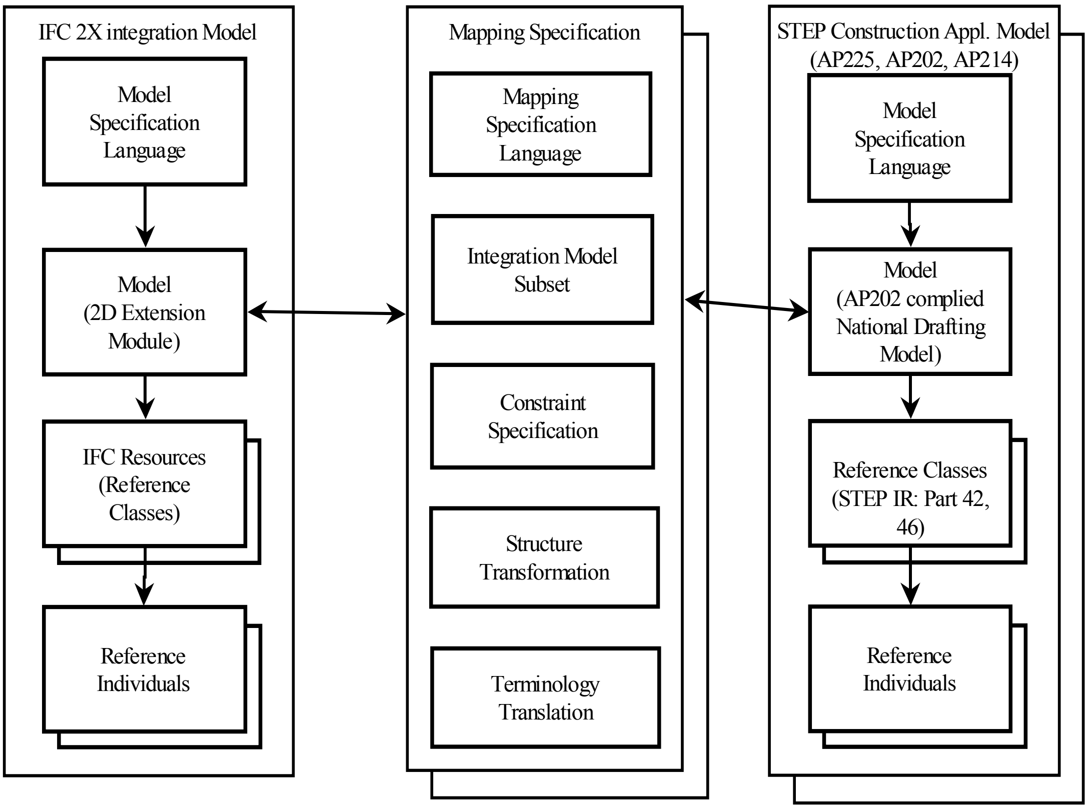

FIG 5: Integration Approach using Mapping methodology [modified from the figure in ISO/TS 18876]

5. ACKNOWLEDGEMENTS

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