IMPLEMENTATION GUIDE:

SPACE BOUNDARIES FOR ENERGY ANALYSIS

Implementation Guide: Space Boundaries for Energy Analysis

CONTENT

Implementation Guide: Space Boundaries for Energy Analysis

1 INTRODUCTION

This document provides guidance to software vendors looking to implement support import and/or export of space boundaries for energy analysis in an IFC Building Information Model (BIM). It compliments Model View Definitions (MVDs) for energy analysis and upcoming MVDs for facility management and other use cases, where space boundaries are required.

1.1 Preface

This guide was first developed in the spring/summer of 2009 to support vendors implementing support for the 'Concept Design BIM 2010.' This standardized BIM has been defined by the US Government Services Administration (GSA), Statsbygg (government buildings owner/manager in Norway), and Senate Properties (government buildings owner/manager in Finland). The 'Concept Design BIM 2010' is intended to enable these (and other) building owners to perform design analysis, beginning early in the design process, in 4 areas. These are:

- Spatial Program Validation
- Energy Performance Analysis
- Human Circulation and Security Analysis
- Quantity Takeoff to enable Cost Estimating

Model View Definitions (MVDs) were developed for end user process/work flows in each of these areas. These MVDs define the information to be exchanged between the BIM authoring (or design) application and analysis applications in each of these areas. Subsequently, these 4 MVDs were integrated into one composite MVD for the 'Concept Design BIM 2010'.

This document is intended to support software vendors in implementing support for exchange of the data/concepts required for Energy Performance Analysis. It was funded by the Public Building Service (PBS) of the GSA.

The document also draws from earlier work on describing support for IFC implementation of space boundaries, notably the work for the European integrated research project InPro - 026716-2 that co-funded an IFC implementation guide for space boundaries[1].

1.2 Target Audience

The target audience for this document includes:

- Developers of BIM authoring software looking to support MVDs from design to energy analysis
- Developers of energy analysis software looking to support MVDs from design to energy analysis
- Energy analysis consultants

Readers should be familiar with the Industry Foundation Classes (IFC) information model schema and, in particular, the STEP part 21 (physical file) format.

1.3 What are Space Boundaries?

Space boundaries are virtual objects used to calculate quantities for various forms of analysis related to spaces or rooms in buildings. Analyses that use space boundaries include:

- Quantity takeoff for Cost Estimating – In early stages of design, many objects have not yet been modeled. In this phase of a project, space boundaries (and other measurements based on the space object) are used to estimate such things as finish materials (i.e. carpeting, tile, paint) and casework.
- Facilities Management Work Package Estimating – During the operations phase of a building's life cycle, space boundaries can be used to estimate areas for facilities management work packages such as re-painting, carpet cleaning, and cleaning of other building element surfaces.
- Energy Analysis – that is, estimating the amount of energy that will be used by a building during operation. Space boundaries energy flow between a space and other spaces or the outside air.

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[1] Matthias Weise, Thomas Liebich, Implementation guide for definition of space boundaries for energy analysis, INPRO Building information model, Appendix, INPRO deliverable 19, 2009

Implementation Guide: Space Boundaries for Energy Analysis

1.3.1 Definitions

1st Level Space Boundaries

- 1st level space boundaries are the boundaries of a space defined by the surfaces of building elements bounding this space (physical space boundaries) or by virtual surfaces provided by an adjacent space with no dividing wall.
- 1st level space boundaries do not consider any change of material in the bounding building elements, or different spaces/zones behind a wall or slab (floor or ceiling).
- 1st level space boundaries are differentiated in two ways: virtual or physical and internal, external, or undefined (internal and external) e.g. for a wall that is partially inside and outside.
- 1st level space boundaries form a closed shell around the space (so long as the space is completely enclosed) and include overlapping boundaries representing openings (filled or not) in the building elements (see implementers agreement below).
- Implementers' Agreements --
    - Connection geometry for 1st level space boundaries may contain arcs (i.e. creating cylindrical surfaces), or polygons (i.e. creating extruded surfaces with orientation changes).

    Commented [RAS1]: Need small graphics for these

    - 1st level space boundaries representing building elements (wall, slabs, columns, beams) do not include inner loops to create voids (e.g. for openings). Instead, there are separate 1st level space boundaries representing such openings (with or without contained doors and windows) -- which overlap and are coplanar with the space boundaries representing the host wall, slab, column, or beam.

2nd Level Space Boundaries

- 2nd level space boundaries still represent building elements that bound the space, but are more granular in that they are subdivided in any of the following cases:
    - Differences in materials and/or material assemblies (e.g. a wainscot or paneling on the lower portion of a wall).
    - Differences in spaces or zones on the other side of the building element (or virtual boundary) represented by the space boundary (e.g. two different spaces on the other side of a wall)
- 2nd level space boundaries are differentiated in two ways: virtual or physical and internal or external, whereby any space boundary that is both internal and external has to be split into segments being either or. .
- 2nd level space boundaries represent both sides of a heat transfer surface separated by the thickness of the building element. They can be used by thermal analysis software, but require, that the two adjacent surfaces are found and be combined to form a single heat transfer surface. This is required even where the two surfaces are of different length (e.g. non-rectangular wall connections and curved walls). See also 3rd level space boundaries.

    Commented [BW2]: Not true. They only need be associated with each other, not combined into a single surface. They may remain separated by the thickenss of the building element.

    How does BSPro merge these? Is there an option to merge or not?

- 2nd level space boundaries form a closed shell around the space (so long as the space is completely enclosed).
- Implementers' Agreements --
    - The connection geometry of 2nd level space boundaries is restricted to planar surfaces only. This means that curved surfaces must be segmented.

Special types of 2nd Level Space Boundaries

- 2nd level space boundaries can be further subdivided into the following types
    - Type 2a occurs when there is a space on the opposite side of the building element providing the space boundary,
    - Type 2b occurs if there is a building element on the opposite side of the building element providing the space boundary.
        - For example: the end of a wall (wall butt) that divides two spaces on the other side of a wall.
        - They are typically ignored in heat transfer calculations for energy analysis because the transfer in these cases is negligible. Identification of such boundaries, as type 2b, enables energy analysis software to ignore them.

- Type 2c occurs at non-orthogonal intersections of building elements where the two sides of the element have different lengths (e.g. angled wall connections). The extra length on one side or the other is defined to be of that type.
  - They are typically ignored in heat transfer calculations for energy analysis because the transfer in these cases is negligible. Some energy analysis packages require defining them in order to establish corresponding space boundaries by equal length.

1.3.2   Use Cases

1st Level Space Boundaries

1st level space boundaries are used e.g. in quantity take-off and facility management as they describe the surfaces for finishes. They cannot be directly used for thermal analysis. However middleware or preprocessors to the thermal analysis software may take 1st level space boundaries and perform the necessary transformation into 2nd and 3rd level space boundaries that are required for energy analysis.

2nd Level Space Boundaries

2nd level space boundaries are used by many analysis packages that require a surface view of the building that can be transformed into the various simple topological models. Examples of such analysis packages include: (1) energy analysis, (2) lighting analysis, (3) computational fluid dynamics (CFD).

> **Commented [BW3]:** Don't need 2LSB.

Adding the differentiation of the different types of 2nd level space boundaries is a special pre-processing of space boundaries for the use by some energy analysis packages (e.g. Energy+ from Lawrence Berkeley National Laboratory (LBNL)). It allows an easier transformation of space boundaries into heat transfer surfaces by the preprocessor.

More detailed information about 1st and 2nd level space boundaries is provided in section 3.

1.3.3   IFC File Representation

The inclusion of space boundaries in the IFC data file has to be indicated in the header section. The space boundary level is also indicated as the *Name* and *Description* attribute for each space boundary instance within the data section.

1st Level Space Boundaries

```
IFC file including:
HEADER;
FILE_DESCRIPTION(('ViewDefinition [CoordinationView,
SpaceBoundary1stLevelAddOnView], …
Space boundaries within the IFC file:
DATA;
#1000= IFCRELSPACEBOUNDARY('1z8$k2wvD8jx4l1WwtstEF',#13, '1stLevel'
```

2nd Level Space Boundaries

```
IFC file including:
HEADER;
FILE_DESCRIPTION(('ViewDefinition [CoordinationView,
SpaceBoundary2ndLevelAddOnView], …
Space boundaries within the IFC file:
DATA;
#1000= IFCRELSPACEBOUNDARY('1z8$k2wvD8jx4l1WwtstEF',#13, '2ndLevel', '2a'
#1001= IFCRELSPACEBOUNDARY('1z8$k2wvD8jx4l1WwtstGH',#13, '2ndLevel', '2b'
```

> **Commented [BW4]:** 2c?

2 IMPLEMENTATION AGREEMENTS

2.1 1st Level Space Boundaries

- Connection geometry for 1st level space boundaries may contain arcs (i.e. creating cylindrical surfaces), or polygons (i.e. creating extruded surfaces with orientation changes). Connection geometry types that must be supported are:

    - *IfcCurveBoundedPlane*
    - *IfcSurfaceOfLinearExtrusion* (with *SweptCurve->IfcArbitraryOpenProfileDef,Curve* being (1) *IfcPolyline* with 2 points, or (2) *IfcTrimmedCurve* with *BaseCurve=IfcLine*.
    - *IfcFaceBasedSurfaceModel*

- 1st level space boundaries representing building elements (wall, slabs, columns, beams) do not include inner loops to create voids (e.g. for openings). Instead, there are separate 1st level space boundaries representing such openings (with or without contained doors and windows) -- which overlap and are coplanar with the space boundaries representing the host wall, slab, column, or beam.

- Space boundaries of a space shall result into a closed shell. The testing of closed shells is to be done by the importing system (middleware, preprocessor, quality checker). The IFC file will not contain topological entities (*IfcVertex, IfcEdge, IfcFace*).

2.2 2nd Level Space Boundaries

- The 2nd level space boundaries are restrictions of 1st level space boundaries in terms of applicable geometry (planar only) and topology (taking into account "what is on the other side"),

- The connection geometry of 2nd level space boundaries is restricted to planar surfaces only. Connection geometry types that must be supported are:

    - *IfcCurveBoundedPlane*
    - *IfcFaceBasedSurfaceModel*

- 2nd level space boundaries representing curved surfaces (in building elements or adjacent spaces) must be segmented. The recommended segmentation is to span 5 or 10 degrees of the curve for each segment. This modules to 18/9 segments for a 90 degree arc (the most common case).

- Space boundaries of a space shall result into a closed shell. The testing of closed shells is to be done by the importing system (middleware, preprocessor, quality checker). The IFC file will not contain topological entities (*IfcVertex, IfcEdge, IfcFace*).

Commented [RAS5]: Need small graphics for these

Commented [TL6]: according to the last telecon it may be excluded.

3 GENERATING SPACE BOUNDARIES

There are different types of space boundaries (see section 2 for definitions) but the principles for their representation in the IFC format are similar. The main difference is the rule for generating 1st, and 2nd level space boundaries based on the spatial/physical configuration of spaces and building elements. These rules must be used by applications to correctly generate connection geometry for space boundaries (e.g. generating the polygon defining a 2nd level space boundary between a space and a wall.

The process for generating connection geometry for 1st, and 2nd level space boundaries is the same. Therefore, it is defined once, in the following 'Common Definition' section. Any additions or special considerations for 1st, and 2nd level space boundaries are then provided in the 3 sections that follow.

3.1 Common Definition for Space Boundaries

Definition Process

From the IFC-viewpoint definition of space boundaries can be divided into three subsequent steps:

- Step 1 - Define the relationship between the space and the bounding element
- Step 2 - Define the connection geometry
- Step 3 - Assign the connection geometry to the relationship

3.1.1 Step 1: Define the Boundary Relationship

Define the relationship between the space and a bounding element. Note that each space boundary requires a unique *IfcRelSpaceBoundary* object.

- Create an instance of *IfcRelSpaceBoundary*
- Set the relationship to the space *IfcRelSpaceBoundary.RelatingSpace*
- Set the relationship to the element *IfcRelSpaceBoundary.RelatedBuildingElement*
- Define general attributes
    - *GloballyUniqueId* [2]
    - *OwnerHistory* [3]
- Provide the *Name* attribute for the space boundary
    - **implementation agreement ([#CV-2x3-151](#)):**
        - For 1st level space boundaries -- set the *Name* attribute to '**1stLevel**'
        - For 2nd level space boundaries -- set the *Name* attribute to '**2ndLevel**'
        - <u>Note</u>: If the exporting application is able to distinguish between 2nd level space boundary types (a), (b), and (c), the specific type will be identified through the *Description* attribute -- set to 2a', '2b', and '2c' respectively
- Determine if it is an internal or external boundary (external = adjacent to open space/outside)
    - **implementation agreement:**
        - For 1st level space boundaries -- set the *InternalOrExternalBoundary* attribute to '**INTERNAL**' or **'EXTERNAL', or** '**NOTDEFINED**'
        - For 2nd level space boundaries -- set the *InternalOrExternalBoundary* attribute to '**INTERNAL**' or **'EXTERNAL'** as appropriate.

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[2] The *GloballyUniqueId* must be provided but - according to the implementation agreements of the Coordination View - is allowed to change for objectified relationships, i.e. all subtypes of *IfcRelationship*. This is important to be aware of in case of roundtrip scenarios.

[3] The OwnerHistory must be provided but can contain dummy data. It is typically implemented by defining a single *IfcOwnerHistory* object, which defines the owner history for all objects.

- Set the *PhysicalOrVirtualBoundary* attribute, based on the type of the boundary element
    - Set the value to 'VIRTUAL', if the bounding element is:
        - An *IfcVirtualElement*
        - An *IfcOpeningElement* with empty set of *HasFillings* (i.e. an opening, that is not filled by a window or door)
    - Set the value to 'PHYSICAL' if the bounding element is any other subtype of *IfcElement*
    - A value of 'NOTDEFINED' may be used in ambiguous cases, but is generally discouraged.
- Define the connection geometry (see Step 2, 3.3.2) <u>only if</u>
    - it is not a logical boundary and
    - space boundaries can be established (e.g. in case of having a b-rep wall geometry the connection geometry might not be calculable from the CAD system)

0000

```
/* define relationship between the space and walls*/
#250=IFCRELSPACEBOUNDARY('0QApvuXVL0KARZbBZn03Jd',#5,'2ndLevel','2a',#46,#67,#252,
      .PHYSICAL.,.NOTDEFINED.);
#256=IFCRELSPACEBOUNDARY('01CG4BHaTCcA15jC$9UONL',#5,'2ndLevel','2a',#46,#84,#258,
      .PHYSICAL.,.NOTDEFINED.);
#262=IFCRELSPACEBOUNDARY('0110I5Gjb5YQW2ce$r10gM',#5,'2ndLevel','2a',#46,#118,#264,
      .PHYSICAL.,.NOTDEFINED.);
#267=IFCRELSPACEBOUNDARY('2969H0_VHEUgXd3Ewr5eeN',#5,'2ndLevel','2a',#46,#101,#269,
      .PHYSICAL.,.NOTDEFINED.);

/* define relationship between the space and the window*/
#273=IFCRELSPACEBOUNDARY('2$khnW135ANPGkd1uMazq2',#5,'2ndLevel','2a',#46,#131,#275,
      .PHYSICAL.,.NOTDEFINED.);

/* define relationship between the space and the door*/
#279=IFCRELSPACEBOUNDARY('3TTCwPaIz17QyJcEOKIdFs',#5,'2ndLevel','2a',#46,#170,#281,
      .PHYSICAL.,.NOTDEFINED.);

/* define relationship between the space and slabs*/
#284=IFCRELSPACEBOUNDARY('0TC0eN3TbBbx8$6ylAEQZf',#5,'2ndLevel','2a',#46,#209,#286,
      .PHYSICAL.,.NOTDEFINED.);
#290=IFCRELSPACEBOUNDARY('0x5L_12l9EbBgOseRvB37b',#5,'2ndLevel', '2a',#46,#222,#292,
      .PHYSICAL.,.NOTDEFINED.);
```

Example 1: Definition of boundary relationships (IfcRelSpaceBoundary)

3.1.2   Step 2: Define the connection geometry

- **The following general implementation agreement is made (#CV-2x3-155):**
- The boundary geometry should always be a surface. Please note that according to implementation agreement #CV-2x3-155 only three types of surface geometry can be used:
  (1) *IfcCurveBoundedPlane*, (2) *IfcSurfaceOfLinearExtrusion* and (3) *IfcFaceBasedSurfaceModel.*

The connection geometry as such is an optional attribute of *IfcRelSpaceBoundary* and is defined by *IfcConnection(Surface)Geometry*. If provided (see agreements of step 1, 3.3.1), the connection geometry has to be defined relative to the space, i.e. using the local coordinate system of the *IfcSpace* object. This is defined by the attribute *IfcConnectionSurfaceGeometry.SurfaceOnRelatingElement*.

More details on defining the connection geometry can be found in the sections dealing the specific types of space boundaries.

> **Commented [MW7]:** I would recommend to refer to section 2.

3.1.3   Step 3: Attach the connection geometry to the space boundary

The connection geometry as defined in step 2 has to be linked with an instance of *IfcRelSpaceBoundary*. This is done by creating an *IfcConnectionSurfaceGeometry* object (#258), which defines a link to the connection geometry via the first attribute (*IfcConnectionSurfaceGeometry.SurfaceOnRelatingElement*).

Please do not use the second attribute (*IfcConnectionSurfaceGeometry.SurfaceOnRelatedElement*) together with the connection geometry that is defined relative to the space. This would lead to a wrong placement and orientation of the connection geometry[4]. Instead, this attribute can be empty as described in step 2 and shown in SPF snippet below.

0

```
#256=IFCRELSPACEBOUNDARY('0lCG4BHaTCcA15jC$9UONL',#5,'2ndLevel','2a',#46,#84,#258,
      .PHYSICAL.,,.NOTDEFINED.);

/* define the connection surface geometry relative to the space*/
#258=IFCCONNECTIONSURFACEGEOMETRY(#259,$);

/* define the connection geometry for the boundary of wall #84 */
#259=IFCCURVEBOUNDEDPLANE(#260,#234,());
```

Example 2: Assignment of the connection geometry to space boundary relationship.

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[4] Only if the local placement of the space and the bounding element is different that is typically the case.

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Figure 1 shows the instance diagram of the example, which gives an overview of required entities and their relationship.
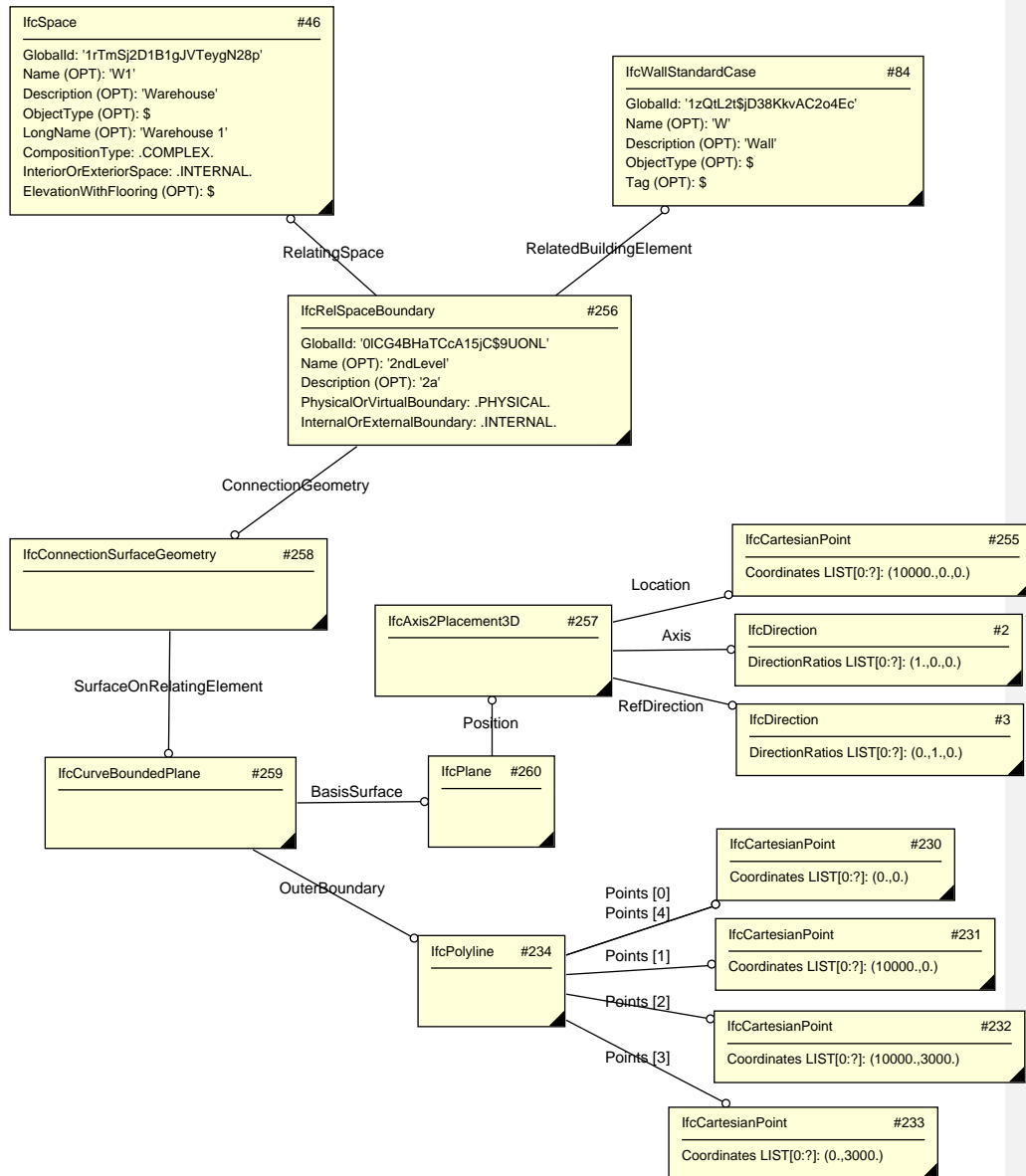

Figure 1: Principle instance diagram for space boundaries

3.2   Specific guidance on 1st Level Space Boundaries

3.2.1   Step 1: Define the Boundary Relationship

The common process, as defined in section 3.1.1, applies.

Special Considerations for 1st Level Space Boundaries:

- None

3.2.2   Step 2: Define the connection geometry

The common process, as defined in section 3.1.1, applies.

Special Considerations for 1st Level Space Boundaries:

- Openings are not subtracted from the connection geometry representing the boundary element. See figure 2 in section 3.3.2

> **Commented [MW8]:** missing

3.2.3   Step 3: Attach the connection geometry to the space boundary

The common process, as defined in section 3.1.1, applies.

Special Considerations for 1st Level Space Boundaries:

- None

3.3   Specific guidance on 2nd Level Space Boundaries

3.3.1   Step 1: Define the boundary relationship

The common process is defined in section 3.1.1.

Special Considerations for 2nd Level Space Boundaries:

- As 2nd level space boundaries depend on the space behind the boundary element there might be a need to have access to that space too. If there is a space on the other side, the sub type is set to "2a" and exported within the *Description* field, if it is a building element, then "2b" is exported.

3.3.2   Step 2: Define the connection geometry

The common process, as defined in section 3.1.1, applies.

Special Considerations for 2nd Level Space Boundaries:

- Openings are not subtracted from the connection geometry representing the boundary element. See figure 2 in section 3.3.2

> **Commented [MW9]:** missing

- If the geometry of the space boundary would be a non-planer surface (e.g. a cylindrical surface for round walls), it has to be faceted. Only planar *ConnectionGeometry* is allowed for 2nd level space boundaries.

3.3.3   Step 3: Attach the connection geometry to the space boundary

The common process, as defined in section 3.1.1, applies.
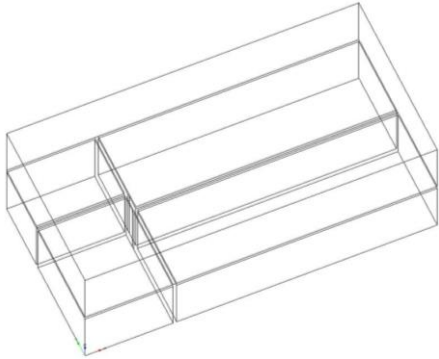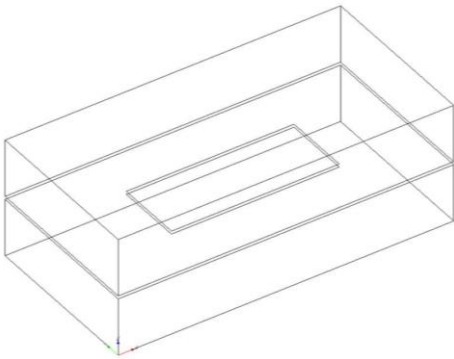
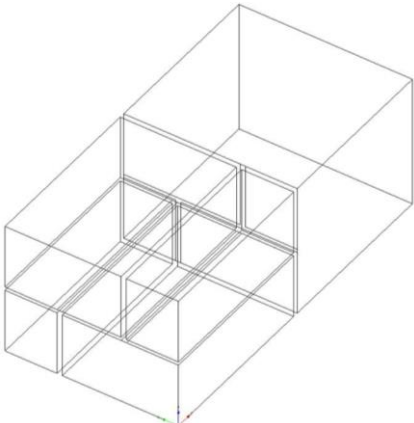Special Considerations for 2nd Level Space Boundaries:

- None
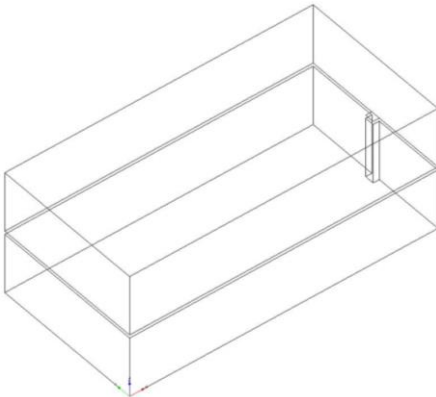
4 TEST CASES

4.1 Overview
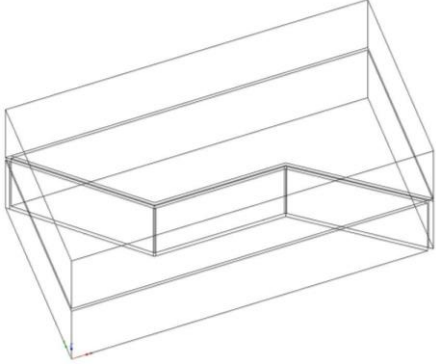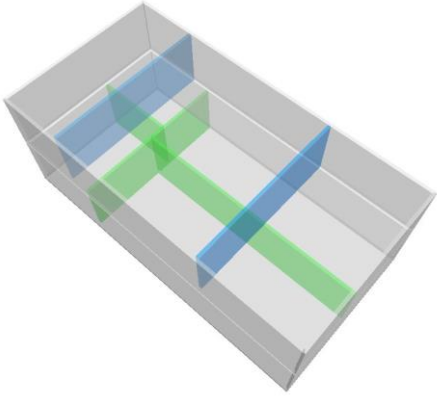
The chosen examples highlight different aspects of space boundary definitions. The following examples are discussed:

Name:	CSW-1		Source:	LBNL, Vladimir Bazjanac
2nd level space boundaries – walls below a slab				

2nd level space boundaries – walls below a slab

Name:	CSO-1		Source:	LBNL, Vladimir Bazjanac

2nd level space boundaries – void fully contained in slab
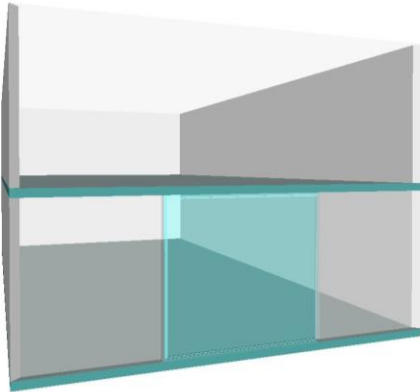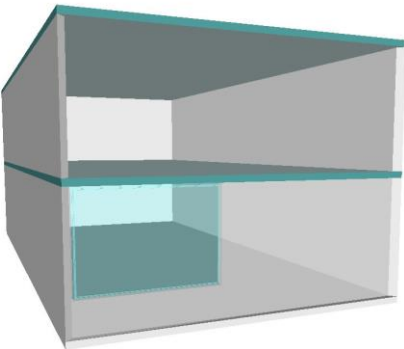
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Name:	**AWS-2**	Source:	LBNL, Vladimir Bazjanac
2nd level space boundaries – multi story space.			

2nd level space boundaries – multi story space.

Name:	**CSC-3**	Source:	LBNL, Vladimir Bazjanac
2nd level space boundaries – multi story space.			

2nd level space boundaries – multi story space.
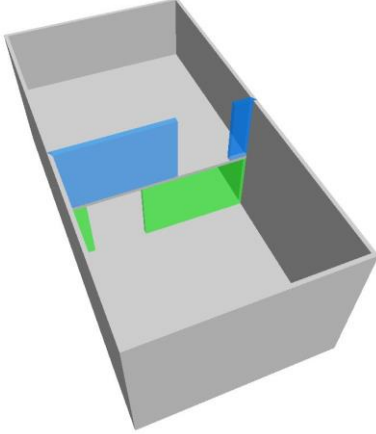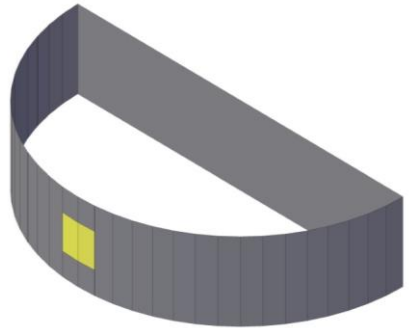
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Name:	CSW-6	Source:	LBNL, Vladimir Bazjanac
2nd level space boundaries – diagonal interior walls.			

2nd level space boundaries – diagonal interior walls.

Name:	SWW-1	Source:	LBNL, Vladimir Bazjanac Granlund, Tuomas Laine

Two storey building with several spaces, slabs and walls below and above each other.

Name:	**WI-3**		Source:	LBNL, Vladimir Bazjanac Granlund, Tuomas Laine
Two storey building with 1 space in each floor. The space in the 1st floor has a big window from floor to ceiling in the middle of wall. In this example the 1st and 2nd level space boundaries are exactly the same.				
Name:	**WI-8**		Source:	LBNL, Vladimir Bazjanac Granlund, Tuomas Laine
Two storey building with 1 space in each floor. The space in the 1st floor has a window in the corner of wall. In this example the 1st and 2nd level space boundaries are exactly the same.				

Name:	AWS-4	Source:	LBNL, Vladimir Bazjanac Granlund, Tuomas Laine
Two storey building with 2 spaces one upon the other and 1 two storey high space. Both small spaces have opening without any filling (window or door). This example shows the differences between 1st level and 2nd level space boundaries in the high space.			

Name:	CSW-4	Source:	LBNL, Vladimir Bazjanac Granlund, Tuomas Laine
Vlado will modify so that one interior wall is curved with 10 degree facets or 9 surfaces.			

Commented [RAS10]: TO BE DONE

Name:	OG-2	Source:	Granlund, Tuomas Laine
Rectangular window in a curved wall. This example shows the differences between 1st and 2nd level space boundaries in the curved wall and related rectangular window opening.			

4.2   CSW-1

Test Case Reference File: CSW-1_2x3.ifc (Source: LBNL, version: 16-Feb-09)

IFC File Generation:

    1st Level Space Boundaries: Revit 2010, Release 1 (Windows),

    2nd Level Space Boundaries: ArchiCAD 12 Release 1 (Windows), Ifc 2x3 interface: 63120 (11-Feb-09)

Use case: Walls below a slab

Issues tested with this test case:

- 2nd level space boundaries for a floor slab that has walls below
- 2nd level space boundaries for walls that have walls intersecting from the other side
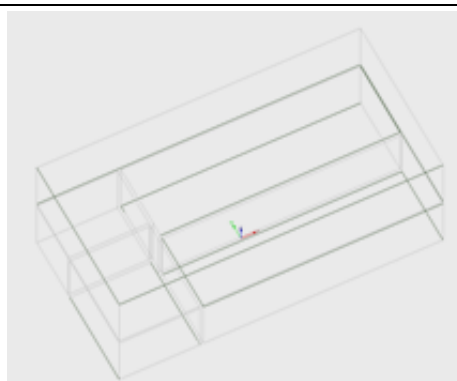
Test case model description:

- A two-story volume has four spaces on the lower and one space/zone on each story
- One interior wall on the lower story extends from one side of the volume to the other; its drawing reference line is on the west (left) edge of the wall
- The two other interior walls on the lower story butt into the one wall that extends from one side of the volume to the other

| Commented [RAS11]: to be updated |
| Commented [RAS12]: to be updated |

4.2.1   Space Boundaries Overview

Name:	**CSW-1_2x3.ifc**		Source:	LBNL, Vladimir Bazjanac

Test Case Features

The wall layout of the two storeys requires subdivision of 1st level space boundaries into 2nd level space boundaries in both the horizontal and vertical directions from the spaces. Compared to 1st level space boundaries with a total number of 30 (5 spaces * 6 space boundaries), there are 5 more 2nd level space boundaries (+3 for the floor of space 002 and +2 for the inner wall 011).

1st Level Space Boundaries (fully enclosed spaces)

Total	**30**	
Interior Surfaces	**13**	
Exterior Surfaces	**17**	
Slab on ground	4	
Ceiling of the lower story	4	
Floor of the upper story	1	
Interior walls	8	
Ceiling of the upper story – roof	1	
Exterior walls	12	
Windows	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	0	
Vertical column surfaces	0	
Number of spaces (thermal zones)	5	

2nd Level Space Boundaries (fully enclosed spaces)	
Total	35
Interior Surfaces	18
Exterior Surfaces	17
Slab on ground	4
Ceiling of the lower story	4
Floor of the upper story	4
Interior walls	10
Ceiling of the upper story – roof	1
Exterior walls	12
Windows	0
Horizontal "air-walls" (virtual slabs)	0
Vertical "air-walls" (virtual walls)	0
Vertical column surfaces	0
Number of spaces (thermal zones)	5
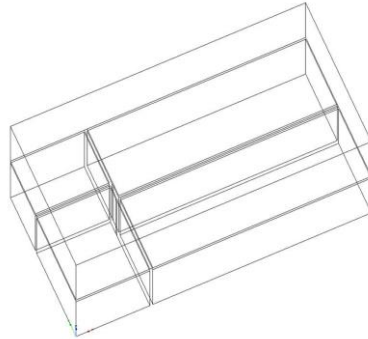
<div style="text-align:right">Commented [MW13]: without type „2b" space boundaries</div>

4.2.2   1st Level Space Boundaries

First level space boundaries depend only on the building elements and virtual boundaries immediately adjacent to the space. In this case, we have (4) spaces on the first floor and (1) space on the second floor, all bounded by walls and slabs with no openings.

First Floor: Each of (4) spaces has (4) 1st level space boundaries corresponding to the walls and (2) 1st level space boundaries corresponding to the floor and ceiling (4 x (4+2) = 24 - 1st level space boundaries; 12 exterior and 12 interior).

Second Floor: (1) space has (4) 1st level space boundaries corresponding to the walls and (2) 1st level space boundaries corresponding to the floor and ceiling (1 x (4+2) = 6 - 1st level space boundaries; 5 exterior and 1 interior).

4.2.3   2nd Level Space Boundaries

Second level space boundaries depend on spaces behind the boundary. Accordingly, second level space boundaries are often a subdivision of first level space boundaries. The difference is explained in a small two-storey example.

Figure 2 shows the floor plan of the first storey. All red lines are second level space boundaries between spaces and walls. It can be seen that space 005 is bounded by four walls but defined by five second level space boundaries. Differently to first level space boundaries where only one space boundary is defined for space 005 and the inner wall #011 there are two parts according to the spaces (003 and 004) that are situated behind the wall.
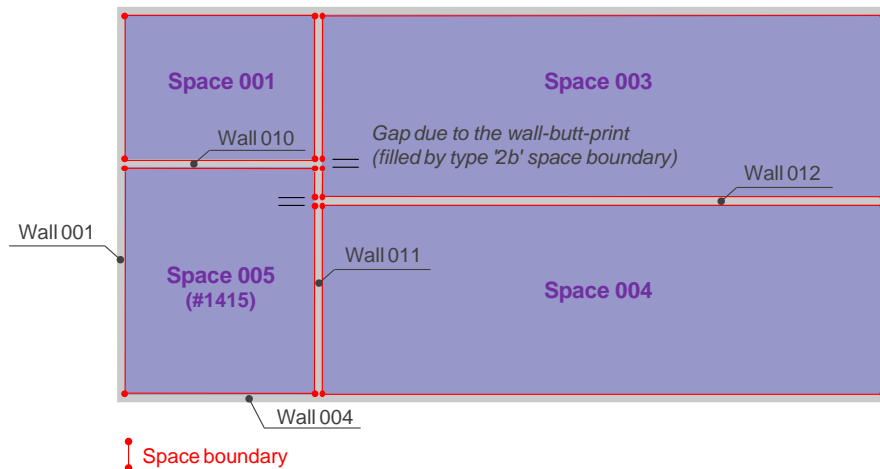
Figure 2: Plan view of the first floor

Figure 3 visualizes the space boundaries of space 005 in a 3D view. Please note that there are two more space boundaries (one to the floor and one to the ceiling) so that there are seven second level space boundaries for space 005.

Similar to space 005 there are seven 2nd level space boundaries for space 003, but only six for the spaces 001 and 004. Accordingly, spaces of the first storey define 26 second level space boundaries, two more than needed to define first level space boundaries.
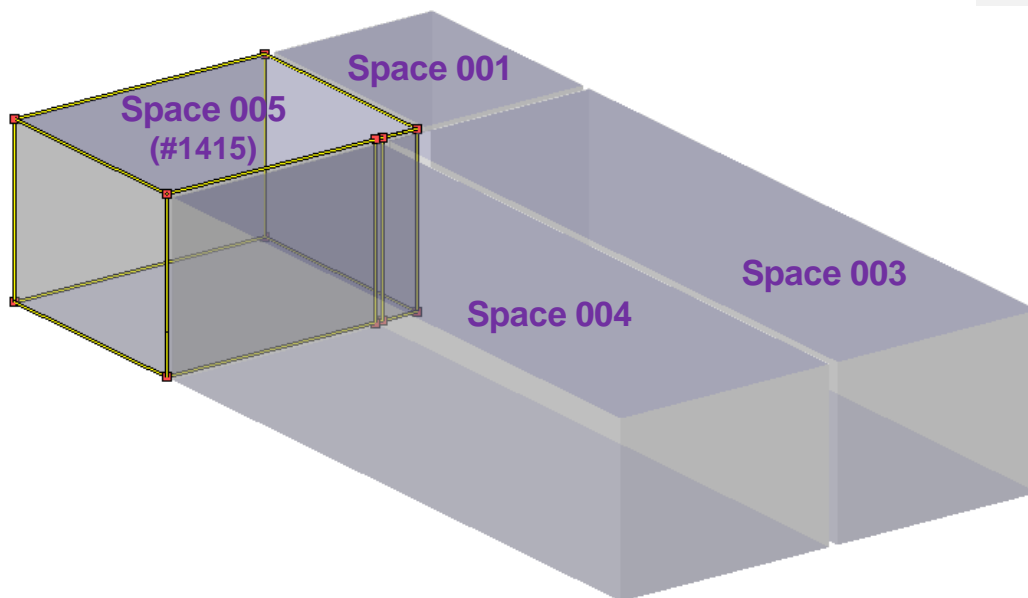

Figure 3: 3D view of second level space boundaries of space 005

The second storey contains only one space (002) that spans over all four spaces of the first storey (see Figure 4). The space is bounded by four exterior walls, one floor and one roof. Accordingly, there are six first level space boundaries, each for each bounding element. Whereas first and second level space boundaries are of the same shape for the walls and the roof the first level space boundary to the floor has to be subdivided into four second level space boundaries because of the four spaces.

0000

```
#1415= IFCSPACE('3_OGvSloT8ehRmCj8UY_0f',#13,'005',$,$,#1412,#1397,'Office',.ELEMENT.,
        .INTERNAL.,$);

/* space boundaries to external walls */
#3041= IFCRELSPACEBOUNDARY('34BraheBr8aR8_vZQrI$Jt',#13,'2ndLevel','2a',#1415,#128,
        #3040,.PHYSICAL.,.EXTERNAL.);
#3121= IFCRELSPACEBOUNDARY('1pixUyzj59kBnRrW0z7xU4',#13,'2ndLevel','2a',#1415,#489,
        #3120,.PHYSICAL.,.EXTERNAL.);

/* space boundaries to internal walls */
#3209= IFCRELSPACEBOUNDARY('3ybvQe4nH2K94m7N0SdHzQ',#13,'2ndLevel','2a',#1415,#763,
        #3208,.PHYSICAL.,.INTERNAL.);

/* space boundaries to wall 011 (#890) */
#3261= IFCRELSPACEBOUNDARY('27wLgUSL90u8Thp2HtxjXC',#13,'2ndLevel','2a',#1415,#890,
        #3260,.PHYSICAL.,.INTERNAL.);
#3305= IFCRELSPACEBOUNDARY('0$lenW$CXAR8xKmmRjJL0M',#13,'2ndLevel','2a',#1415,#890,
        #3304,.PHYSICAL.,.INTERNAL.);

/* space boundaries to slabs (floor = external, ceiling = internal) */
#3081= IFCRELSPACEBOUNDARY('3G30vBCZP8d8Weceub8Rkm',#13,'2ndLevel','2a',#1415,#1086,
        #3080,.PHYSICAL.,.EXTERNAL.);
#3161= IFCRELSPACEBOUNDARY('24x5ki4s9B4AoAPAMDvf0t',#13,'2ndLevel','2a',#1415,#1948,
        #3160,.PHYSICAL.,.INTERNAL.);
```

Example 3: All eight type "2a" space boundaries of space 005 (#1415)
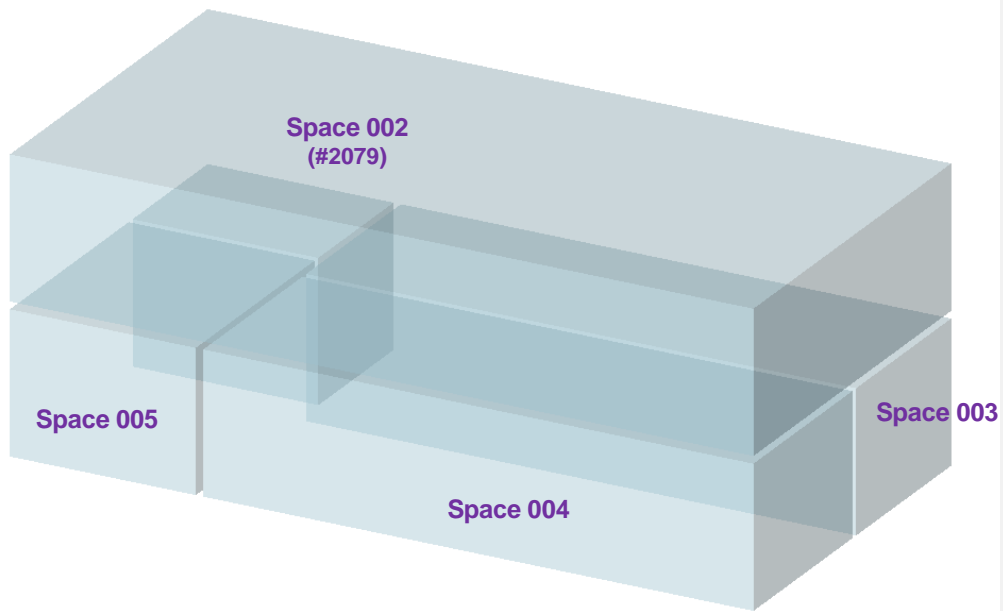
Figure 4: Space 002 of the second floor and adjacent spaces of the first floor.

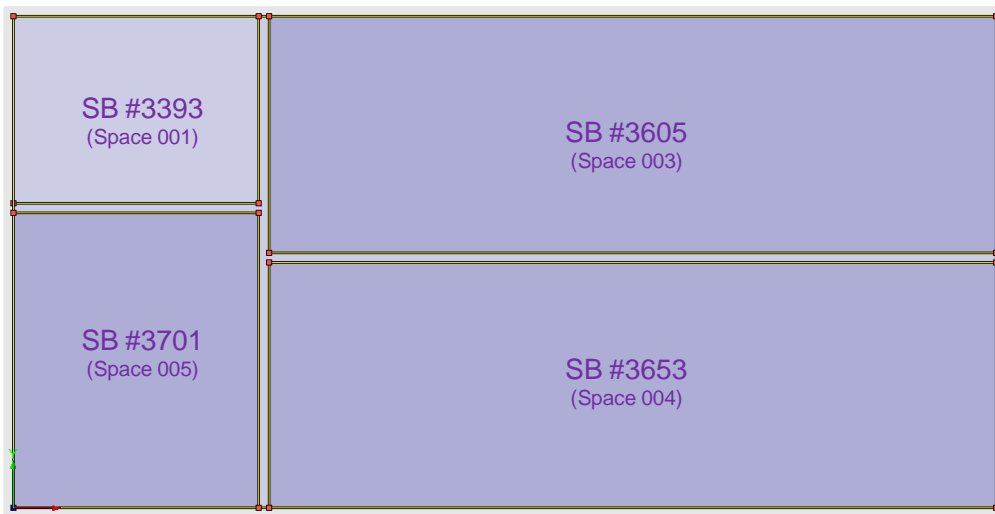Figure 5 shows the four type "2a" space boundaries to the floor SLA-006 (#1948).

Figure 5: Space boundaries to the floor SLA-006

```
/* Space 002 */
#2079= IFCSPACE('0hSs6zP5jDRvVdEa2fOdli',#13,'002',$,$,#2076,#2061,'Office',.ELEMENT.,
       .INTERNAL.,$);

/* Space boundaries to external walls */
#3345= IFCRELSPACEBOUNDARY('021XH_g$H4QP4swUACla$b',#13,'2ndLevel','2a',#2079,#1554,
       #3344,.PHYSICAL.,.EXTERNAL.);
#1554= IFCWALLSTANDARDCASE('3gd2UT04H77g0cqyoRloU8',#13,'SW - 006',$,$,#1551,#1624,
       'AA3C9D22-2BF3-4145-91-B5-AA3855CE68B1');
#3433= IFCRELSPACEBOUNDARY('04eab2$InDxelvGDaoevFW',#13,'2ndLevel','2a',#2079,#1459,
       #3432,.PHYSICAL.,.EXTERNAL.);
#1459= IFCWALLSTANDARDCASE('0BtSh7TKzB59s4LtWyid$a',#13,'SW - 005',$,$,#1456,#1529,
       '5C10A272-6537-4749-98-8C-F33744DF22F3');
#3521= IFCRELSPACEBOUNDARY('2oAq4dFzD1oh10qXqAwGm7',#13,'2ndLevel','2a',#2079,#1681,
       #3520,.PHYSICAL.,.EXTERNAL.);
#1681= IFCWALLSTANDARDCASE('3TeS2u$9r2SQWRHgYZAwse',#13,'SW - 007',$,$,#1678,#1751,
       'CAE8605A-DF31-4ED4-96-F3-84AF564A54DA');
#3565= IFCRELSPACEBOUNDARY('0UwxzzZsD5CxTMLxu4uADW',#13,'2ndLevel','2a',#2079,#1808,
       #3564,.PHYSICAL.,.EXTERNAL.);
#1808= IFCWALLSTANDARDCASE('3tSPxLkib3_P6RhatfFstA',#13,'SW - 008',$,$,#1805,#1878,
       '937693F1-7770-4B9B-88-20-586974C1522A');

/* Space boundaries to the roof */
#3473= IFCRELSPACEBOUNDARY('1z3W1GYDfFsuaJrAMii98c',#13,'2ndLevel','2a',#2079,#2116,
       #3472,.PHYSICAL.,.EXTERNAL.);
#2116= IFCSLAB('0PPKN$AOvAvw6BVKWh8glx',#13,'SLA - 007',$,$,#2179,#2168,
       'B656F4A2-1F03-407E-B3-A9-28B5E075914B',.FLOOR.);

/* Space boundaries to the floor */
#1948= IFCSLAB('0jZqj6QkL58xkTYwg98Ybe',#13,'SLA - 006',$,$,#2011,#2000,
       '9720E548-A1AA-4030-BD-14-444CDDA0CB8E',.FLOOR.);
#3393= IFCRELSPACEBOUNDARY('2yYAEktgL99hC6SaogWl4v',#13,'2ndLevel','2a',#2079,#1948,
       #3392,.PHYSICAL.,.INTERNAL.);
#3605= IFCRELSPACEBOUNDARY('1afdCV$uTAYuZa9wDEG1Jv',#13,'2ndLevel','2a',#2079,#1948,
       #3604,.PHYSICAL.,.INTERNAL.);
#3653= IFCRELSPACEBOUNDARY('3OOfwKQlX7TOmBjHIeOFzt',#13,'2ndLevel','2a',#2079,#1948,
       #3652,.PHYSICAL.,.INTERNAL.);
#3701= IFCRELSPACEBOUNDARY('1VXUZzIo57Jgrkv1$umrMt',#13,'2ndLevel','2a',#2079,#1948,
       #3700,.PHYSICAL.,.INTERNAL.);
```

Example 4: Space boundaries of space 002

Example 4 shows the SPF definition of the 2nd level space boundaries of space 002. Please also note that there is no link to the space below the floor, i.e. the element that is responsible for division of first level space boundaries. Thus, matching elements have to be selected on the basis of the connection geometry if needed.

Definition of connection geometry is straight forward as shown chapter 3.3.2, i.e. using *IfcCurveBoundedPlane* and *IfcPolyline.*

The gaps for the wall butts and the wall footprints on the slab (i.e. where a building element is on the other side) are closed by 2nd level space bounadries of type "2b". Compared to Figure 5 showing four 2nd level space boundaries of type "2a" between space 002 and floor SLA-006, Figure 7 shows the four added 2nd level space boundaries of type "2b". Example 5 is showing the name and description attribute of *IfcRelSpaceBoundary* instances that enable to differentiate between type "2a" and "2b" of the 2nd level space boundaries.

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Figure 6: File statistics for CSW-1.ifc with 3rd level space boundaries.
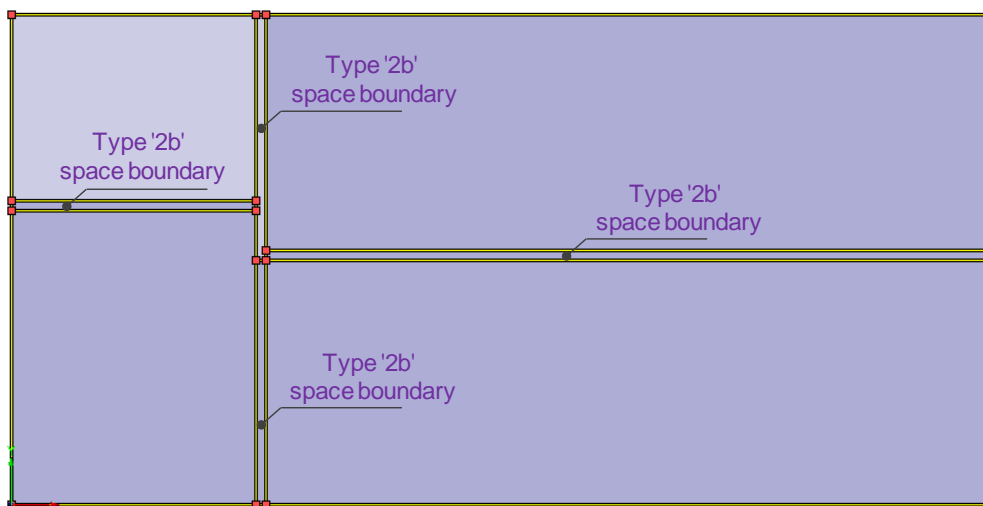
Figure 7: Same view as shown in Figure 5 but now showing added type "2b" space boundaries.

```
/* Type '2b' space boundary */
#2797= IFCRELSPACEBOUNDARY('1lVwzri_H73OPnEHzRaj1Q',#13,'2ndLevel','2b',#1287,#890,
      #2796,.PHYSICAL.,.INTERNAL.);
#2796= IFCCONNECTIONSURFACEGEOMETRY(#2792,$);
#2792= IFCCURVEBOUNDEDPLANE(#2757,#2788,());
```

Example 5: Definition of type "2b" space boundaries using the name and description attribute
of IfcRelSpaceBoundary

4.3 CSO-1

Test Case Reference File: CSO-1_2x3.ifc (author: LBNL, version: 16-Feb-09)

IFC File Generation:

    1st Level Space Boundaries: Revit 2010, Release 1 (Windows),

    2nd Level Space Boundaries: ArchiCAD 12 Release 1 (Windows), Ifc 2x3 interface: 63120 (11-Feb-09)

Use case: 2nd level space boundaries – void fully contained in slab

Issues tested with this test case:

- 2nd level space boundaries of the slab that contains a void
- 2nd level space boundaries of the void in the slab

Test case model description:

- A two-story volume has one space/zone on each story
- Rectangular void in the center of slab that separates the two stories
- Void fully contained within the slab (void does not "touch" any walls)
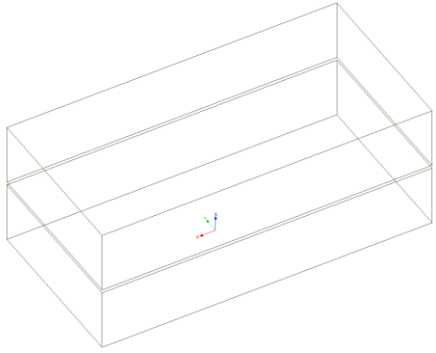
IFC implementation details:

Two issues are addressed by this example:

- use of virtual elements for definition of virtual space boundaries
- geometry definition of openings that are fully contained in a boundary element

4.3.1 Space Boundaries Overview

Name:	**CSO-1_2x3.ifc**		Source:	LBNL, Vladimir Bazjanac
Test Case Features				
A two-story building has one space/zone on each story. A rectangular void in the center of the slab separating the two stories. The void is fully contained in the slab and does not touch any walls.				
1st Level Space Boundaries (fully enclosed spaces)				

Total		
Interior Surfaces	**2**	
Exterior Surfaces	**10**	
Slab on ground	1	
Ceiling of the lower story	1	
Floor of the upper story	1	
Interior walls	0	
Ceiling of the upper story – roof	1	
Exterior walls	8	
Windows	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	0	
Vertical column surfaces	0	
Number of spaces (thermal zones)	**2**	

Comments in right margin:

Commented [RAS14]: to be updated

Commented [RAS15]: to be updated

Commented [RAS16]: where are the virtual SBs for the opening? This appears to be a bug in Revit!

2nd Level Space Boundaries (fully enclosed spaces)		
Total	14	
Interior Surfaces	4	
Exterior Surfaces	10	
Slab on ground	1	
Ceiling of the lower story	2	
Floor of the upper story	2	
Interior walls	0	
Ceiling of the upper story – roof	1	
Exterior walls	8	
Windows	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	0	
Vertical column surfaces	0	
Number of spaces (thermal zones)	2	

4.3.2   1st Level Space Boundaries

First level space boundaries depend only on the building elements and virtual boundaries immediately adjacent to the space. In this case, we have (1) space on each building story, each bounded by (4) walls and (2) slabs. The slab separating the (2) spaces has an opening with a virtual boundary facing each space (one up, one down).

First Floor: (1) space has (4) 1st level space boundaries representing the surrounding walls, (2) 1st level space boundaries representing the floor and ceiling, and (1) virtual boundary representing the opening in the ceiling (1 x (4+2+1) = 7 1st level space boundaries; 5 exterior and 2 interior).

Second Floor: (1) space has (4) 1st level space boundaries representing the surrounding walls, (2) 1st level space boundaries representing the floor and ceiling, and (1) virtual boundary representing the opening floor (1 x (4+2+1) = 7 1st level space boundaries; 5 exterior and 2 interior).

4.3.3   2nd Level Space Boundaries

The two storey building contains the two spaces 001 (#762) and 002 (#1492), which are separated by the slab SLA-006 (#1299) and a virtual element (#1711) that acts as boundary for the opening of the slab. In fact, the virtual element is not integrated in the building structure and is only a dummy object due to a *Where Rule*[5] of IFC. The definition of virtual space boundaries between the spaces and the "opening" of the slab (represented by the virtual element) is shown in Example 6. The virtual element defines a local placement but no geometry. Even the local placement is not needed because the connection geometry (*IfcConnectionSurfaceGeometry*, #1700) is given relative to the local placement of the space (*IfcConnectionSurfaceGeometry.SurfaceOnRelatingElement*, #1696) and not the virtual element (*IfcConnectionSurfaceGeometry.SurfaceOnRelatedElement*, $).

---

[5] The rule does require virtual elements. In fact it only does not allow to use opening elements for definition of space boundaries. *"…If the space boundary is virtual, it shall either have a virtual element providing the space boundary, or none.".* This rule is changed by implementation agreements for space boundaries and will be removed in IFC2x4.

Space 002

Space 001

Opening #1408
Virtual element #1711

Slab SLA 006
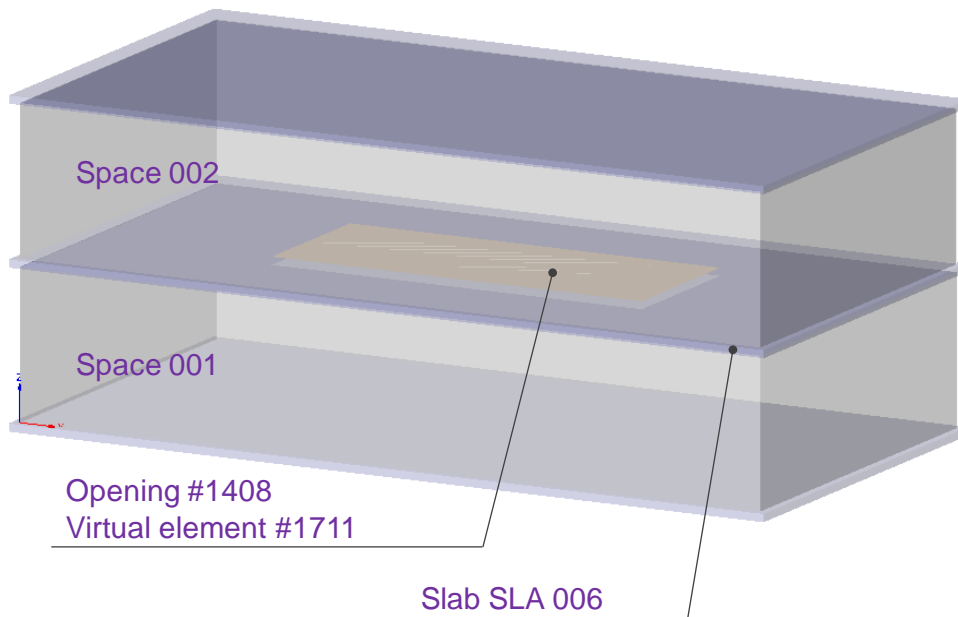
Figure 8: Main elements of example CSO-1 (two spaces, slab with opening and virtual element)

```
/* virtual element */
#1711= IFCVIRTUALELEMENT('1509f0GaHAsfy7UBa91g6x',#13,$,$,$,#1708,$,$);
#1708= IFCLOCALPLACEMENT($,#1705);

/* space 001 */
#762=  IFCSPACE('3abTS$8lTFMxYsLMD5QHXI',#13,'001',$,$,#759,#744,'Office',.ELEMENT.,
       .INTERNAL.,$);
#1730= IFCRELSPACEBOUNDARY('2gOpAsSZf0Zv7F6pkKDuGM',#13,'2ndLevel','2a',#762,#1711,
       #1653,.VIRTUAL.,.INTERNAL.);

/* space 002 */
#1492= IFCSPACE('0hSs6zP5jDRvVdEa2fOdli',#13,'002',$,$,#1489,#1474,'Office',.ELEMENT.,
       .INTERNAL.,$);
#1731= IFCRELSPACEBOUNDARY('3_e3bbKL5FIBI4e_4_4LTs',#13,'2ndLevel','2a',#1492,#1711,
       #1700,.VIRTUAL.,.INTERNAL.);
#1700= IFCCONNECTIONSURFACEGEOMETRY(#1696,$);
#1696= IFCCURVEBOUNDEDPLANE(#1661,#1692,());
#1661= IFCPLANE(#1658);
#1692= IFCCOMPOSITECURVE((#1688),.U.);
#1688= IFCCOMPOSITECURVESEGMENT(.CONTINUOUS.,.F.,#1684);
#1684= IFCPOLYLINE((#1664,#1668,#1672,#1676,#1680));
#1664= IFCCARTESIANPOINT((6999.9999,4799.9999,0.));
#1668= IFCCARTESIANPOINT((6999.9999,14800.,0.));
#1672= IFCCARTESIANPOINT((2999.9999,14800.,0.));
#1676= IFCCARTESIANPOINT((2999.9999,4799.9999,0.));
#1680= IFCCARTESIANPOINT((6999.9999,4799.9999,0.));
```

Example 6: Virtual element and virtual space boundaries

The example also shows that it cannot be expected that space boundaries are positioned within the same plane. This is shown in Figure 9 where a small gap (thickness of the slab) exists between the space boundary of the slab and the virtual element. Thus, similar to example CSW-1, the space is not necessarily fully closed by space boundaries.
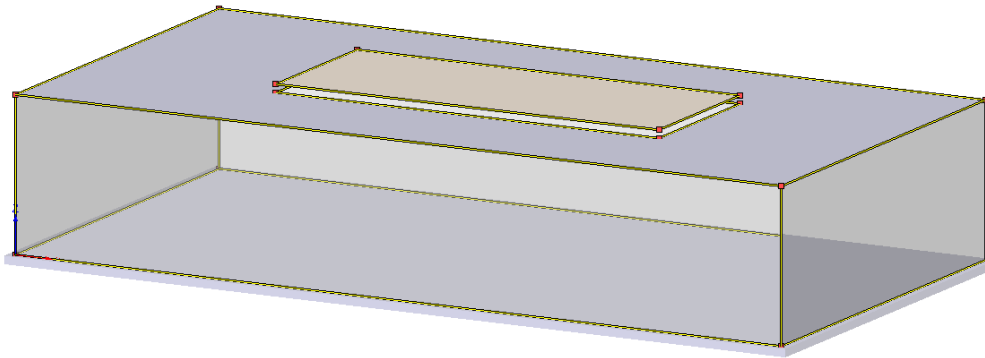
Commented [MW17]: I am not sure if this is on purpose or if it needs to be corrected.

Commented [RAS18]: This looks like a problem that should be fixed. Two alternatives are:
(1) add space boundaries around the 4 sides of the opening in the slab
(2) push space boundary down to be coplanar with the ceiling space boundaries. Of course this creates the same problem for the space above ;-)

THIS IS THE PROBLEM VLADO RAISED IN MAY --- WHICH I RAISED BACK IN FEBRUARY!!

Figure 9: Shift of space boundaries for space 001

Another interesting topic related to geometry definition is the question about reuse of instances in order to reduce the file size but also to identify dependencies (equality). In our example it would be possible for instance to share the connection geometry of the opening and the virtual element (for space 002). However, this possibility is very

rarely used in the example files so that comparison of connection geometry must check the values and cannot stop on instance level. This can be seen in Example 7 there the same connection geometry is defined by different instances. Contrary to this solution reuse of instances could use the *IfcCompositeCurve* #1692 by both *IfcCurveBoundedPlane* #1696 and #2138 instead of defining a new *IfcCompositeCurve* #2134 (and the seven depending instances).

**Commented [MW19]:** Not sure if we want to discuss this issue in the implementation guide.

Example 7: There is no noteworthy reuse of connection geometry

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Adding type "2b" space boundaries will close the gaps between the virtual space boundary and the slab as shown in Figure 9. As these gaps exist only for space 001 and not for space 002 there are only four type "2b" space boundaries for the "slab butt prints" between the slab SLA 006 and space 001 (see Figure 10).
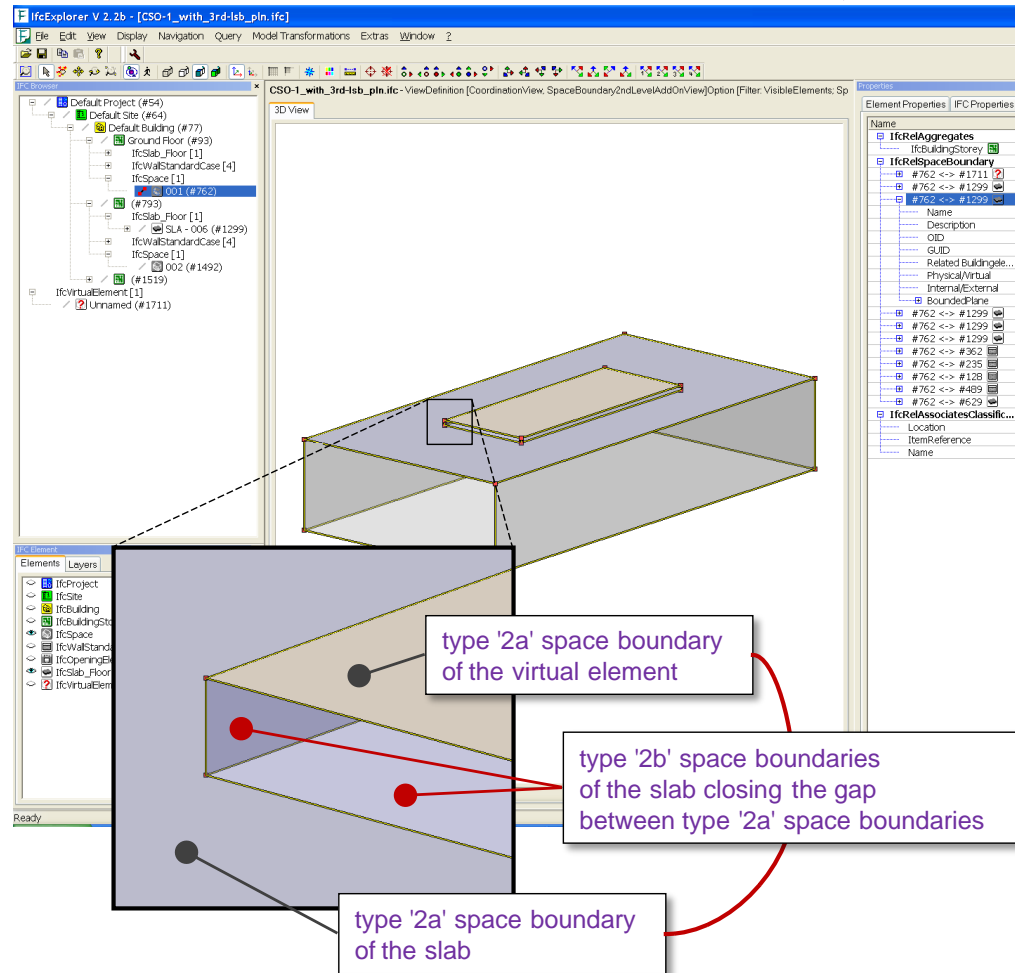
Commented [MW20]: Why not using to virtual space boundaries in order to avoid the gaps?

Figure 10: type "2b" space boundaries of CSO-1 closing existing gaps between the type "2a" space boundaries – the sum of 2nd level space boundaries provides a closed shell

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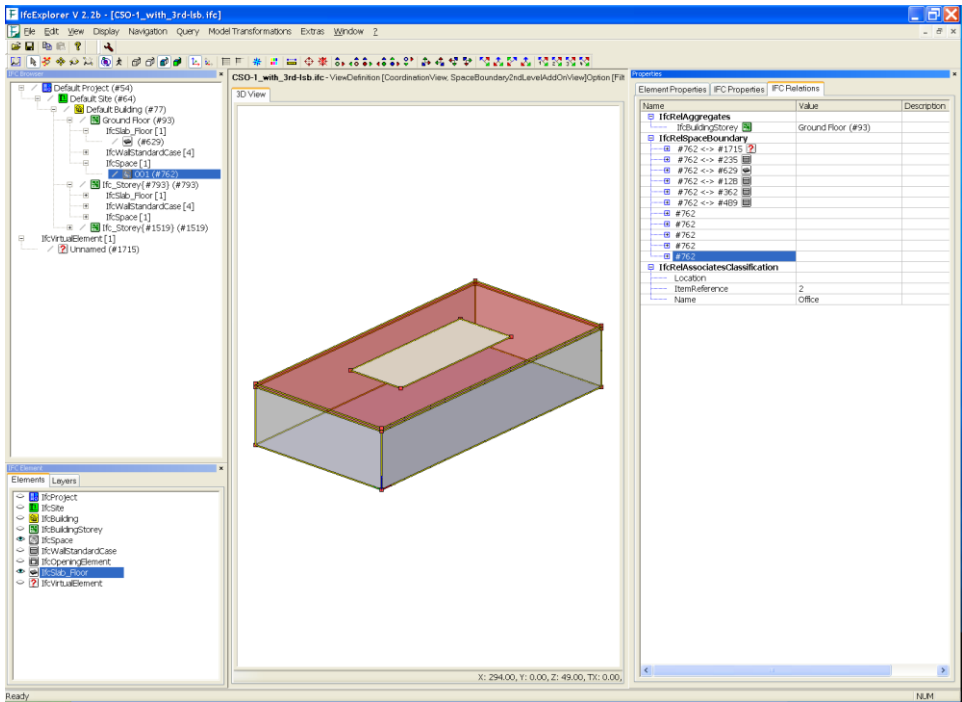
Figure 11: Different results when using IFC and PLN as import file

Commented [MW21]: Example was created by importing IFC with 2nd level space boundaries and then exporting with 3rd level space boundaries!

In this example the shift of the virtual space boundaries has been eliminated by adding some strange 2nd level space boundaries.

There are no 3rd level space boundaries but 5 2nd level space boundaries for the slab (without relationship to the slab object)! -> Bug?

IS THIS REOLVED IN NEW VERSION?

4.4   AWS-2

Test Case Reference File: AWS-2_2x3.ifc (Source: LBNL, version: 16-Feb-09)

IFC File Generation:

   1st Level Space Boundaries: Revit 2010, Release 1 (Windows),

   2nd Level Space Boundaries: ArchiCAD 12 Release 1 (Windows), Ifc 2x3 interface: 63120 (11-Feb-09)

Use case: 2nd level space boundaries – multi story space

Issues tested with this test case:

- 2nd level space boundaries of walls in a multi story space/zone that have intersecting walls and/or slabs on the other side
- 2nd level space boundaries of walls that have a multi story space/zone on the other side

Test case model description:

- A two-story volume has one two-story space/zone and two one-story spaces/zone on the lower story, and two one-story spaces/zones on the upper story
- The two one-story spaces/zones of the lower story are not vertically aligned with the two one-story spaces/zones of the upper story
- One two-story wall in the two-story space/zone has two stories and multiple (four) spaces/zones on the other side

4.4.1   Space Boundaries Overview

Name:	**AWS-2_2x3.ifc**		Source:	LBNL, Vladimir Bazjanac
Test Case Features				
A two story building containing one two-story space/zone and four one-story spaces/zones; two on the first story and two on the second story.				

1st Level Space Boundaries (fully enclosed spaces)		
Total	**26**	
Interior Surfaces	**9**	
Exterior Surfaces	**17**	
Slab on ground	3	
Ceiling of the lower story	2	
Floor of the upper story	2	
Interior walls	5	
Ceiling of the upper story – roof	3	
Exterior walls	11	
Windows	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	0	
Vertical column surfaces	0	
Number of spaces (thermal zones)	5	

<!-- Commented [RAS22]: to be updated -->
<!-- Commented [RAS23]: to be updated -->

2nd Level Space Boundaries (fully enclosed spaces)	
Total	**35**
Interior Surfaces	**18**
Exterior Surfaces	**17**
Slab on ground	3
Ceiling of the lower story	3
Floor of the upper story	3
Interior walls	12
Ceiling of the upper story – roof	3
Exterior walls	11
Windows	0
Horizontal "air-walls" (virtual slabs)	0
Vertical "air-walls" (virtual walls)	0
Vertical column surfaces	0
Number of spaces (thermal zones)	5
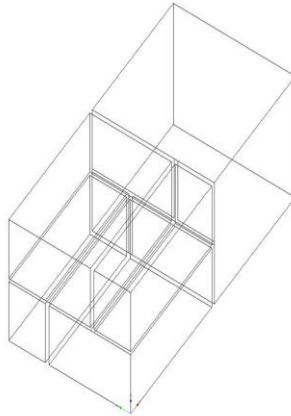
Commented [MW24]: only „2a"

4.4.2   1st Level Space Boundaries

First level space boundaries depend only on the building elements and virtual boundaries immediately adjacent to the space. In this case, we have (3) spaces on the first floor (one of which is two stories high) and (2) space on the second floor, all bounded by walls and slabs with no openings.

First Floor - 2-Story space: (1) space bounded by (4) 1st level space boundaries representing 2-story walls and (2) 1st level space boundaries representing the floor and ceiling (1 x (4+2)=6 - 1st level space boundaries; 5 exterior and 1 interior).

First Floor - 1-Story spaces: (2) spaces bounded by (4) 1st level space boundaries representing walls and (2) 1st level space boundaries representing the floor and ceiling (2 x (4+2)=12 - 1st level space boundaries; 6 exterior and 6 interior).

Second Floor: (2) space bounded by (4) 1st level space boundaries corresponding to the walls and (2) 1st level space boundaries corresponding to the floor and ceiling (2 x (4+2)=12 - 1st level space boundaries; 6 exterior and 6 interior).

4.4.3   2nd Level Space Boundaries

IFC implementation details:

There are a lot of similarities between AWS-2 and CSW-1. If turned about 90 degrees around the Y-axis so that space 001 is on top (Figure 12) it looks like CSW-1 except that there are two walls (SW-009: #976 and #2334) and one slab (SLA-006: #2553) instead of only one slab being a boundary element "below" the space (Figure 13). As there are two spaces behind the walls #976 and #2334 there are four 2nd level space boundaries, two for each wall (see Figure 14). Further differences are not relevant for 2nd level space boundaries but can be seen if comparing both examples with their 1st level space boundaries. Whereas the four 2nd level space boundaries of example CSW-1 will be unified to one 1st level space boundary (one slab), example AWS-2 will contain three 1st level space boundaries due to having three boundary elements (two walls and one slab).

Further details are shown in the figures below.
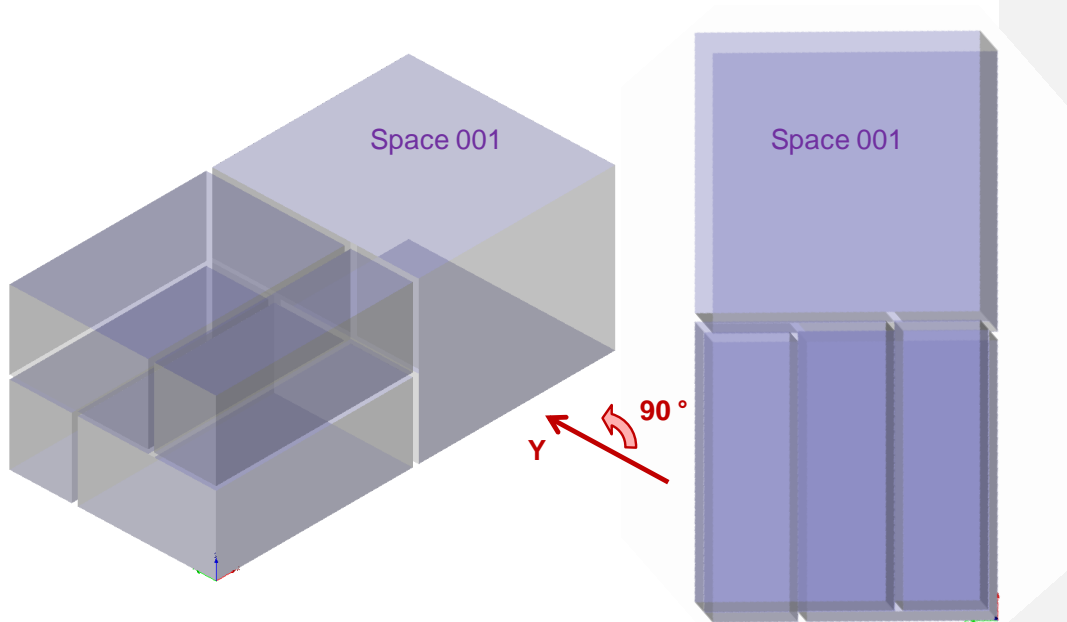
Figure 12: Turning AWS-2 makes the similarity to CSW-1 more obvious
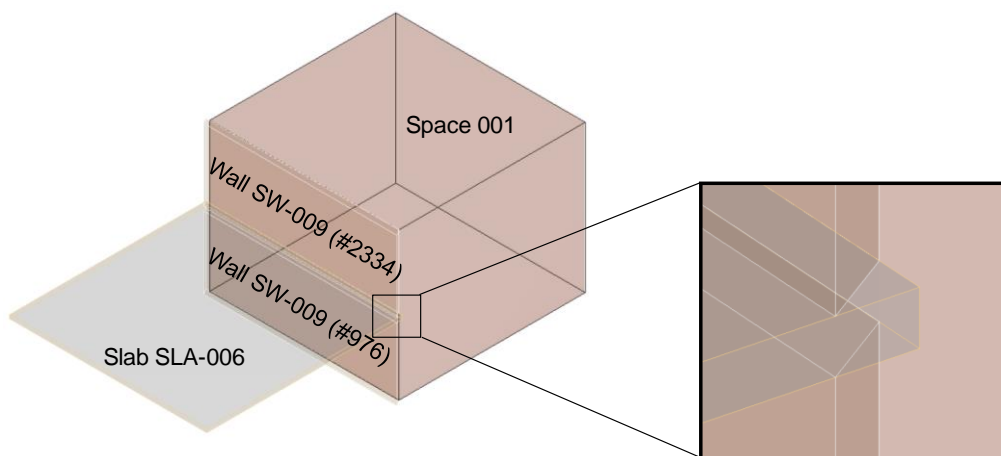
Figure 13: Differently to CSW-1 there are three boundary elements instead of only one (slab)

Gap due to
the wall-butt-print

**Space boundary
#3650**

**Space
boundary
#3562**

**Space
boundary
#3602**

**Space boundary
#3302**

Gap due to
the slab-butt-print

Gap due to
the wall-butt-print
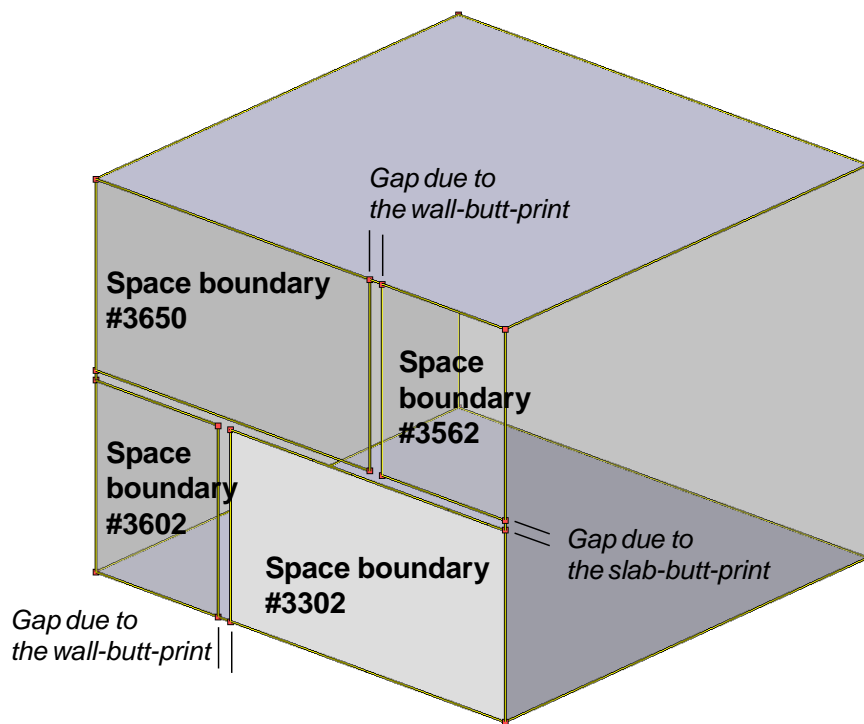
Figure 14: Internal 2nd level space boundaries for multi-storey space 001

```
/* multi-storey space */
#1616= IFCSPACE('3_gYqoe8bD5PBic4ioY2W$',#13,'001',$,$,#1613,#1598,'Office',.ELEMENT.,
        .INTERNAL.,$);

/* boundary elements (interior elements) */
#2553= IFCSLAB('2GhmppPobFWOOM5oMhk31h',#13,'SLA - 006',$,$,#2620,#2605,
        '9720E548-A1AA-4030-BD-14-444CDDA0CB8E',.FLOOR.);
#976= IFCWALLSTANDARDCASE('0Jw_IrGYj8zuLypn6e1Xw6',#13,'SW - 009',$,$,#973,#1046,
        'F1F23E79-1E96-4912-84-E7-7810D6D45C9E');
#2334= IFCWALLSTANDARDCASE('3KfUuFDzTEEhPYS4c24orA',#13,'SW - 009',$,$,#2331,#2404,
        'D4A5EE0F-37D7-4E3A-B6-62-704982132D4A');


/* 2nd level space boundaries to interior element*/
#3302= IFCRELSPACEBOUNDARY('1JWYZpeynDaftUCAgcpZJJ',#13,'2ndLevel','2a',#1616,#976,
        #3301,.PHYSICAL.,.INTERNAL.);
#3562= IFCRELSPACEBOUNDARY('1CzeXSAQD87PXWeruot$yA',#13,'2ndLevel','2a',#1616,#2334,
        #3561,.PHYSICAL.,.INTERNAL.);
#3602= IFCRELSPACEBOUNDARY('3H5Mljuvb6K8dy_$IFp5MI',#13,'2ndLevel','2a',#1616,#976,
        #3601,.PHYSICAL.,.INTERNAL.);
#3650= IFCRELSPACEBOUNDARY('0EMzQJ9jr5Cvkbr0nUaxJ4',#13,'2ndLevel','2a',#1616,#2334,
        #3649,.PHYSICAL.,.INTERNAL.);
```

Example 8: Internal 2nd level space boundaries for multi-storey space 001

Similar to example CSW-1 type "2b" space boundaries will fill the gaps of the wall and the slab butt prints. Again there are no overlapping or intersecting elements so that there are only 2nd level space boundaries of type "2a" and "2b" in the file.
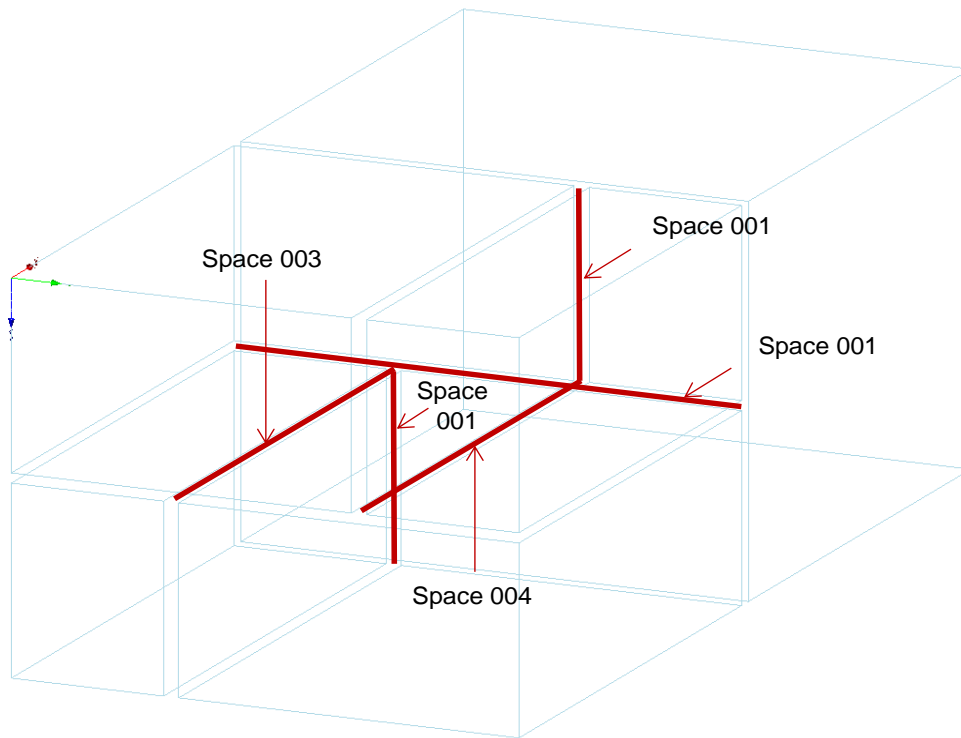
Figure 15: type "2b" space boundaries and related space that have been added.

Figure 15 shows all added type "2b" space boundaries and related spaces. There are three type "2b" space boundaries for space 001 and one for space 003 and space 004 each so that there are 35 + 5 = 40 space boundaries in total. All five type "2b" space boundaries are defined between the slab SL-006 and different spaces. Four of them are necessary due to the inner walls behind the slab and one of them is because the orientation of slab related to space 001 (see also Figure 13). Accordingly, it is not only the element behind the boundary that is important for deciding between type "2a" and "2b" space boundaries. It is also the orientation of the element.

This example is available as IFC file AWS-2_with_2nd-lsb_pln.ifc.

4.5   CSC-3

Test Case Reference File: CSC-3_2x3.ifc (Source: LBNL, version: 16-Feb-09)

IFC File Generation:

    1st Level Space Boundaries: Revit 2010, Release 1 (Windows),

    2nd Level Space Boundaries: ArchiCAD 12 Release 1 (Windows), Ifc 2x3 interface: 63120 (11-Feb-09)

Use case: 2nd level space boundaries – column partially embedded in wall
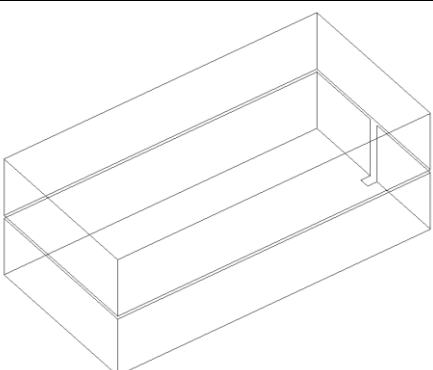
Issues tested with this test case:

- Column partially embedded in an exterior wall
- "Exterior" 2nd level space boundary of the column
- No space boundaries for the two sides of the column that face each other
- Space boundary geometry of the ceiling of the lower and the floor of the upper story (correct indentation from the embedded column)

Test case model description:

- A two-story volume has one space/zone on each story
- The two-story volume has a column embedded in one of the exterior walls of the lower story space/zone
- Exterior surface of the column is flush with exterior surface of the wall in which it is embedded

4.5.1   Space Boundaries Overview

Name:	**CSC-3_2x3.ifc**	Source:	LBNL, Vladimir Bazjanac

Test Case Features			
A two-story building with one space/zone on each story. A pilaster (embedded column) is connected to a wall bounding the lower story space/zone.			

1st Level Space Boundaries (fully enclosed spaces)

Total	16	
Interior Surfaces	2	
Exterior Surfaces	14	
Slab on ground	1	
Ceiling of the lower story	1	
Floor of the upper story	1	
Interior walls	0	
Ceiling of the upper story – roof	1	
Exterior walls	12	
Windows	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	0	
Vertical column surfaces	3	
Number of spaces (thermal zones)		

2nd Level Space Boundaries (fully enclosed spaces)		
Total	**16**	
Interior Surfaces	**2**	
Exterior Surfaces	**14**	
Slab on ground	1	
Ceiling of the lower story	1	
Floor of the upper story	1	
Interior walls	0	
Ceiling of the upper story – roof	1	
Exterior walls	12	
Windows	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	0	
Vertical column surfaces	3	
Number of spaces (thermal zones)	**2**	

> **Commented [MW28]:** Should be 2, or?
> 1x „2a" and 1x „2b"

> **Commented [MW29]:** If columns are counted seperately (3 vertical column surfaces) I would expect 9 instead of 12.

4.5.2   1st Level Space Boundaries

First level space boundaries depend only on the building elements and virtual boundaries immediately adjacent to the space. In this case, we have (1) space on each building story, each bounded by (4) walls and (2) slabs, but on the lower story, we also have a bounding pilaster (or embedded column).

First Floor: (1) space has (5) 1st level space boundaries representing the surrounding walls, (3) 1st level space boundaries representing the pilaster, and (2) 1st level space boundaries representing the floor and ceiling (1 x (5+3+2) = 10 1st level space boundaries; 9 exterior and 1 interior).

Second Floor: (1) space has (4) 1st level space boundaries representing the surrounding walls and (2) 1st level space boundaries representing the floor and ceiling (1 x (4+2) = 6 1st level space boundaries; 5 exterior and 1 interior).

4.5.3   2nd Level Space Boundaries

IFC implementation details:

The column that is contained in space 001 divides the wall and creates a little niche, which results in some interesting space boundaries around the column.

Slab SL-006

Slab SL-005

Wall SW-003
(#408)

Column CRE-001
between SL-006 and SL-005,
between walls SW-003 (#408, #708)

Space 002

Space 001

Wall SW-003
(#708)
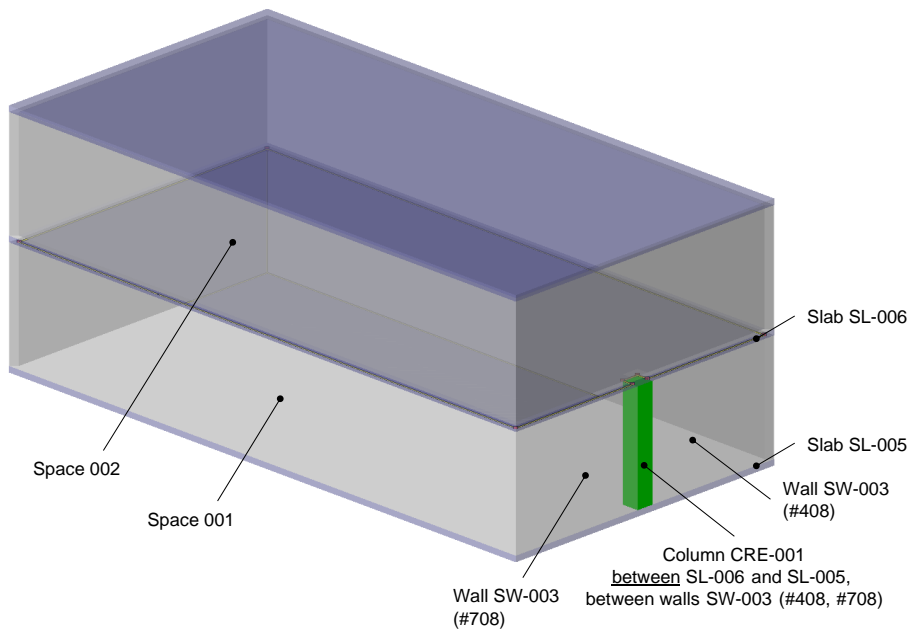
Figure 16: Main elements of example CSC-3.

The horizontal space boundaries of slab SL-005 and both sides of slab SL-006 take into account the "cutout" of the columns footprint, which means that they are defined by a polygon with eight corners as shown in Figure 17. The vertical 2nd level space boundaries to the column and the walls SW-003 are defined for faces that are parallel to the walls so that there is a gap between the space boundaries of the walls and the column. A gap exists also for the space boundaries of space 002 because the butt-print of the column has to be taken into account so that the connection geometry is similar to the space boundaries of space 001 (see Figure 18).

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Shape of space boundary between slab SL-006 and space 001

Shape of space boundary between slab SL-005 and space 001

Shape of 2nd level space boundary between column CRE-001 and space 001

Shape of space boundaries between walls SW-003 and space 001

Figure 17: 2nd level space boundaries for space 001
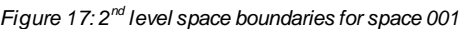
Implementation Guide: Space Boundaries for Energy Analysis
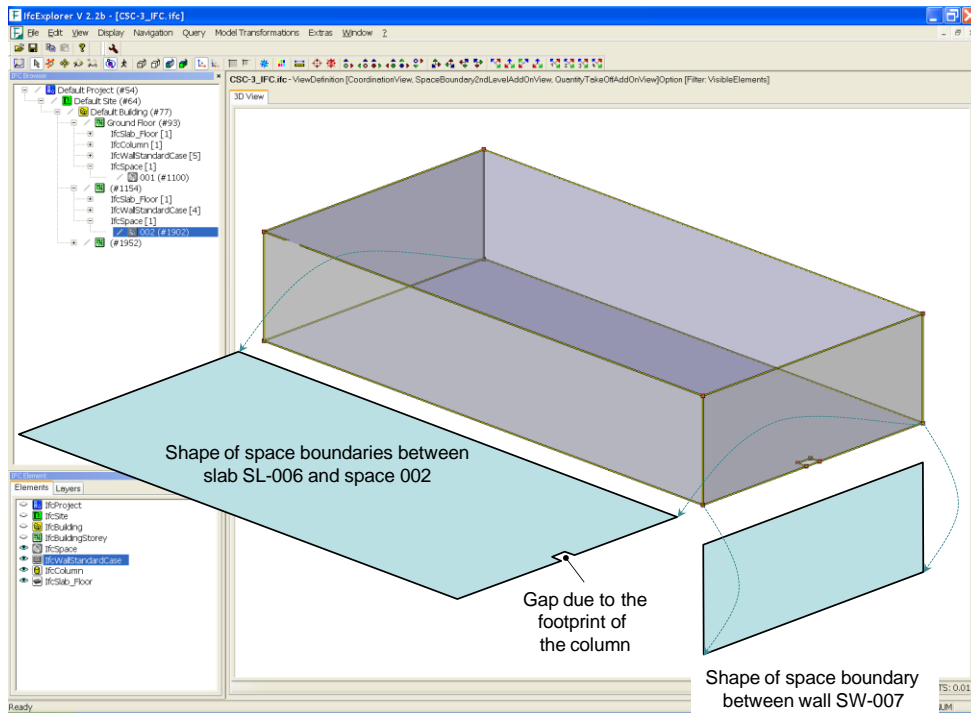
Figure 18: 2nd level space boundaries for space 002

Similar to the other examples type "2b" space boundaries will close the gaps that are shown in Figure 17 and Figure 18, which means to have 14 + 3 = 17 space boundaries in total.

This example is available as IFC file CSO-1_with_2nd-lsb_pln.ifc.

4.6   CSW-6

Test Case Reference File: CSW-6_2x3.ifc (Source: LBNL, version: 16-Feb-09)

IFC File Generation:

    1st Level Space Boundaries: Revit 2010, Release 1 (Windows),

    2nd Level Space Boundaries: ArchiCAD 12 Release 1 (Windows), Ifc 2x3 interface: 63120 (11-Feb-09)

Use case: 2nd level space boundaries – diagonal interior walls
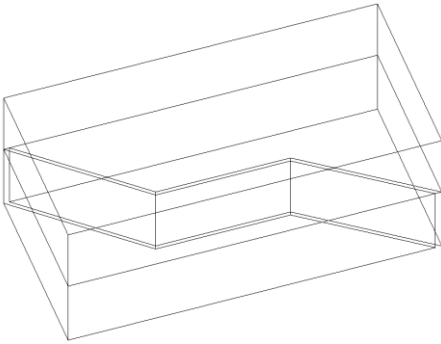
Issues tested with this test case:

- 2nd level space boundaries for floor slabs and ceilings that have diagonal walls below
- 2nd level space boundaries for interior walls that connect and/or intersect at angles ≠ 90˚

Test case model description:

- A two-story volume has two spaces on the lower and one space/zone on the upper story
- Two interior walls extend diagonally from two opposite corners of the lower story and connect with a wall running straight east-west to form a "three-piece" internal wall
- The two diagonal internal walls extend at 45˚ relative to external walls and the internal wall on the lower story running straight east-west
- The "three-piece" internal wall divides the lower story into two spaces/zones

4.6.1   Space Boundaries Overview

Name:	**CSW-6 _2x3.ifc**		Source:	LBNL, Vladimir Bazjanac	
Test Case Features					
A 2-story building with two spaces/zones on the first story (separated by diagonal walls) and 1 space on the second story, all bounded by walls and slabs with no openings.					
1st Level Space Boundaries (fully enclosed spaces)					
Total	**20**				
Interior Surfaces	**9**				
Exterior Surfaces	**11**				
Slab on ground	2				
Ceiling of the lower story	2				
Floor of the upper story	1				
Interior walls	6				
Ceiling of the upper story – roof	1				
Exterior walls	8				
Windows	0				
Horizontal "air-walls" (virtual slabs)	0				
Vertical "air-walls" (virtual walls)	0				
Vertical column surfaces	0				
Number of spaces (thermal zones)	**3**				

2nd Level Space Boundaries (fullyenclosed spaces)		

Total	**21**	
Interior Surfaces	**10**	
Exterior Surfaces	**11**	
Slab on ground	2	
Ceiling of the lower story	2	
Floor of the upper story	2	
Interior walls	6	
Ceiling of the upper story – roof	1	
Exterior walls	8	
Windows	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	0	
Vertical column surfaces	0	
Number of spaces (thermal zones)	**3**	

Commented [MW32]: 2 of type „2a" and, in my Graphisoft example, another 5 of type "2b"

Commented [MW33]: 6 of type „2a", but another 6 of type „2b"

4.6.2   1st Level Space Boundaries

First level space boundaries depend only on the building elements and virtual boundaries immediately adjacent to the space. In this case, we have (2) spaces on the first floor and (1) space on the second floor, all bounded by walls and slabs with no openings.

First Floor: Each of (2) spaces has (5) 1st level space boundaries corresponding to the walls and (2) 1st level space boundaries corresponding to the floor and ceiling (2 x (5+2) = 14 - 1st level space boundaries; 6 exterior and 8 interior).

Second Floor: (1) space has (4) 1st level space boundaries corresponding to the walls and (2) 1st level space boundaries corresponding to the floor and ceiling (1 x (4+2) = 6 - 1st level space boundaries; 5 exterior and 1 interior).

4.6.3   2nd Level Space Boundaries

IFC implementation details:

Differently to the previous examples test case CSW-6 contains walls with non-rectangular connections. Such kind of connections, in particular those being higher than 90°, require additional type "2b" space boundaries as shown in the Figure 19. Accordingly, space 003 and space 001 have three type "2b" space boundaries to inner walls.

Similar to the examples AWS-2 and CSW-1 the inner walls of the first storey need to considered in the space of the second storey. A possible breakdown into type "2b" space boundaries between the floor SLA-006 and the space 002 are shown in Figure 20. We would have expected three type "2b" space boundaries due to three inner walls behind the slab, but there are five because of the chosen, suboptimum clipping algorithm.

type '2b' space boundary
of space 003 due to
a wall connection angle < 90°

type '2a' space boundary
of space 003

90°

Space 003

type '2b' space boundaries
of space 003 due to
a wall connection angle > 90°

>90°

90°

90°

type '2a' space boundaries
of space 003
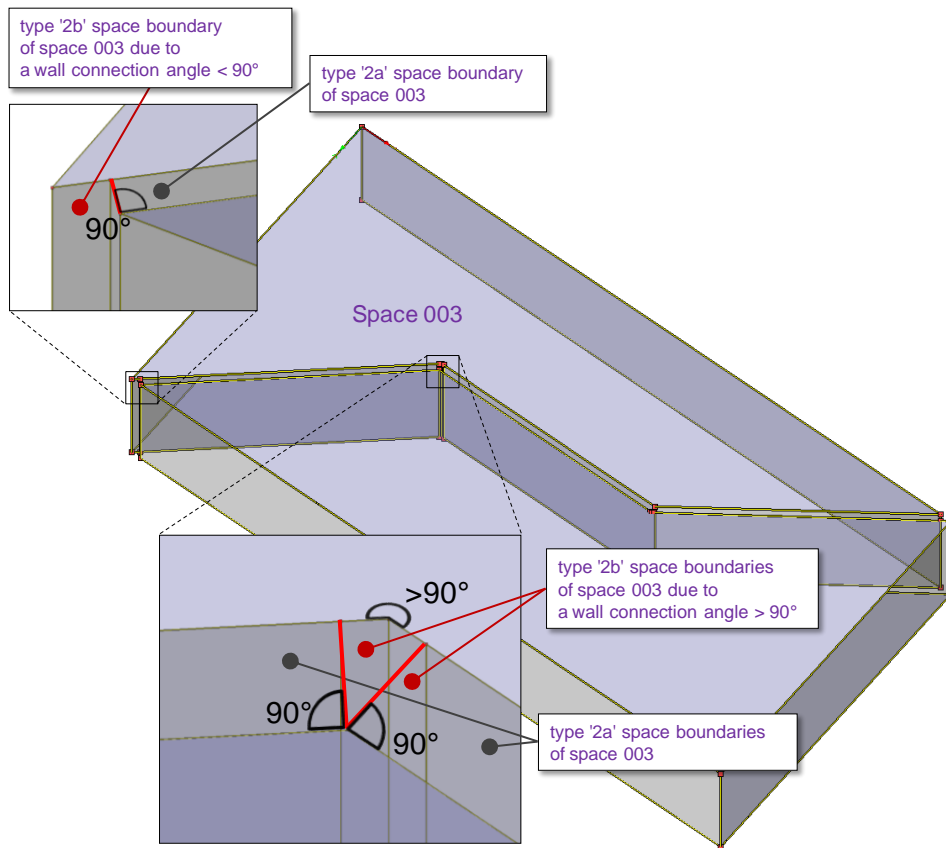
Figure 19: Type "2b" space boundaries due to non-rectangular wall connections
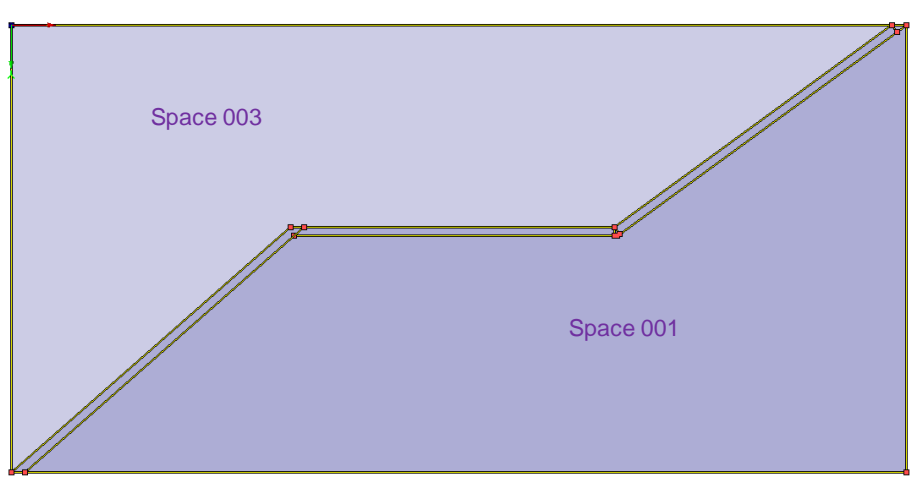
Figure 20: 2nd level space boundaries (type "a" and "b") for space 002 and the floor SLA-006

Space 003

Space 001

Commented [MW34]: Result of the Graphisoft export. Probably not a good example as there seems to be no logic behind the selection of type "2b" space boundaries.

4.7 SWW-1

<u>Test Case Reference File:</u> SWW-312x3.ifc (Source: LBNL)

<u>IFC File Generation:</u>

   <u>1st Level Space Boundaries</u>: Revit 2010, Release 1 (Windows)

   <u>2nd Level Space Boundaries</u>: ArchiCAD 12 Release 1 (Windows)
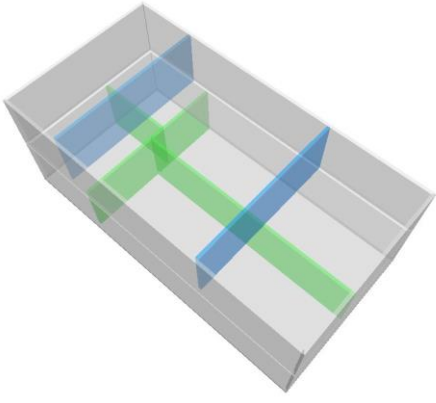
<u>Use case:</u> 2nd level space boundaries – several internal walls in two storeys

<u>Issues tested with this test case:</u>
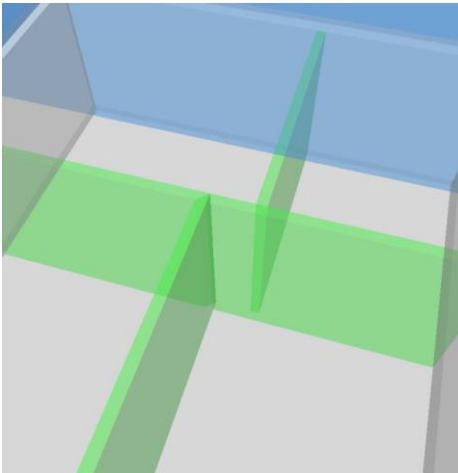
- 2nd level space boundaries for floor slab that has internal walls below and above
- 2nd level space boundaries for separating wall related to several other spaces

<u>Test case model description:</u>

- Two storey building with slabs and 4 spaces below and 3 spaces above
- All spaces are bounded by external and internal walls, all internal walls are in different locations
- 2 of the second floor spaces link to 2 of the first floor spaces and the third space in the middle of the second floor link to all 4 spaces in the first floor
- All 4 spaces in the first floor have each links to 2 different spaces in the second floor

Name:	**Test SWW-1**		Source:	LBNL, Vladimir Bazjanac
Test Case Features				
Two storey building with several spaces, slabs and walls below and above each other.				

1st Level Space Boundaries (fully enclosed spaces)		
Total	**42**	
Interior Surfaces	**19**	
Exterior Surfaces	**23**	
Slab on ground	4	
Ceiling of the lower story	4	
Floor of the upper story	3	
Interior walls	12	
Ceiling of the upper story – roof	3	
Exterior walls	16	
Windows	0	
Doors	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	0	
Vertical column surfaces	0	
Number of spaces (thermal zones)	7	

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2nd Level Space Boundaries (fullyenclosed spaces)	
Total	64
Interior Surfaces	41
Exterior Surfaces	23
Slab on ground	4
Ceiling of the lower story	12
Floor of the upper story	13
Interior walls	16
Ceiling of the upper story – roof	3
Exterior walls	16
Windows	0
Doors	0
Horizontal "air-walls" (virtual slabs)	0
Vertical "air-walls" (virtual walls)	0
Vertical column surfaces	0
Number of spaces (thermal zones)	7

4.7.1 1st Level Space Boundaries

First level space boundaries depend only on the building elements and virtual boundaries immediately adjacent to the space. In this case, we have (4) spaces on the first floor and (3) spaces on the second floor, each bounded by (4) walls and (2) slabs.

First Floor: (4) spaces of which each has (2) 1st level space boundaries representing the surrounding internal walls, (2) 1st level space boundaries representing the surrounding external walls, and (2) 1st level space boundaries representing the floor and ceiling (4 x (2+2+2) = 24 1st level space boundaries; 12 exterior and 12 interior).

Second Floor: (3) spaces of which each has (4) 1st level space boundaries representing the surrounding walls and (2) 1st level space boundaries representing the floor and ceiling (3 x (4+2) = 18 1st level space boundaries; 11 exterior and 7 interior).

4.7.2 2nd Level Space Boundaries

Second level space boundaries depend on spaces behind the boundary. Accordingly, second level space boundaries are often a subdivision of first level space boundaries. The differences between first and second level space boundaries in this example are related to division of space boundaries connected to internal walls and slabs.

The two storey building contains four spaces (001, 003, 004, 005) in the first floor and three spaces (002, 006, 007) in the second floor. The first floor spaces 003 and 005 have an internal wall, which is connected to two other spaces. This creates three different boundaries for that internal wall, where two are type "2a" and one type "2b" for wall butts (see Figures 21 and 22).
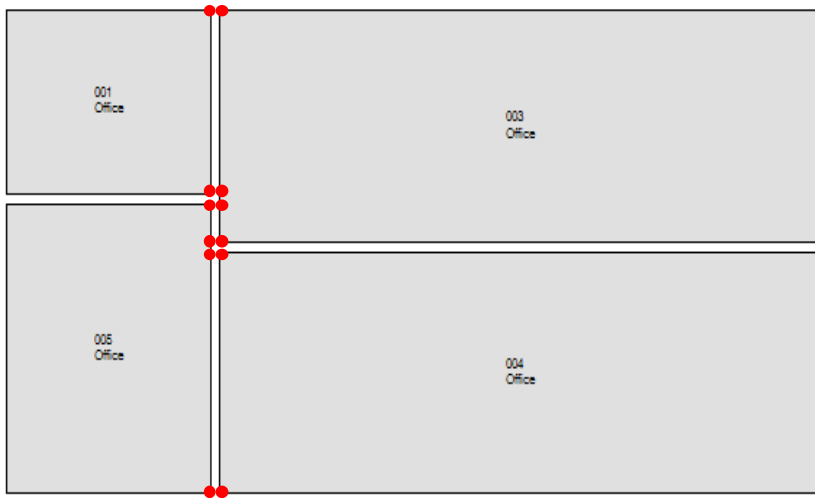
Figure 21: In the first floor 2nd level space boundaries of the internal wall are divided into 3 pieces in the spaces 003 and 005, of which 2 are type "2a" and 1 type "2b" for wall butts.
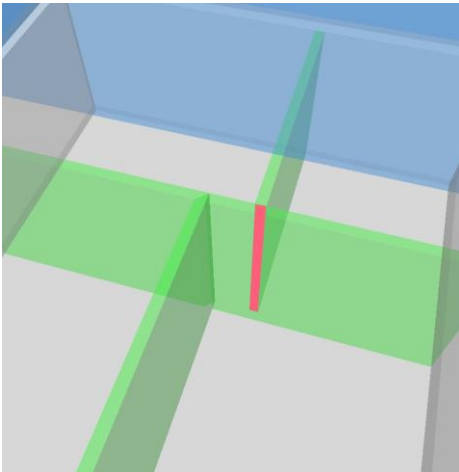
Figure 22: 2nd level space boundary type "2b" (marked by red color) for the wall butt in space 003 in the first floor. The space 005 has similar type "2b" space boundary from another wall butt.

The second level space boundaries connected to the slab between the floors are divided according to spaces and separating walls on the other floor. The space 006, in the middle of the second floor, has four type "2a" space boundaries related to all four spaces downstairs. The separating walls on the first floor create three additional type "2b" space boundaries, which are visualized in Figure 23. The other spaces (002, 007) on the second floor have each three horizontal second level space boundaries related to the separating slab, where two are type "2a" and one type "2b".
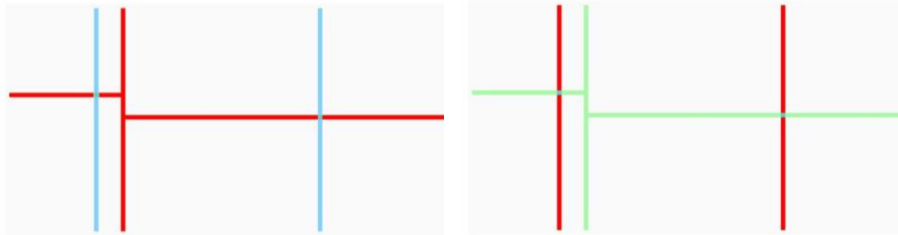
Figure 23: 2nd level space boundaries type "2b" (by red color) for floors of the spaces in the second floor (left) and for ceilings of the spaces in the first floor (right).

4.8 WI-3

Test Case Reference File: SWW-312x3.ifc (Source: LBNL)

IFC File Generation:

    1st Level Space Boundaries: Revit 2010, Release 1 (Windows)

    2nd Level Space Boundaries: ArchiCAD 12 Release 1 (Windows)

Use case: 2nd level space boundaries – high window

Issues tested with this test case:

- 1st and 2nd level space boundaries for high window
- Shows an example of case, where 1st and 2nd level space boundaries are exactly the same

Test case model description:

- Two storey building with 1 space in each floor, each have the same form and xy location
- The space in the 1st floor has a big window from floor to ceiling in the middle of wall
- Both spaces are bounded also by external walls, roof, floor and separating slab

Name:	**Test Wi-3**		Source:	LBNL, Vladimir Bazjanac
Test Case Features				
Two storey building with 1 space in each floor. The space in the 1st floor has a big window from floor to ceiling in the middle of wall.				

1st Level Space Boundaries (fully enclosed spaces)		
Total	**13**	
Interior Surfaces	**2**	
Exterior Surfaces	**11**	
Slab on ground	1	
Ceiling of the lower story	1	
Floor of the upper story	1	
Interior walls	0	
Ceiling of the upper story – roof	1	
Exterior walls	8	
Windows	1	
Doors	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	0	
Vertical column surfaces	0	
Number of spaces (thermal zones)	2	

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2nd Level Space Boundaries (fully enclosed spaces)		
Total	**13**	
Interior Surfaces	**2**	
Exterior Surfaces	**11**	
Slab on ground	1	
Ceiling of the lower story	1	
Floor of the upper story	1	
Interior walls	0	
Ceiling of the upper story – roof	1	
Exterior walls	8	
Windows	1	
Doors	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	0	
Vertical column surfaces	0	
Number of spaces (thermal zones)	2	

4.8.1   1st Level Space Boundaries

First level space boundaries depend only on the building elements and virtual boundaries immediately adjacent to the space. In this case, we have (2) similar form spaces on top of each other, which results similar space boundaries on both levels 1st and 2nd.

First Floor: (1) space has (4) 1st level space boundaries representing the surrounding external walls, (1) 1st level space boundary for the window, and (2) 1st level space boundaries representing the floor and ceiling (1 x (4+1+2) = 7 1st level space boundaries; 6 exterior and 1 interior).

Second Floor: (1) space has (4) 1st level space boundaries representing the surrounding external walls and (2) 1st level space boundaries representing the floor and ceiling (1 x (4+2) = 6 1st level space boundaries; 5 exterior and 1 interior).

4.8.2   2nd Level Space Boundaries

Second level space boundaries depend on spaces behind the boundary. So in this case, where the both spaces on top of each other have the same form, the result is similar 2nd level as 1st level space boundaries.

The space 001 in the first floor contains a floor to ceiling window in the middle of the wall. It has to be noticed that the opening of the wall is not considered by using 'inner bounds' due to an implementer agreement. According to the agreement, openings, doors and windows are considered by an own space boundary.

4.9 WI-8

<u>Test Case Reference File:</u> SWW-312x3.ifc (Source: LBNL)

<u>IFC File Generation:</u>

    <u>1st Level Space Boundaries</u>: Revit 2010, Release 1 (Windows)

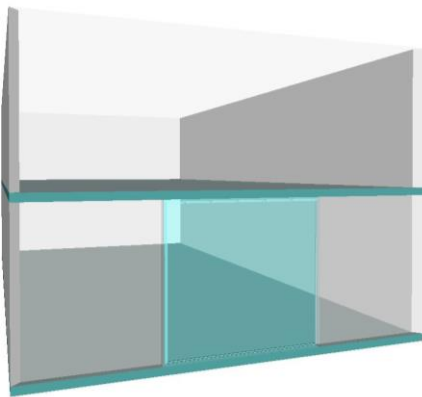   <u>2nd Level Space Boundaries</u>: ArchiCAD 12 Release 1 (Windows)

<u>Use case</u>: 2nd level space boundaries – window in the corner

<u>Issues tested with this test case</u>:

- 1st and 2nd level space boundaries for window in the corner of the wall
- Shows an example of case, where 1st and 2nd level space boundaries are exactly the same

<u>Test case model description</u>:

- Two storey building with 1 space in each floor, each have the same form and xy location
- The space in the 1st floor has a window in the corner of the wall
- Both spaces are bounded also by external walls, roof, floor and separating slab

Name:	**Test Wi-8**		Source:	LBNL, Vladimir Bazjanac
Test Case Features				
Two storey building with 1 space in each floor. The space in the 1st floor has a window in the corner of wall.				

1st Level Space Boundaries (fully enclosed spaces)		
Total	13	
Interior Surfaces	2	
Exterior Surfaces	11	
Slab on ground	1	
Ceiling of the lower story	1	
Floor of the upper story	1	
Interior walls	0	
Ceiling of the upper story – roof	1	
Exterior walls	8	
Windows	1	
Doors	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	0	
Vertical column surfaces	0	
Number of spaces (thermal zones)	2	

2nd Level Space Boundaries (fully enclosed spaces)		
Total	13	
Interior Surfaces	2	
Exterior Surfaces	11	
Slab on ground	1	
Ceiling of the lower story	1	
Floor of the upper story	1	
Interior walls	0	
Ceiling of the upper story – roof	1	
Exterior walls	8	
Windows	1	
Doors	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	0	
Vertical column surfaces	0	
Number of spaces (thermal zones)	2	

4.9.1   1st Level Space Boundaries

First level space boundaries depend only on the building elements and virtual boundaries immediately adjacent to the space. In this case, we have (2) similar form spaces on top of each other, which results similar space boundaries on both levels 1st and 2nd.

First Floor: (1) space has (4) 1st level space boundaries representing the surrounding external walls, (1) 1st level space boundary for the window, and (2) 1st level space boundaries representing the floor and ceiling (1 x (4+1+2) = 7 1st level space boundaries; 6 exterior and 1 interior).

Second Floor: (1) space has (4) 1st level space boundaries representing the surrounding external walls and (2) 1st level space boundaries representing the floor and ceiling (1 x (4+2) = 6 1st level space boundaries; 5 exterior and 1 interior).

4.9.2   2nd Level Space Boundaries

Second level space boundaries depend on spaces behind the boundary. So in this case, where the both spaces on top of each other have the same form, the result is similar 2nd level as 1st level space boundaries.

The space 001 in the first floor contains a floor to ceiling window in the corner of the wall. The space boundary related to this window is generated according to same principles as in 4.8.2. It has to be noticed that the opening of the wall is not considered by using 'inner bounds' due to an implementer agreement. According to the agreement, openings, doors and windows are considered by an own space boundary.

4.10 AWS-4

<u>Test Case Reference File:</u> SWW-312x3.ifc (Source: LBNL)

<u>IFC File Generation:</u>

   <u>1st Level Space Boundaries</u>: Revit 2010, Release 1 (Windows)

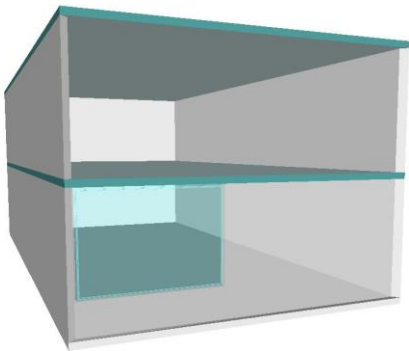   <u>2nd Level Space Boundaries</u>: ArchiCAD 12 Release 1 (Windows)
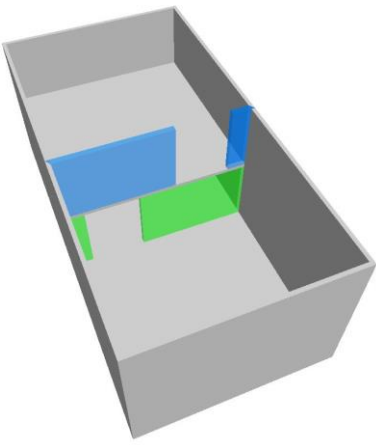
<u>Use case</u>: 2nd level space boundaries – two storey high space

<u>Issues tested with this test case</u>:

- 2nd level space boundaries for slab butt in a two storey high space
- 2nd level space boundaries for openings without fillings
- Shows an example of case, where 1st and 2nd level space boundaries are exactly the same

<u>Test case model description</u>:

- A two storey building has two spaces on the lower and one space on the upper story
- One space in each floor are on top of each other and the other space in the lower story is two floors high
- There are two openings without filling between the high space and both of the lower spaces

Name:	**Test AWS-4**	Source:	LBNL, Vladimir Bazjanac
Test Case Features			
Two storey building with 2 spaces one upon the other and 1 two storey high space. Both small spaces have opening without any filling (window or door).			

1ˢᵗ Level Space Boundaries (fully enclosed spaces)		
Total	28	
Interior Surfaces	15	
Exterior Surfaces	13	
Slab on ground	2	
Ceiling of the lower story	1	
Floor of the upper story	1	
Interior walls	9	
Ceiling of the upper story – roof	2	
Exterior walls	9	
Windows	0	
Doors	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	4	
Vertical column surfaces	0	
Number of spaces (thermal zones)	3	

2nd Level Space Boundaries (fully enclosed spaces)		
Total	**28**	
Interior Surfaces	**15**	
Exterior Surfaces	**13**	
Slab on ground	2	
Ceiling of the lower story	1	
Floor of the upper story	1	
Interior walls	9	
Ceiling of the upper story – roof	2	
Exterior walls	9	
Windows	0	
Doors	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	4	
Vertical column surfaces	0	
Number of spaces (thermal zones)	3	

4.10.1   1st Level Space Boundaries

First level space boundaries depend only on the building elements and virtual boundaries immediately adjacent to the space. In this case, we have (2) spaces on top of each other in different floors and (1) two storey high space next to these. Both low spaces are bounded by (4) walls, (2) slabs and (1) opening without filling (window or door) and the two storey high space is bounded by (5) walls, (2) slabs and (1) slab butt.

First Floor: (2) spaces have totally (3) 1st level space boundaries representing the surrounding internal walls, (6) 1st level space boundaries representing the surrounding external walls, (4) 1st level space boundaries representing the floor and ceiling, (1) 1st level space boundary for slab butt, (2) 1st level space boundaries representing the wall butts in both sides of the opening and (3) 1st level space boundaries for openings (3+6+4+1+2+3 = 19 1st level space boundaries; 9 exterior and 10 interior).

Second Floor: (1) space has (4) 1st level space boundaries representing the surrounding walls, (2) 1st level space boundaries representing the floor and ceiling, (2) 1st level space boundaries representing the wall butts in both sides of the opening and (1) 1st level space boundary for opening in the internal wall (1 x (4+2+2+1) = 9 1st level space boundaries; 4 exterior and 5 interior).

4.10.2   2nd Level Space Boundaries

Second level space boundaries depend on spaces behind the boundary. Accordingly, second level space boundaries are often a subdivision of first level space boundaries. In this case the first level space boundaries are similar to second level, because modeling of the separating walls between the two storey high space and the smaller spaces equals to space division.

In the two storey high space 001 space boundary division according to adjacent spaces 002 (first floor) and 003 (second floor) is not needed, when the connection is totally covered by the separating walls to the neighboring spaces. The space boundary for the slab butt is type "2b" for the second level space boundaries, while the two boundaries for separating walls and two boundaries for openings without filling are type "2a" (Figure 24).
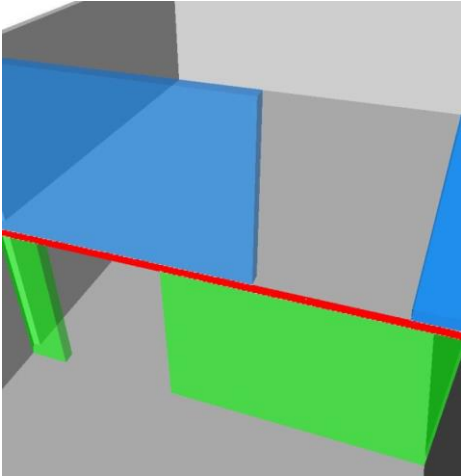
Figure 24: 2nd level space boundary type "2b" (by red color) for slab butt in the two storey high space 001. The same space boundary is needed also when using the first level space boundaries.

The two superposed spaces 002 (first floor) and 003 (second floor) have each an opening without any filling (window or door). The modeling of the example is done so that the opening areas are belonging to these spaces, not to the two storey high space 001. So the 2 space boundaries for the opening are type "2a" and the 4 space boundaries for the wall butts on both sides of the openings are type "2b" (Figure 25). Also the horizontal space boundaries in these spaces for the slabs are not rectangular, but have an extension on below and above the openings. This corresponds both to the 1st and 2nd level space boundaries.

Note: When bounding element is an IfcOpeningElement, PhysicalOrVirtualBoundary is set VIRTUAL. This ignores the IfcRelSpaceBoundary.WR (would generate an error in IFC2x3, but is already fixed in the next release IFC2x4).

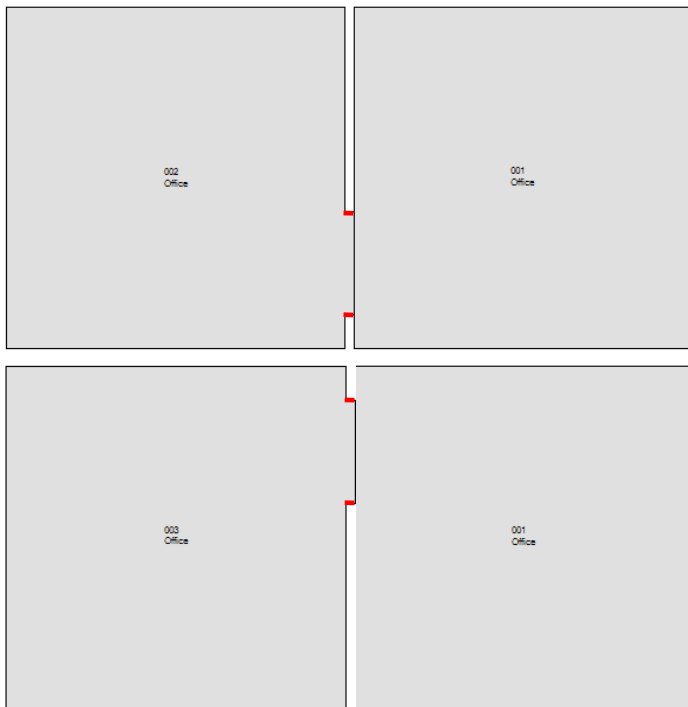*Figure 25: The two superposed spaces 002 (first floor) and 003 (second floor) have each an opening without any filling (window or door). The space boundaries for the openings are type "2a" and the 4 space boundaries for the wall butts on both sides of the opening (red lines) are type "2b".*

4.11 CSW-4

Test Case Reference File: SWW-312x3.ifc (Source: ???)
IFC File Generation:
    1st Level Space Boundaries: Revit 2010, Release 1 ((Windows), ?version?)
    2nd Level Space Boundaries: ArchiCAD 12 Release 1 ((Windows), ?version?)
Use case: to be defined ...
Issues tested with this test case:
- to be documented ...

Test case model description:
- to be documented ...

> **Commented [RAS35]:** to be done by Granlund

Name:	Test CSW-4	Source:	LBNL, Vladimir Bazjanac
Test Case Features			

Vlado will modify so that one interior wall is curved with 10 degree facets or 9 surfaces ...

> **Commented [LT36]:** Vlado's model is required to be able to write the text. Should we leave this example to next versions?

1st Level Space Boundaries (fully enclosed spaces)

Total	
Interior Surfaces	
Exterior Surfaces	
Slab on ground	
Ceiling of the lower story	
Floor of the upper story	
Interior walls	
Ceiling of the upper story – roof	
Exterior walls	
Windows	
Doors	
Horizontal "air-walls" (virtual slabs)	
Vertical "air-walls" (virtual walls)	
Vertical column surfaces	
Number of spaces (thermal zones)	

2nd Level Space Boundaries (fully enclosed spaces)

Total	
Interior Surfaces	
Exterior Surfaces	
Slab on ground	
Ceiling of the lower story	
Floor of the upper story	
Interior walls	
Ceiling of the upper story – roof	
Exterior walls	
Windows	
Doors	
Horizontal "air-walls" (virtual slabs)	
Vertical "air-walls" (virtual walls)	
Vertical column surfaces	

Number of spaces (thermal zones)		

4.11.1 1st Level Space Boundaries

[To be written …]

Commented [RAS37]: to be done by Granlund

4.11.2 2nd Level Space Boundaries

[To be written …]

Commented [RAS38]: to be done by Granlund

4.12 OG-2

Test Case Reference File: OG-22x3.ifc (Source: Granlund)
IFC File Generation:
    1st Level Space Boundaries: Revit 2010, Release 1 (Windows)
    2nd Level Space Boundaries: ArchiCAD 12 Release 1 (Windows)
Use case: 2nd level space boundaries – rectangular window in a curved wall
Issues tested with this test case:

- 2nd level space boundaries for rectangular window in a curved wall

Test case model description:

- A single storey building has one space
- The space is bounded by external walls, where the other is curved 180°
- The curved wall has a rectangular window

Name:	Test OG-2		Source:		Granlund, Hannu Lahtela
Test Case Features					
Rectangular window in a curved wall.					
1st Level Space Boundaries (fully enclosed spaces)					

Total	5	
Interior Surfaces	0	
Exterior Surfaces	5	
Slab on ground	1	
Ceiling of the lower story	0	
Floor of the upper story	0	
Interior walls	0	
Ceiling of the upper story – roof	1	
Exterior walls	2	
Windows	1	
Doors	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	0	
Vertical column surfaces	0	
Number of spaces (thermal zones)	1	

2nd Level Space Boundaries (fullyenclosed spaces)		
Total	**37**	
Interior Surfaces	**0**	
Exterior Surfaces	**37**	
Slab on ground	1	
Ceiling of the lower story	0	
Floor of the upper story	0	
Interior walls	0	
Ceiling of the upper story – roof	1	
Exterior walls	33	
Windows	2	
Doors	0	
Horizontal "air-walls" (virtual slabs)	0	
Vertical "air-walls" (virtual walls)	0	
Vertical column surfaces	0	
Number of spaces (thermal zones)	1	
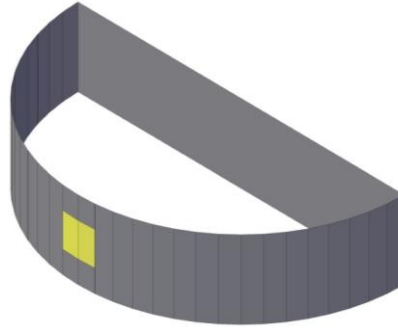
4.12.1   1st Level Space Boundaries

First level space boundaries depend only on the building elements and virtual boundaries immediately adjacent to the space. In this case, we have (1) space bounded by (2) external walls, (2) slabs and (1) window. The other external wall is rectangular, which results in IFC 1st level space boundary representation by curved polyline with extrusion geometry.

(1) space has (2) 1st level space boundaries representing the surrounding external walls, (2) 1st level space boundaries representing the floor and ceiling, and (1) 1st level space boundary for window (1 x (2+2+1) = 5 1st level space boundaries; 5 exterior and 0 interior).

4.12.2   2nd Level Space Boundaries

Second level space boundaries depend on spaces behind the boundary. Accordingly, second level space boundaries are often a subdivision of first level space boundaries. In this case the second level space boundaries differ from the first level, because of limitations in defining the connection geometry. By second level space boundaries only planar surface geometry representation should be used instead of curved polyline with extrusion, which is also allowed with the first level space boundaries.

The space boundaries for window should correspond to the same faceting as for the wall.

5 VISUAL EVALUATION OF SPACE BOUNDARIES

The figure below gives a quick guide about settings to show space boundaries. It is based on the IfcStoreyView (and its successor FZKViewer) both developed by the Forschungszentrum Karlsruhe.
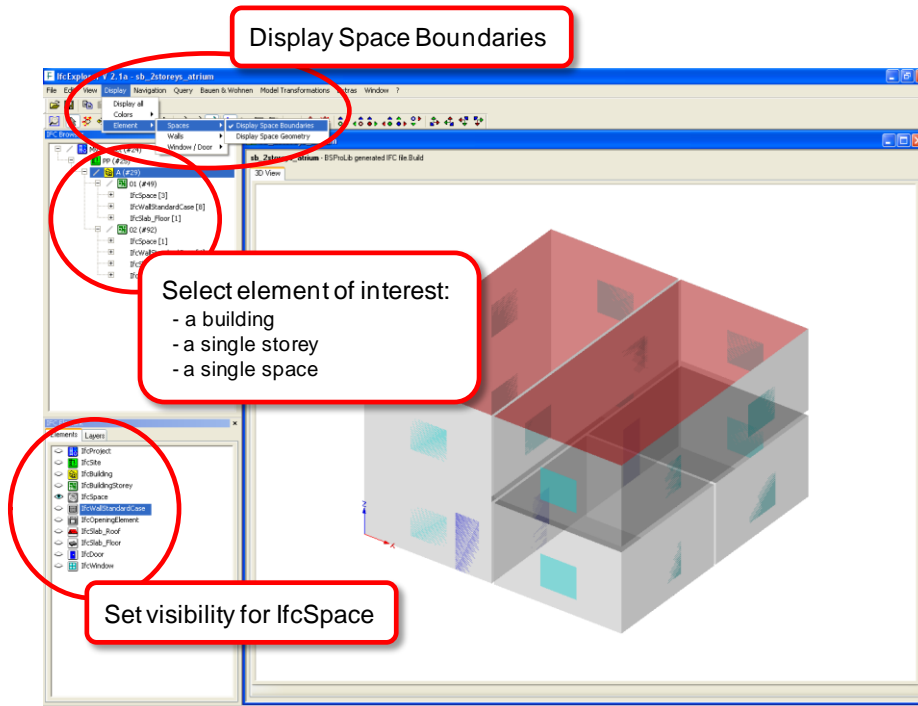
Figure 26: Required settings to show space boundaries with FZKViewer/IfcStoreyViewer

6 REFERENCES

IFC2x3 Online Documentation
available at: http://www.iai-international.org/Model/R2x3_final/index.htm

Liebich T. ed. (2004): *IFC2x Edition 2 – Model Implementation Guide.* International Alliance for Interoperability, Version 1.7, 2004. Available at: http://www.iai-international.org/Model/IFC(ifcXML)Specs.html

Web-site of the Implementer Support Group (ISG): http://www.iai.hm.edu/

Weise M. & Liebich T. (2008): *Implementation Guide for Definition of Space Boundaries for Energy Analysis.* Report of the InPro project, available at: …

7 OPEN ISSUES

This section documents issues that have not yet been resolved, such as incompatibilities between agreements for 1st level space boundaries and agreements for 2nd level space boundaries.

Issues that have not been resolved as of this version of the document include:

- Issue #1: ~~General definition of different space boundary types (1st, 2nd, 3rd, 4th and 5th level) and use case scenarios.~~ DONE! -- in section 1.
- Issue #2: ~~Connection geometry: used types.~~ DONE! -- in section 2.
- Issue #3: Connection geometry: definition of openings.
- Issue #4: ~~Connection geometry: topological constraints.~~ DONE! -- in section 2.
- Issue #5: Clarify use of virtual elements (minimum requirements).
- Issue #6: efinition of virtual space boundaries for voids/openings.
- Issue #7: If going for "unification" of 3rd, 4th and 5th level space boundaries what about constraints for subdivision of space boundaries.
- Issue #8: Segmentation of round space boundaries.
- Issue #9: How to map 3rd level subtypes to IFC (name and description attribute).

Issue #2 (geometry types):

Description:

Due to the implementation agreement #CV-2x3-155 the connection geometry (of 1st level space boundaries) is limited to three types of surface geometry:

- *IfcCurveBoundedPlane*
- *IfcSurfaceOfLinearExtrusion*
- *IfcFaceBasedSurfaceModel*

▪ Planar connection geometries are defined by *IfcCurveBoundedPlane* (subtype of *IfcSurface -> IfcBounded-Surface*). Polygonal bounded connection geometry it is given by *IfcPolyline* whereas 2nd level space boundary examples always use *IfcCompositeCurve*.

Discussion:

Available 2nd level space boundary examples only deal with planar polygonal connection geometries that not necessarily require *IfcCompositeCurve*[6]. Possible geometry types should be discussed and harmonized with 1st level space boundary agreements.

Proposal:

The connection geometry for 2nd level shall be an restriction of the connection geometry for 1st level space boundaries. The restriction is that only planar faces with a single orientation are allowed. Therefore connection geometry for 1st level shall be:

- *IfcCurveBoundedPlane*
- ~~*IfcSurfaceOfLinearExtrusion* (with *SweptCurve->IfcArbitraryOpenProfileDef,Curve* being (1) *IfcPolyline* with 2 points, or (2) *IfcTrimmedCurve* with *BaseCurve=IfcLine*.~~
- *IfcFaceBasedSurfaceModel*

Agreement:

Second level will use only the IfcCurveBoundedPlane and IfcFaceBasedSurfaceModel. Curved geometries will be segmented.

Issue #3 (connection geometry with openings):

---

[6] For 1st level space boundaries *IfcCompositeCurve* is used for curve-bounded planes only.

> **Commented [RAS39]:** Will not use for 2nd level -- section 3 need explanation of what to do for 2nd level -- 16-32 facets in a full circle (i.e. 5 to 10 degrees of curve per segment)

> **Commented [RAS40]:** Let's not 'bake' this limitation in. There will be curved surface examples in the future. FURTHERMORE: this proposal is incompatible with the proposal that 2nd level space boundaries must represent a 'breakdown' of 1st level space boundaries.

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Description:

1st level space boundaries omit the feature of inner boundaries (void within a surface) (*IfcCurveBoundedPlane.InnerBoundaries*), even if there is an opening (that might be filled by a window, door or virtual element). This is different to available examples of 2nd level space boundary connection geometry definitions. In addition to the surface without openings (e.g. for wall) there is a space boundary for the "opening" (e.g. a window in the wall) so that the surface of the opening is covered twice.

For further information see **Error! Reference source not found.**.

Possible solutions:

A decision needed how to deal with openings and what "relationships" might be needed to remove overlapping connection geometries.

Solution proposed by Thomas -- Handling of openings shall be consistent between all space boundary levels, i.e. 1st level, 2nd + 3rd levels. An opening defines a virtual boundary.

Agreement:

This will be done as with 1st level SB.

Issue #4 (Topological constraints of connection geometry):
Description:

Energy analysis requires connections geometries defining a closed shell for the space. Gaps are regarded as an error or incomplete structure and thus must be identified when importing the data. Definition and testing of closed shells can be supported by using a topological structure that is defined on the basis of equal 0D (vertexes) and 1D (edges) elements.

For further information see Example 7 and Figure 9.

Possible solutions:

General questions:
- Do we want to ask for topological structures?
- What constraints should apply for equal elements (equal by value -> requires to talk about precision, or equal by instance)

Agreement:

Space boundaries of a space shall result into a closed shell for all space boundary levels, i.e. 1st level, 2nd level, 3rd level. The testing of closed shells is to be done by the importing system (middleware, preprocessor, quality checker). The IFC file will not contain topological entities (*IfcVertex, IfcEdge, IfcFace*).

Issue #5 (Virtual elements):
Description:

In case of having a void 1st level space boundaries require the opening (as a void of a wall/ slab) to define a virtual space boundary It thus changes a where rule WR of IFC2x3[7]. According to the WR openings are currently not allowed to be used for virtual space boundaries. This is withdrawn by the implementer agreement #155[8].

Possible solutions:

General questions:
- Do we want to allow using opening elements (*IfcOpeningElement*) to be a boundary element for virtual space boundaries as agreed for 1st level space boundaries?

---

[7] The implementation agreement #CV-2x3-155 extends WR1 of *IfcRelSpaceBoundary*, which does not include opening elements for virtual space boundaries.

[8] This will be changed in IFC2x4 where a space boundary element becomes mandatory also for virtual space boundaries.

Commented [RAS41]: It would be much better to require openings in 1st and 2nd level SB such that the SB for doors/windows 'fit' the opening --- and we truly have a close shell --- not multiple overlaps.

Commented [RAS42]: I believe this is now handled. Any objections to removing this section?

Commented [RAS43]: LBNL says this is NOT TRUE. Who is saying this?

Commented [RAS44]: YES

Commented [RAS45]: If we maintain the '2nd level is a breakdown of 1st level' proposal -- then the topological relationships should be very simple. I.e. a collection of 2nd level SB together shall be equal to one first level SB.

Commented [RAS46]: WHY?

Commented [RAS47]: It seems to me -- this should be treated the same as a virtual space boundary. That is --- large heat flow, no resistance.

- In case of asking for virtual elements (*IfcVirtualElement*) what minimum requirements should be fulfilled by such elements (just a dummy object, definition of local placement + geometry, integration into the building structure, etc.). For further comments see chapter 4.3.

Possible solutions:

Solution proposed by Thomas -- Handling of openings shall be consistent between all space boundary levels, i.e. 1st level, 2nd level, 3rd level. An opening defines a virtual boundary.

Agreement:

We will ignore WR #CV-2x3-155 in all 2x3 implementations. It has been removed in 2x4.

Issue #6 (Virtual space boundaries):

Description:

What constraints apply for virtual space boundaries? This question is related to issues #3, #4 and #5 and is described in Figure 9.

Possible solutions:

General questions:
- Do we allow "displacement" of virtual boundaries as shown in Figure 9?
- If "inner boundaries" are use for describing openings should we make assertions about definition/reuse of virtual space boundary geometry?
- Depending on minimum requirements for virtual elements (placement, geometry) what constraints are expected?

Agreement:

For apps that model opening as an OpeningElement we will have 1 Virtual SB on each side of the opening -- consistent with the resolution of Issue #3.

For apps that model the opening as Brep -- they will be expected to include 3rd level space boundaries around the 'sides' of the opening + 1 virtual SB at the plane where the two spaces touch -- OR 2 virtual SBs that are coplanar with each face of the wall or slab.

Issue #7 (constraints for >2nd level space boundaries):

Description:

Issue #1 provides a very general definition for >2nd level space boundaries, which in case of avoiding further subdivision into 3rd, 4th and 5th level gives some freedom for its definition. This is shown in Figure 27 and Figure 28 where for the same example two slightly different results have been achieved.

SB #5609
(Wall #1274)

SB #5457
(Wall #1083)

SB #5409
(Wall #1274)

SB #5553
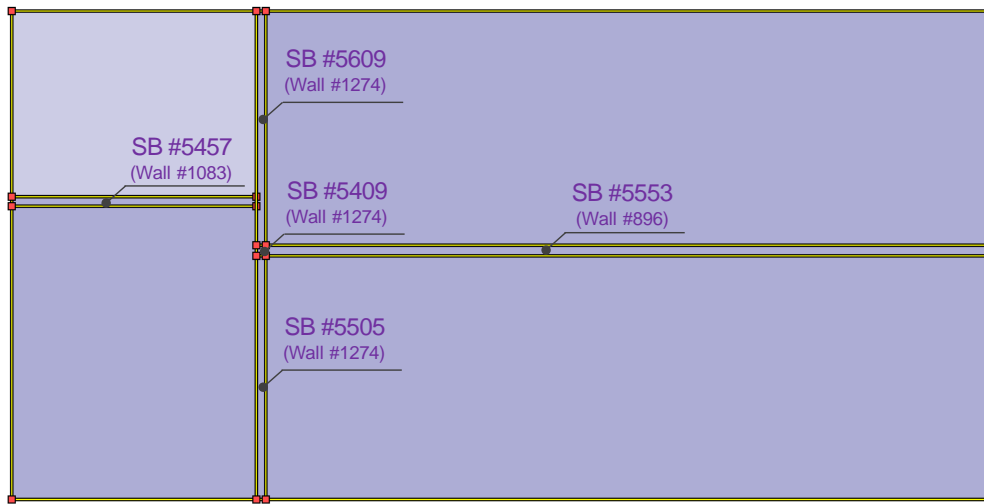(Wall #896)

SB #5505
(Wall #1274)

Figure 27: 5 ">2nd Level" space boundaries for a slab according to three inner walls.
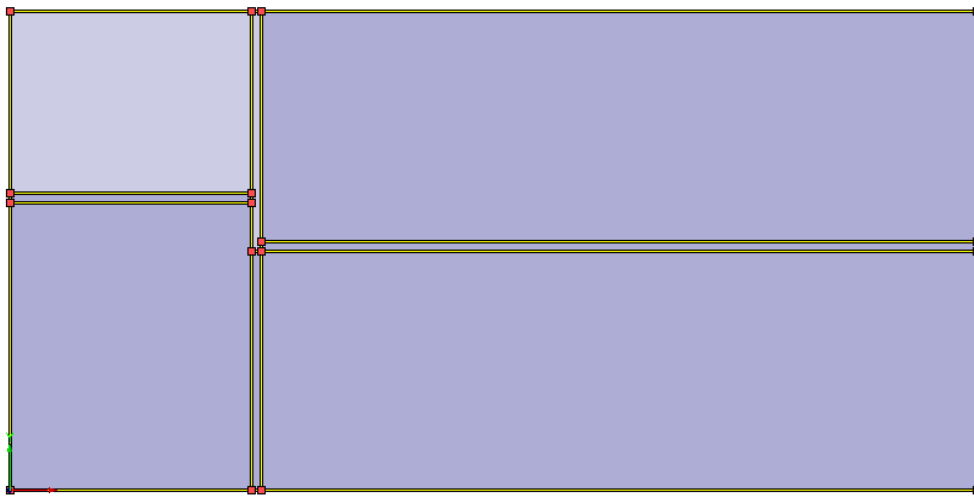

Figure 28: Same example as shown in Figure 27 but with only 4 ">2nd Level" space boundaries.

Possible solutions:

General questions:

-   Do we want to provide rules for creation of >2nd level space boundaries

Agreement:

We will only include in the file 1st, and/or 2nd/3rd level SB --- we will document the 3 cases of 3rd level for review.

Implementation Guide: Space Boundaries for Energy Analysis

Issue #8 (segmentation of round space boundaries):

Description:

Thermal boundaries for thermal calculations need to be planar. Space boundaries of round walls may be cylindrical. How are round space boundaries segmented, and where does it occur (on export or on import)?

A further issue is, whether it is sufficient to have a single instance of *IfcSpaceBoundary* having multiple planar surfaces, e.g. by extruding a polyline into an *IfcSurfaceOfLinearExtrusion*, and by an *IfcFaceBasedSurfaceModel*, or does every planar surface has to be assigned to a separate instance of *IfcSpaceBoundary*.

Possible solutions:

See examples in the 1st level implementation guide (Weise & Liebich 2008).

- ☐ Use of *IfcSurfaceOfLinearExtrusion* + *IfcTrimmedCurve* (with constant height and radius)
- ☐ Segmentation for sloped boundaries

Agreement:

1 SB per segment in the segmented arc. Note: there will be SB of type 3(c) on each side of the vertex on the outside (convex) face of the curve. We need to test to ensure that these are included. If 2nd level SB is extended to the vertex, it won't work in 1D transfer simulation engines. Virtually all of today's simulation engines are 1D.

Issue #9 (Mapping of 3rd level space boundaries to IfcRelSpaceBoundary attributes):

Description:

See section 3.1.1. Do we expect subdivision of 3rd level space boundaries into subtypes a, b and c?

Possible solutions:

- IfcRelSpaceBoundary.Name = "2ndLevel"
- *IfcRelSpaceBoundary.Description* = "subtype a"=Space on other side, "subtype b"=building element on other side, "subtype c"=overlapping buildling elements on other side, "subtype d"=building element on other side in angled wall case. (b), (c), (d) were previously referred to as 3rd, 4th, and 5th level SB

Agreement:

Yes -- BIM authoring apps will put this information in the Description field --- and we will specify the strings. See page 8 of the Helsinki PPT slide deck.