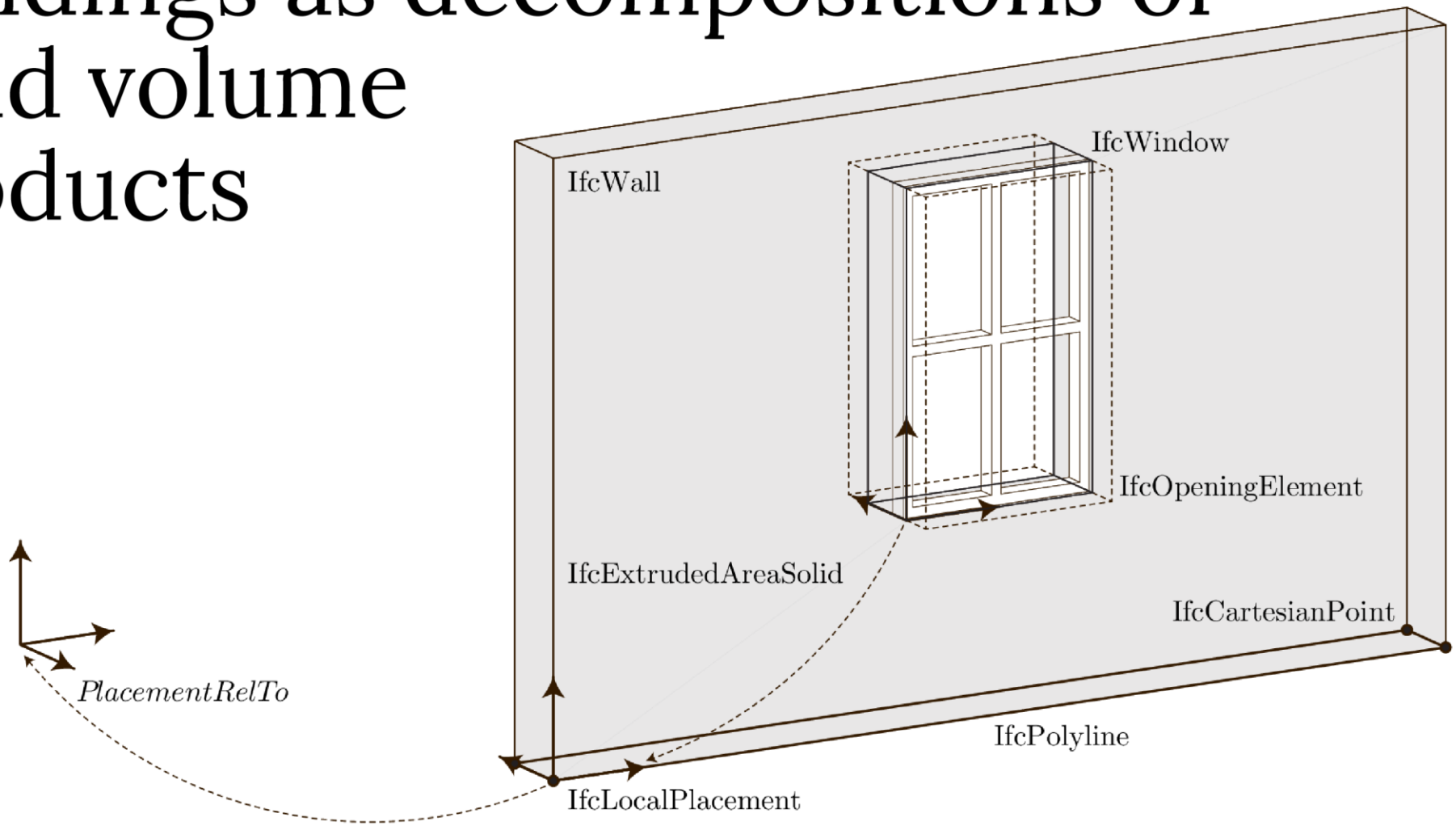
Multi-disciplinary geometry (libraries) in BIM and the IfcOpenShell software library

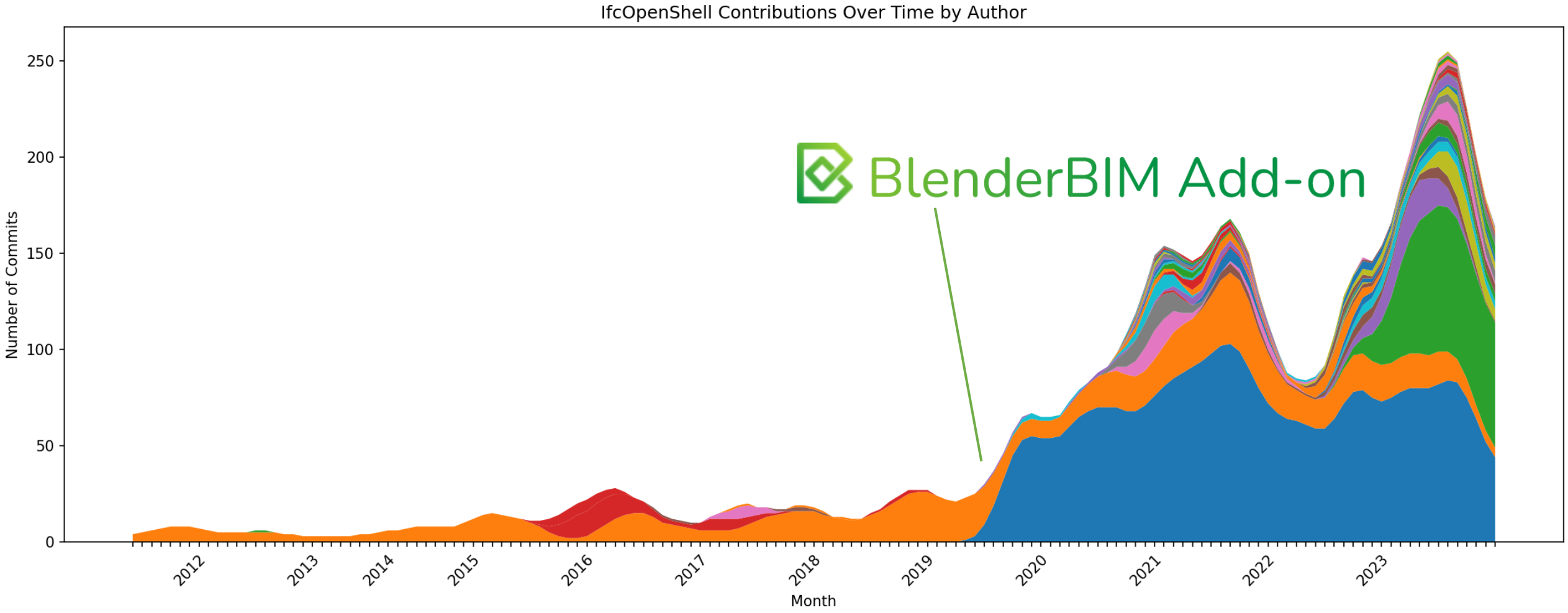
Thomas Krijnen

Buildings as decompositions of solid volume products

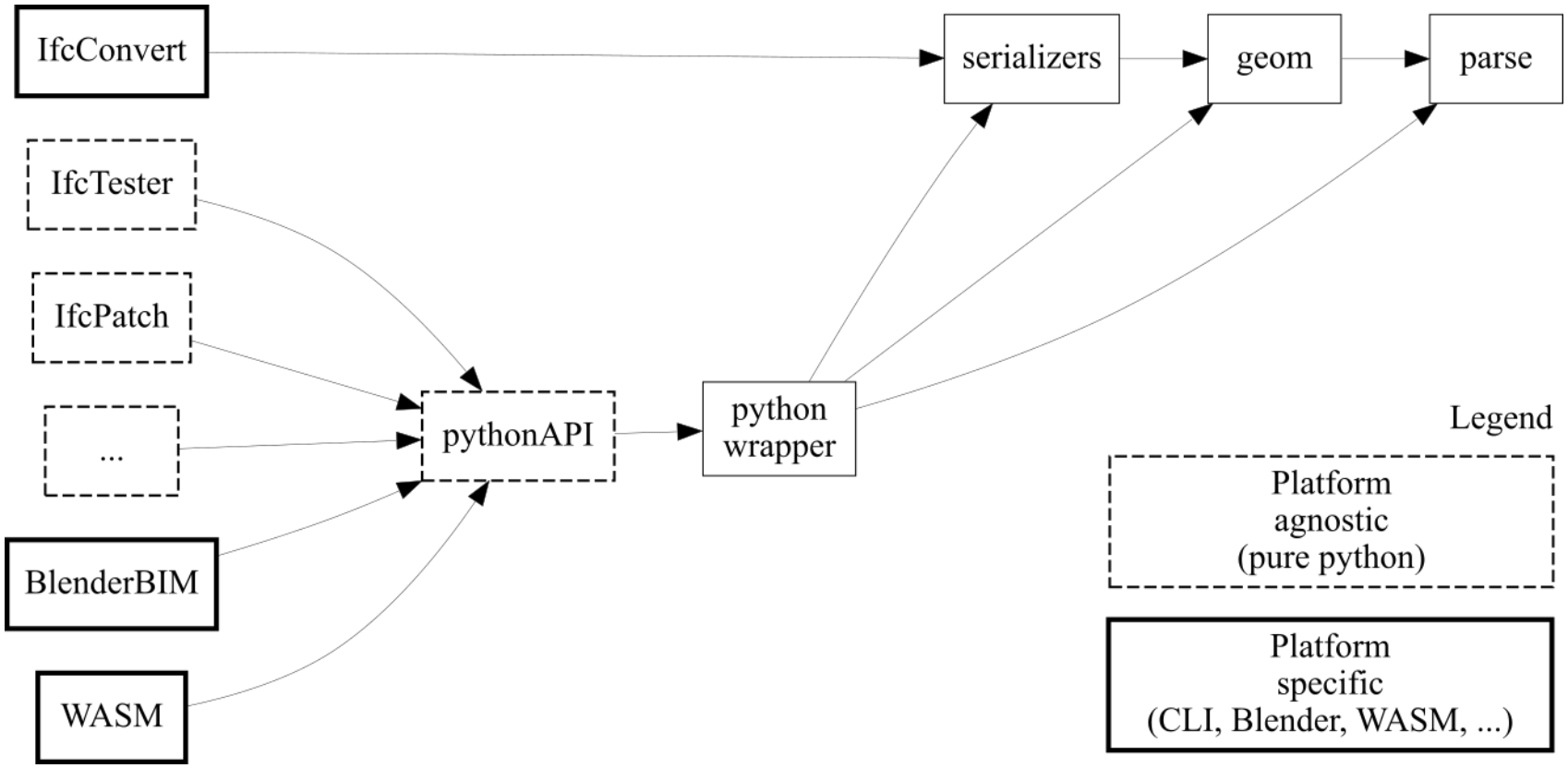


source: **(Pauwels, Krijnen, Terkaj & Beetz 2016)**

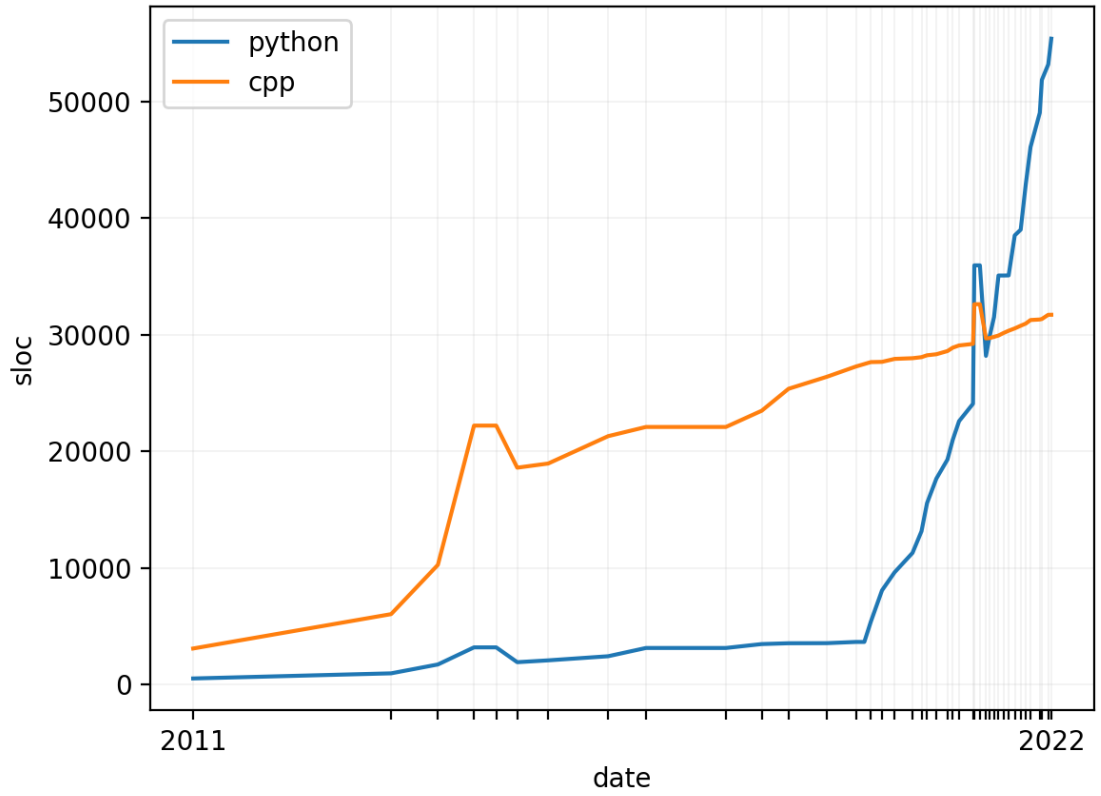
IfcOpenShell: contributors



IfcOpenShell: modules



IfcOpenShell: language



The aim: automation on BIM

Derive higher level geometric concepts in BIM

ex: an efficient manifold representation of the facade

A digital twin that can be updated over the operation phase of a building

ex: add a wall that splits a space in two, or the reverse

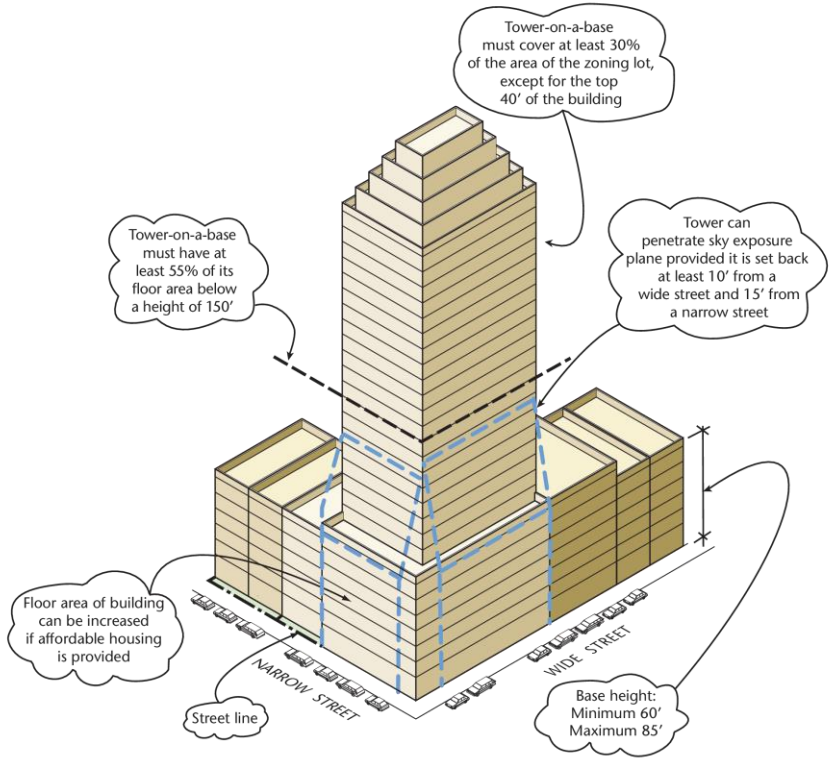
Multi-disciplinary challenges

Geometric analysis
- Solar potential
- Building code compliance
- Zoning regulations

Efficient visualization

Light weight models for mutation

Simulations
- thermal
- acoustics
- light



R10 General Residence District: Tower-on-a-Base				
R10[1]	**FAR** (max)	**Base Height** (min/max)	**Tower Lot Coverage** (min/max)	**Required Parking**[4] (min)
	10.0[2]	60–85 ft	30%–40%[3]	40% of dwelling units[5]

[1] *Commercial districts with an R10* ***residential district equivalent*** *are C1-9, C2-8, C4-6, C4-7, C5, C6-4, C6-5, C6-6, C6-7, C6-8 and C6-9*
[2] *Up to 12.0 FAR with* ***Inclusionary Housing Program*** *bonus*
[3] *Up to 50% for a zoning lot smaller than 20,000 square feet*
[4] *Waived in* ***Manhattan Core*** *and Long Island City*
[5] *20% if zoning lot is between 10,001 and 15,000; waived if zoning lot is 10,000 square feet or less, or if 15 or fewer spaces required*

https://www.nyc.gov/assets/planning/download/pdf/zoning/districts-tools/r10_tower.pdf

Multi-disciplinary challenges

Heat dissipation among spaces with thermal interfaces

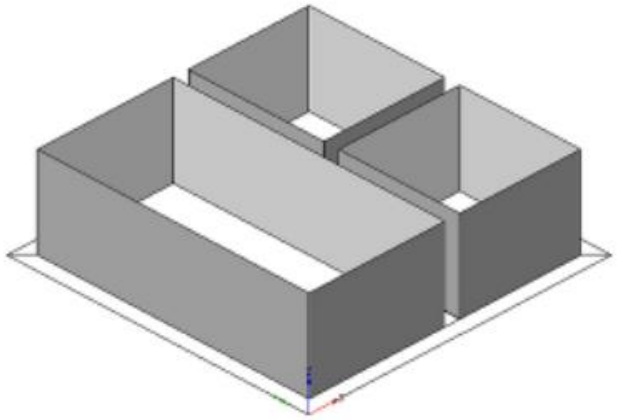


Figure 176 — Space boundary at first level

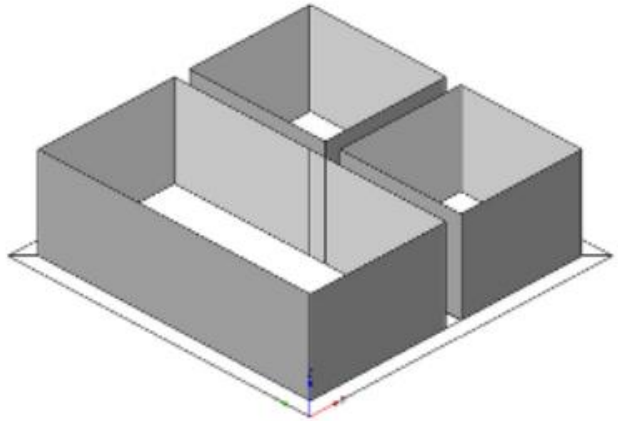


Figure 177 — Space boundary at second level

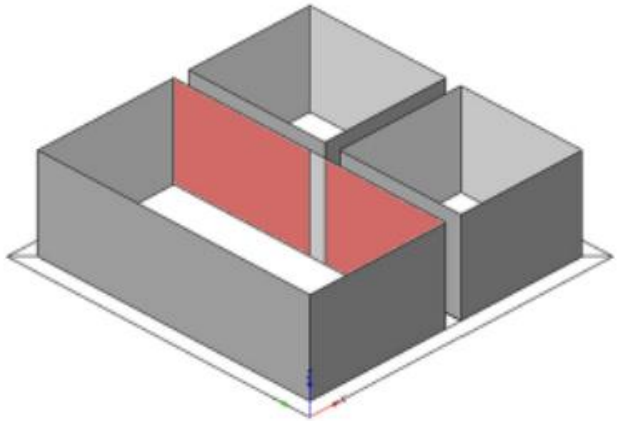


Figure 178 — Space boundary at second level type A

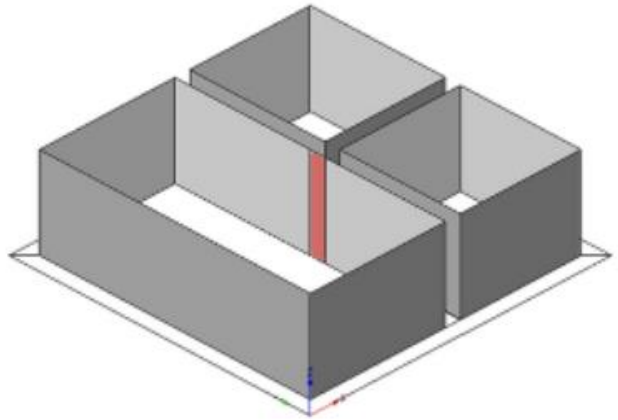
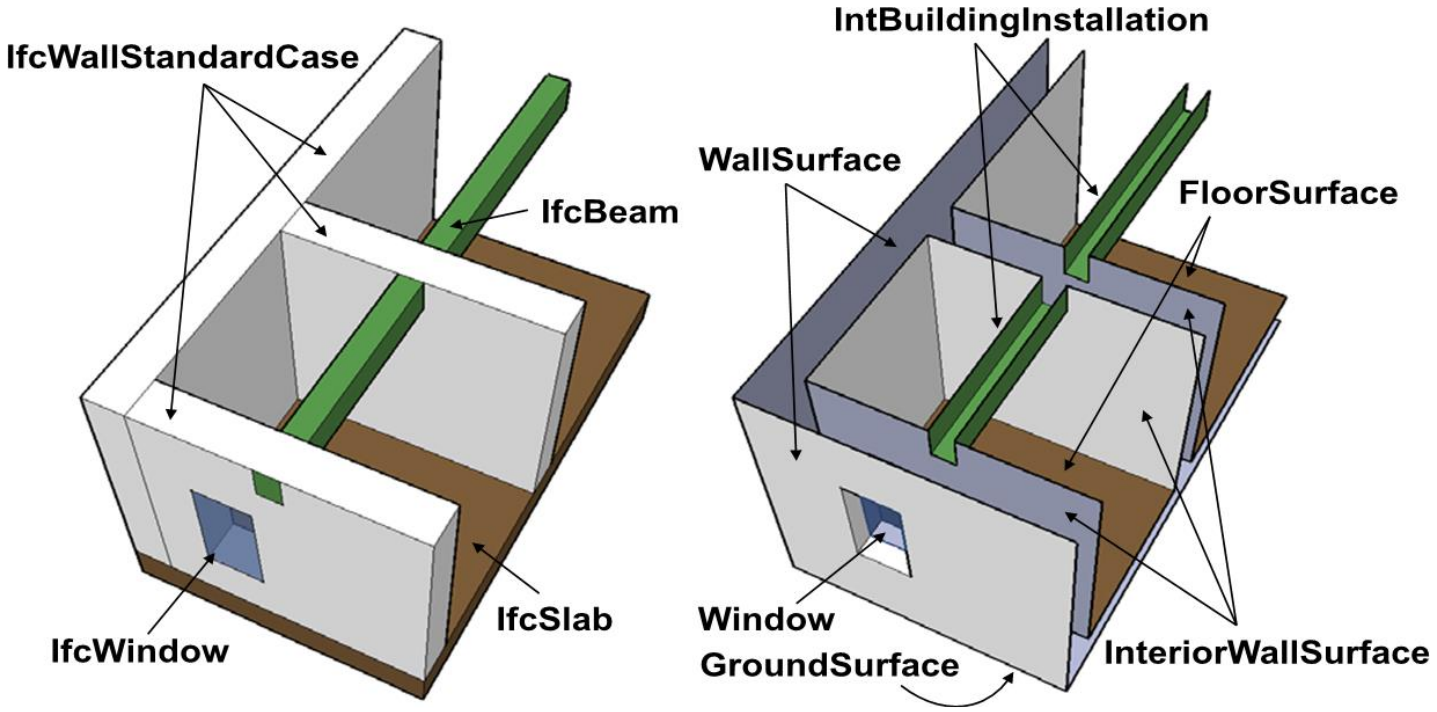


Figure 179 — Space boundary at second level type B

https://ifc43-docs.standards.buildingsmart.org/IFC/RELEASE/IFC4x3/HTML/lexical/IfcRelSpaceBoundary.htm

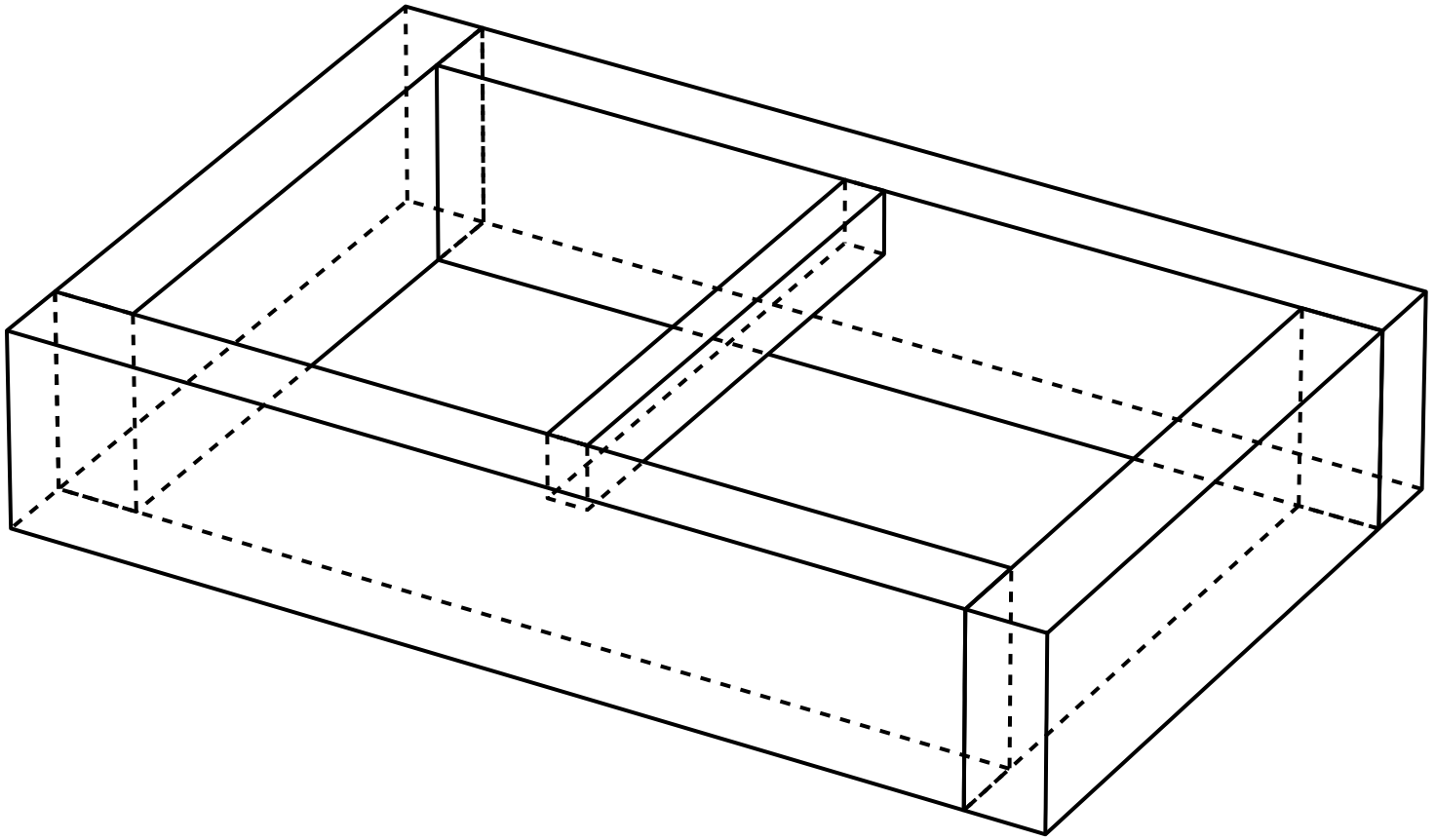
Multi-disciplinary challenges

Observable content in geospatial information

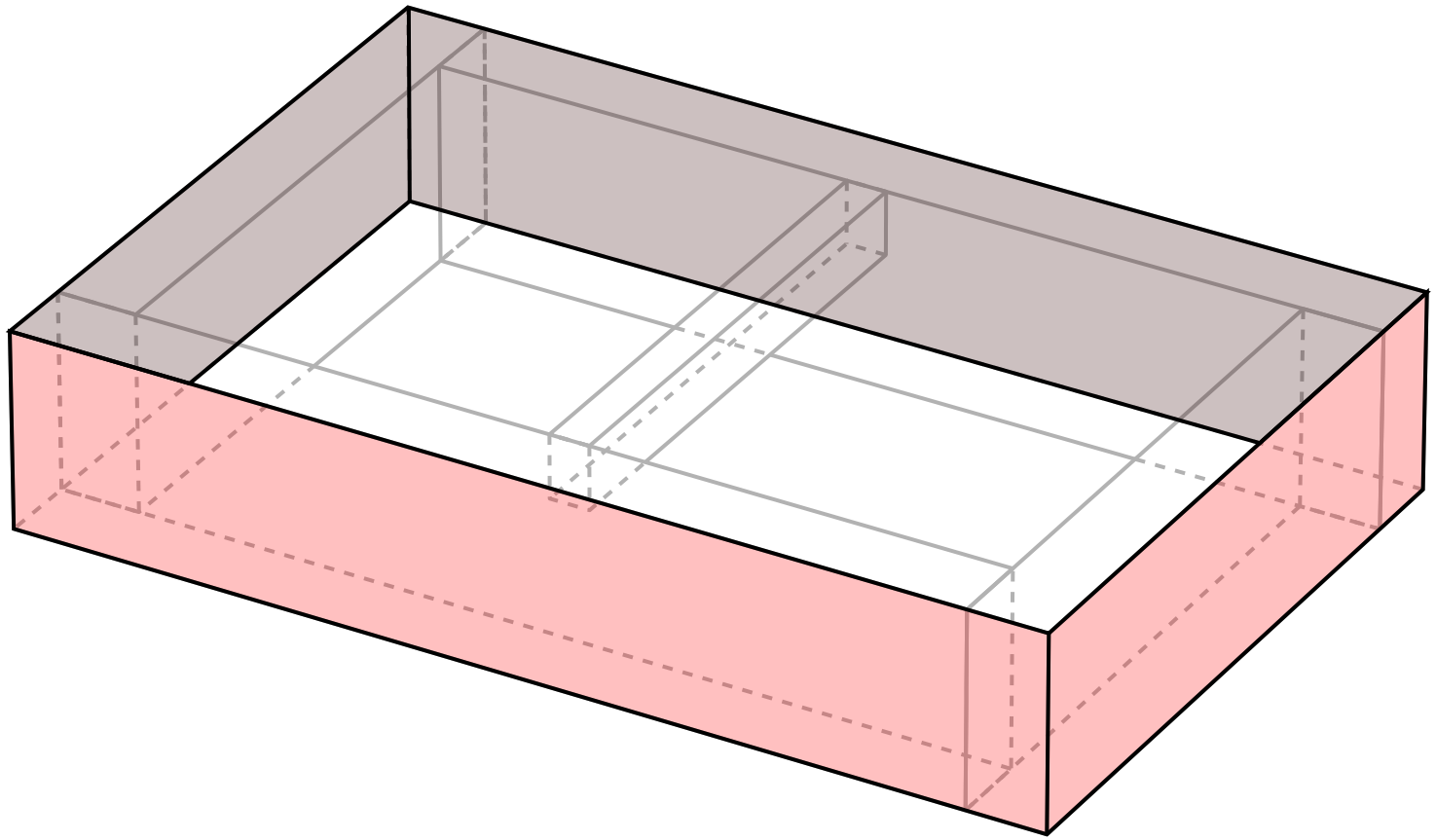


Nagel, Stadler, and Kolbe (2009)

Disjoint geometries



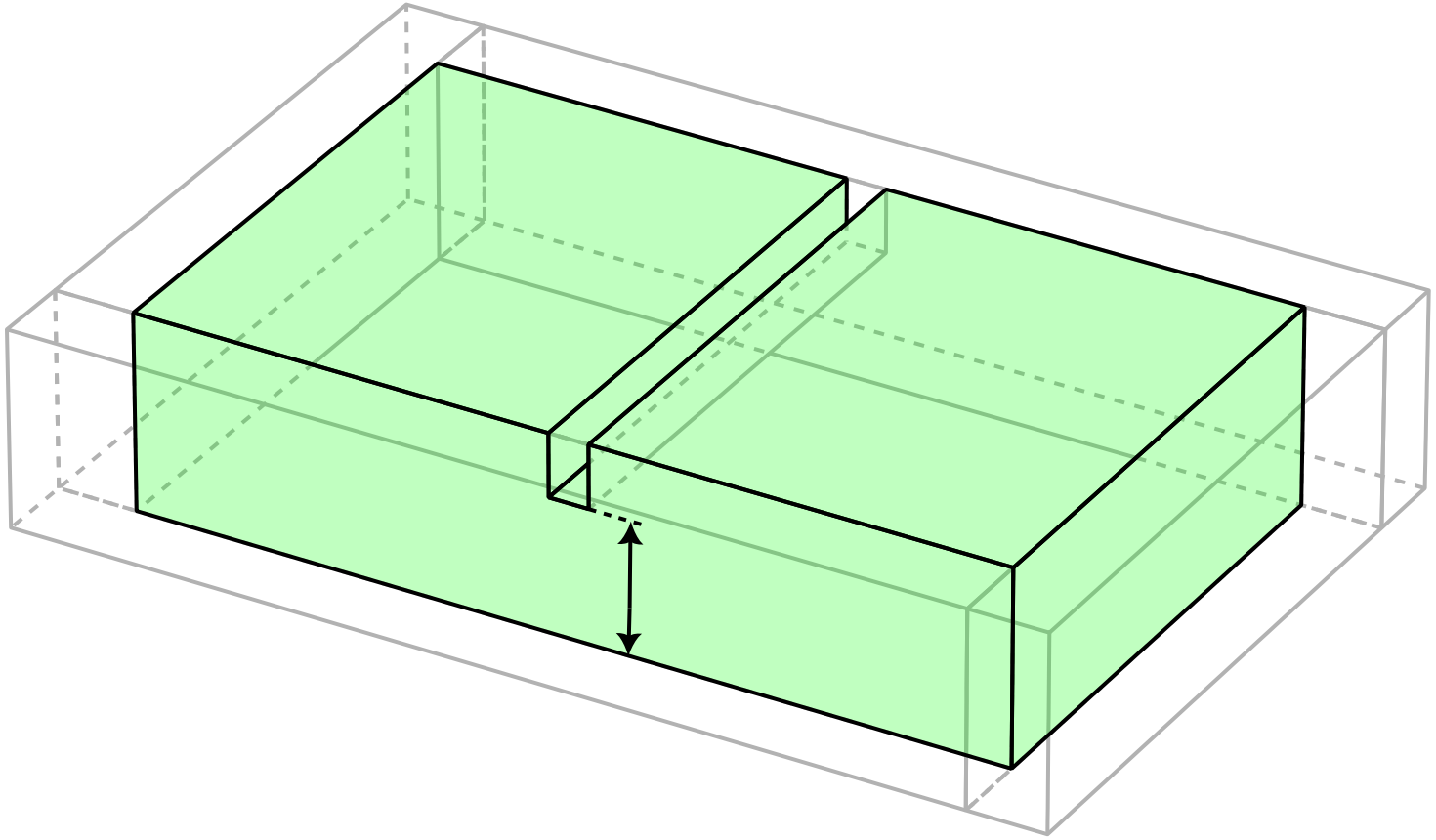
Aim: Manifold exterior shell of the building facade



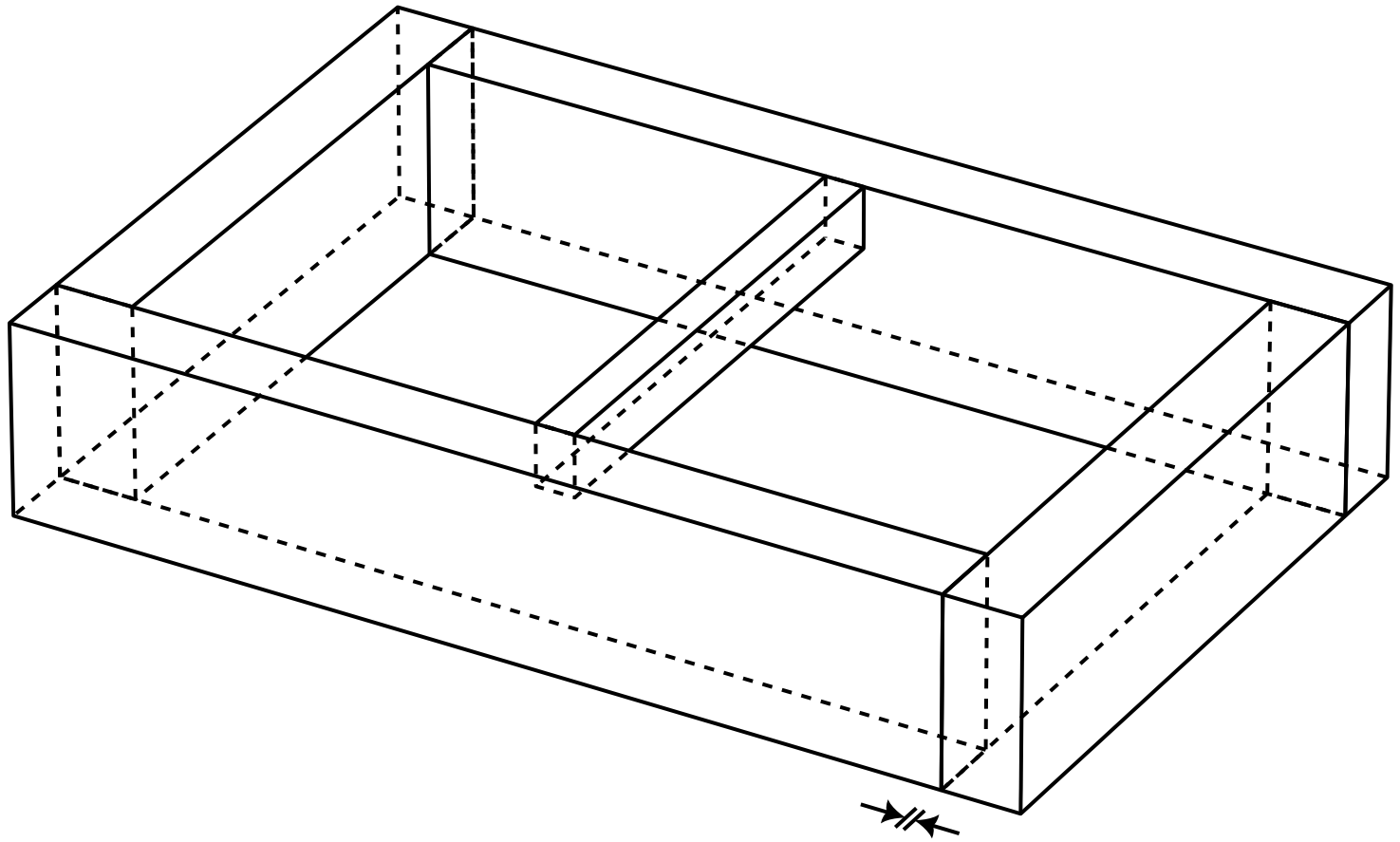
A problem

Data comes from heterogenous sources, cannot rely on a single authoring tool to construct such secondary representations

Aim: Interior space with interior elements imprinted



A problem: geometric imprecision



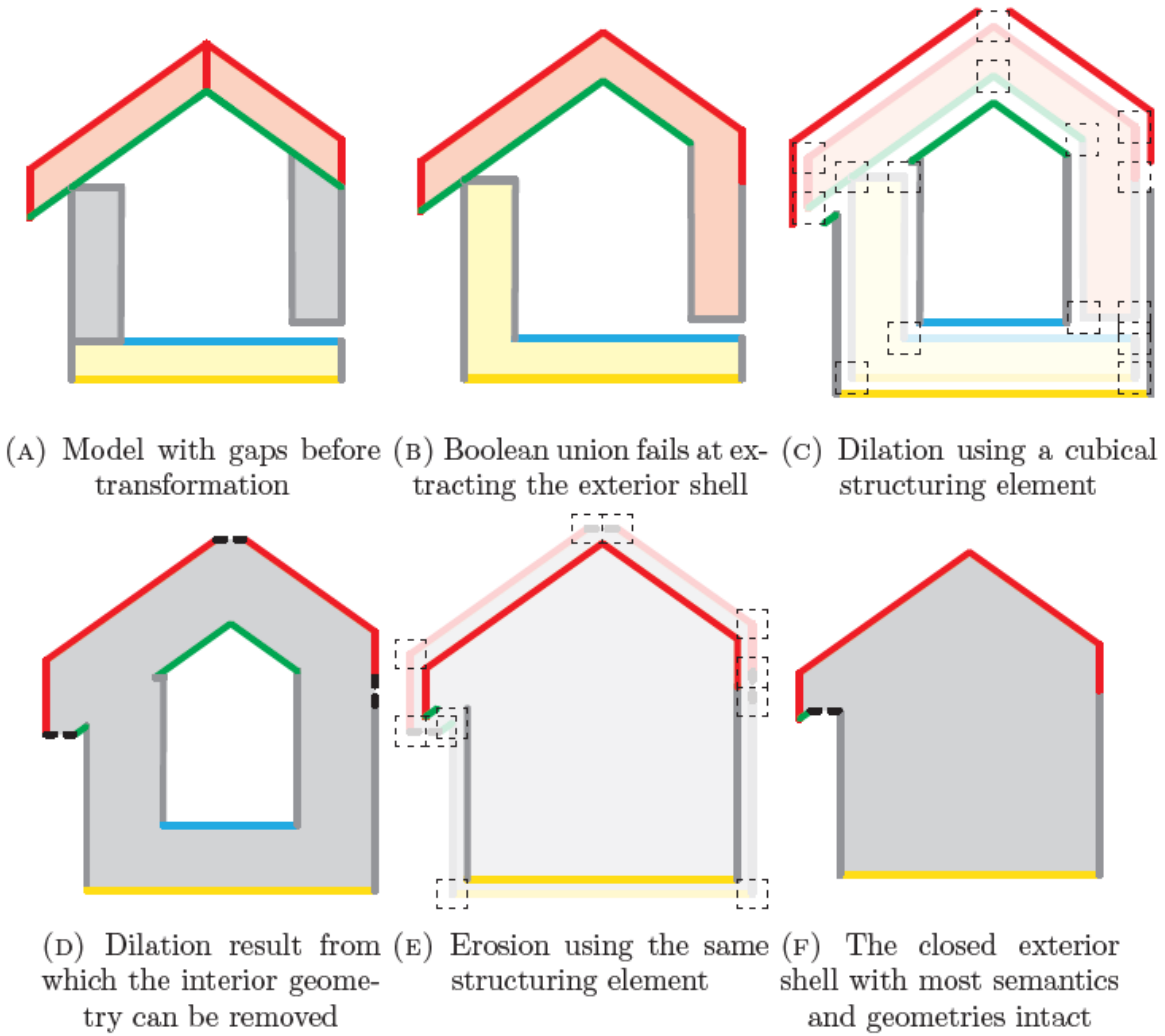
A problem:

Computational challenges

- ‘Fuzzy’ boolean operations have limited robustness

- ‘Exact’ boolean operations do not ‘fuse’ disjoint elements

Earlier attempt



(A) Model with gaps before transformation

(B) Boolean union fails at extracting the exterior shell

(C) Dilation using a cubical structuring element

(D) Dilation result from which the interior geometry can be removed

(E) Erosion using the same structuring element

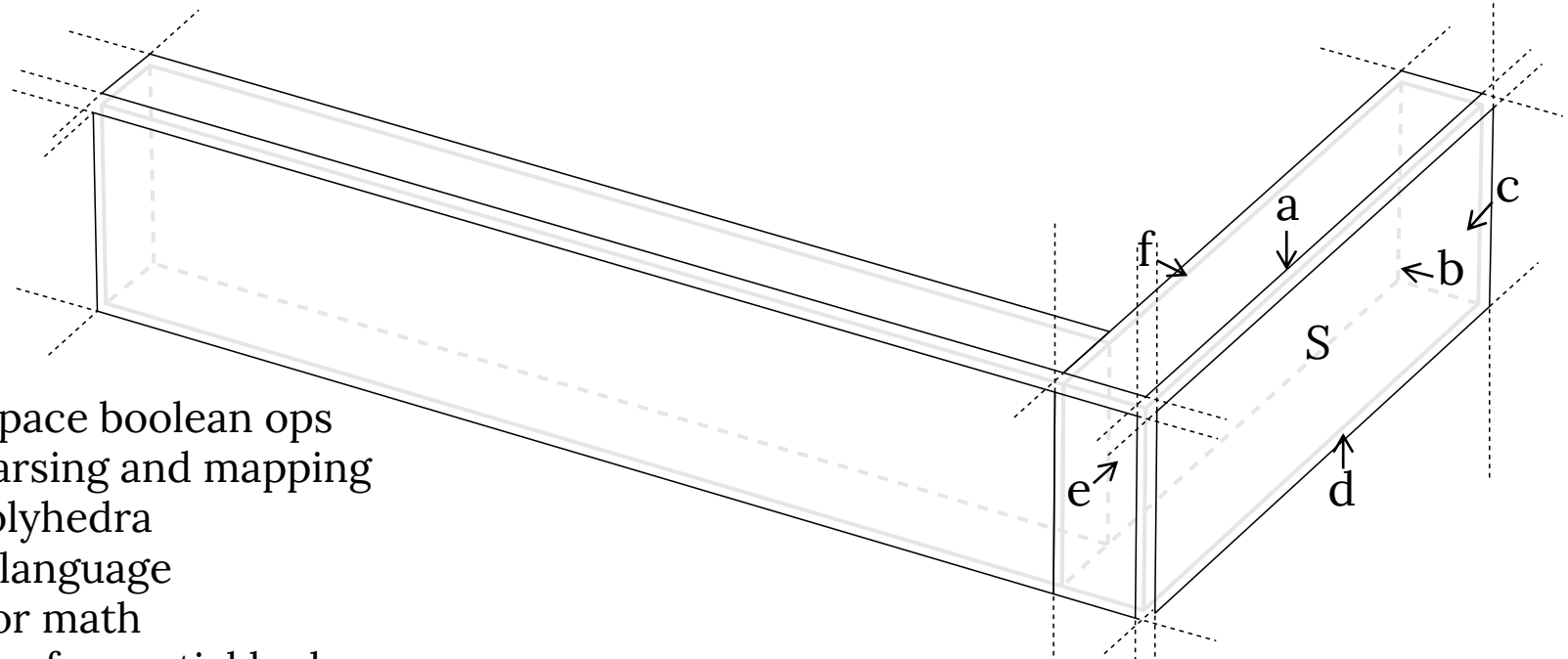
(F) The closed exterior shell with most semantics and geometries intact

FIGURE 3.9: Visualisation of the exterior shell extraction with closing

Donkers, Ledoux, Zhao and Stoter (2013)

Decompose into - and align - halfspaces

$a = ax + by + cz + d$
$b = \ldots$
$\ldots$
$S = a \cup b \cup c \cup d \cup e \cup f$

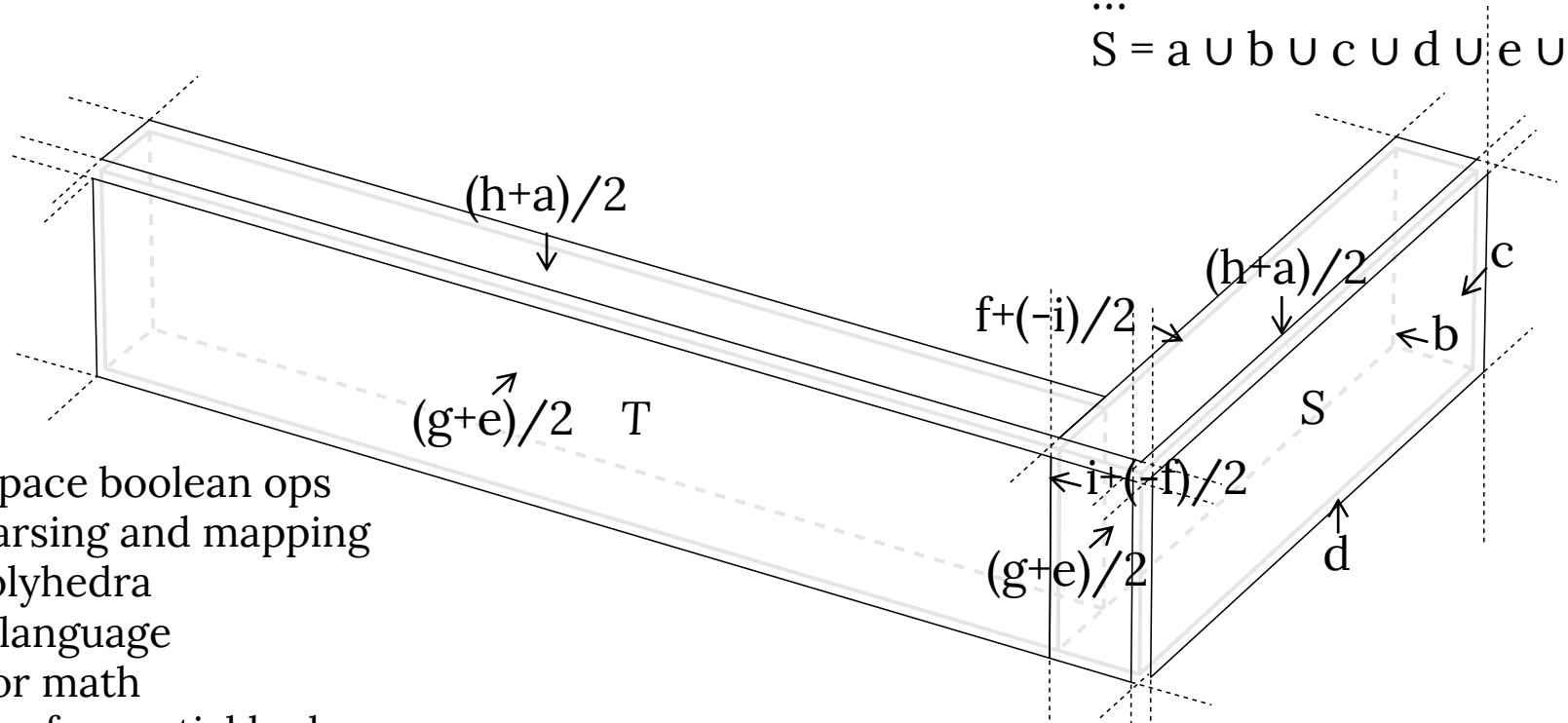


CGAL - halfspace boolean ops
IfcOpenShell - ifc parsing and mapping to polyhedra
python - glue language
numpy - vector math
scipy - kdtree for spatial lookup
igraph - connected components
C++ - main implementation language

https://cesium.com/blog/2023/07/26/ecosystem-grant-recipients-summer-2023/

Decompose into - and align - halfspaces

a = ax + by + cz + d
b = ...
...
S = a ∪ b ∪ c ∪ d ∪ e ∪ f



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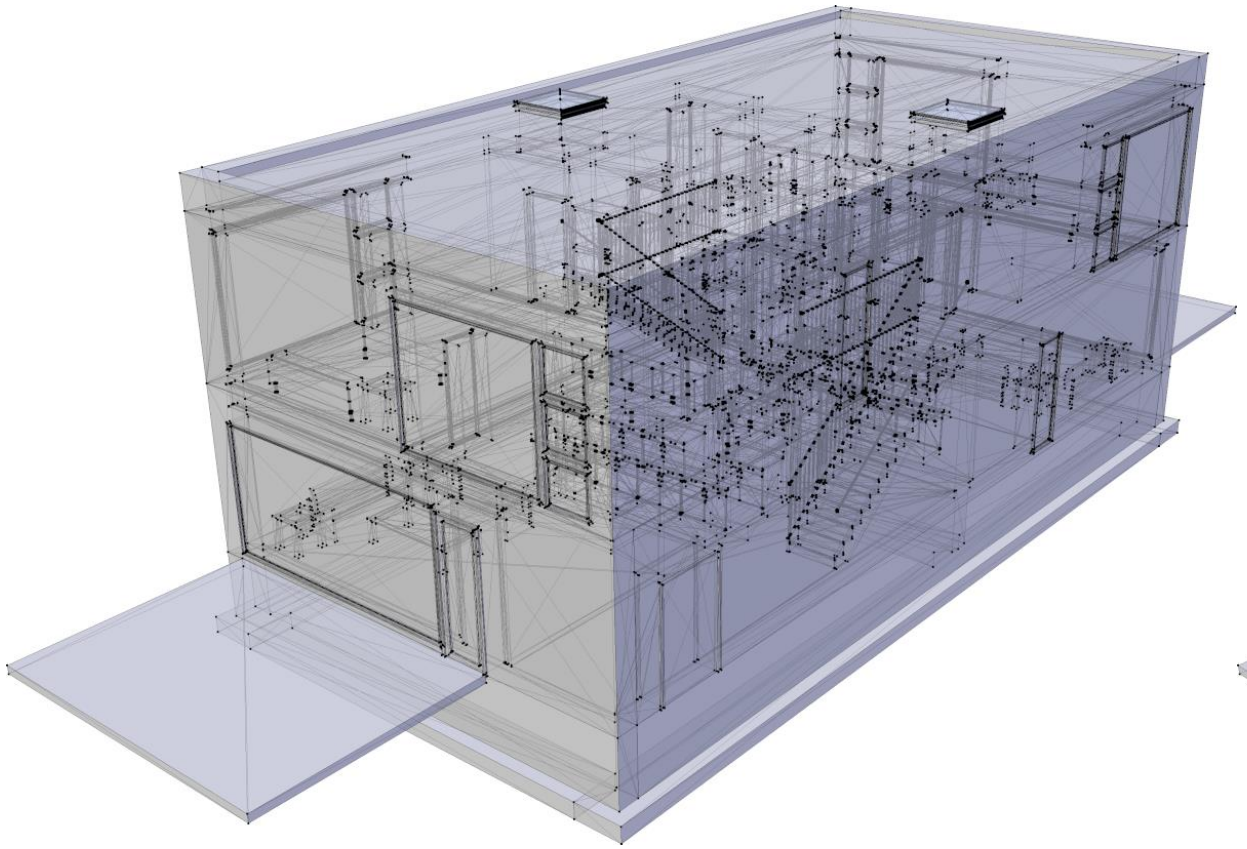
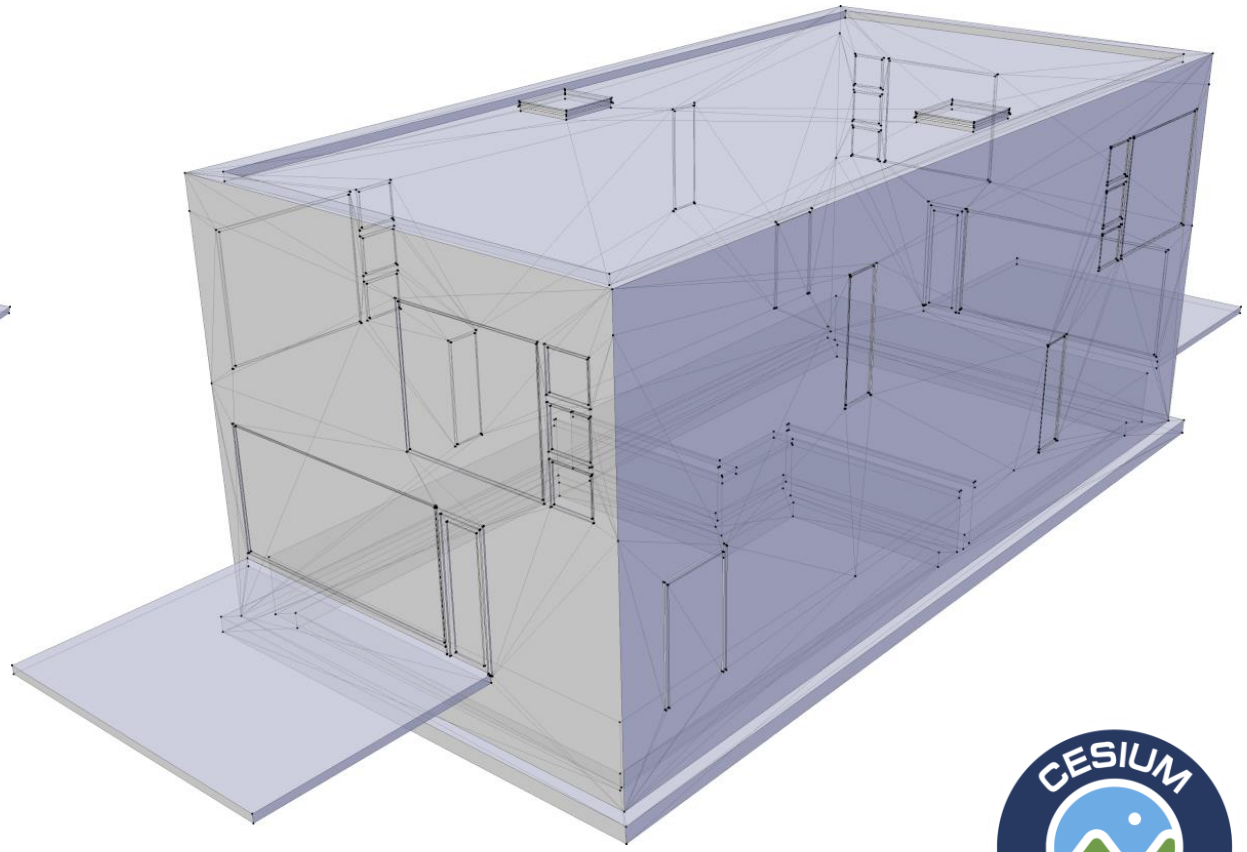
CESIUM ECOSYSTEM GRANT

The result

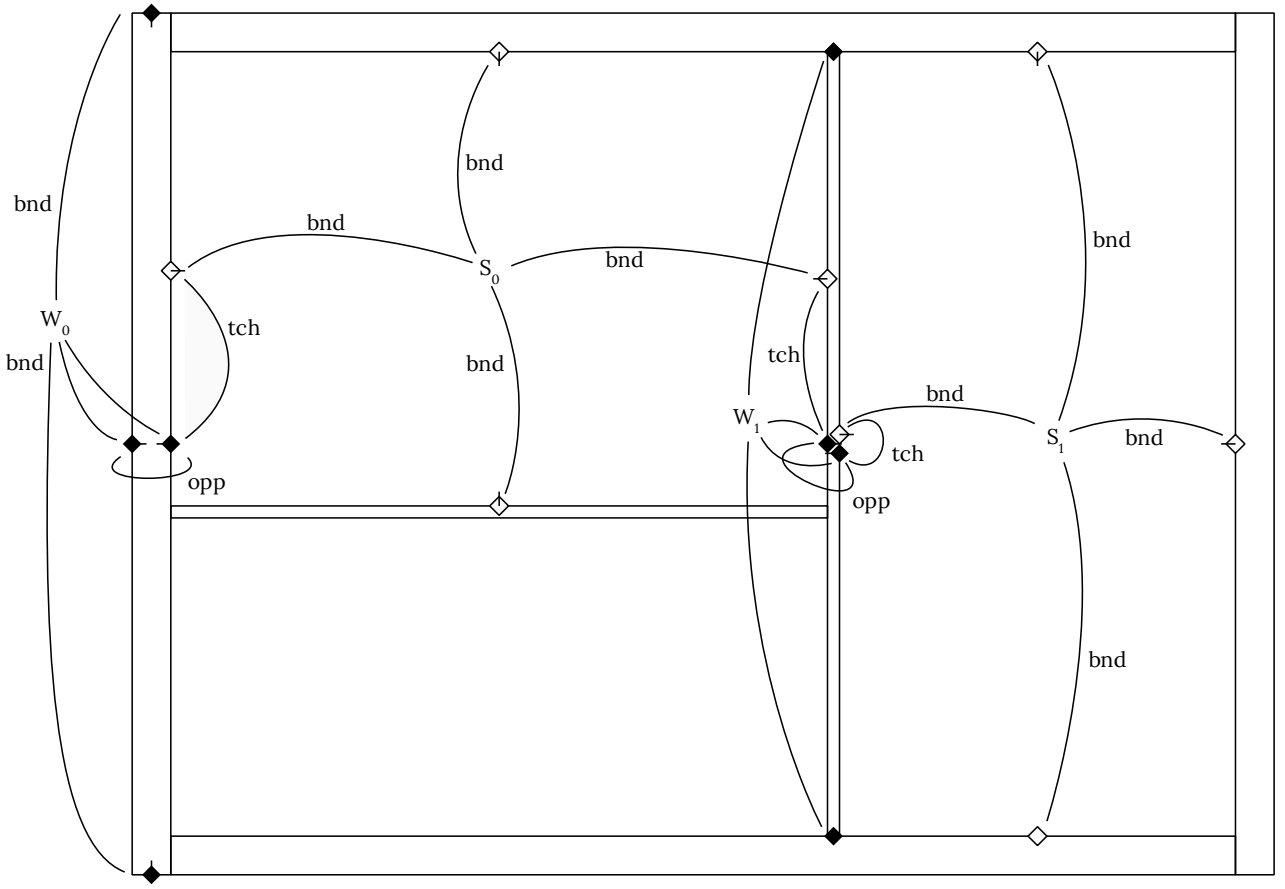




https://cesium.com/blog/2023/07/26/ecosystem-grant-recipients-summer-2023/

From spaces to zones using halfspaces

W_0	- wall
s_0	- space
opp	- opposite halfspace within solid
bnd	- boundary halfspace of solid
tch	- opposite halfspaces touching



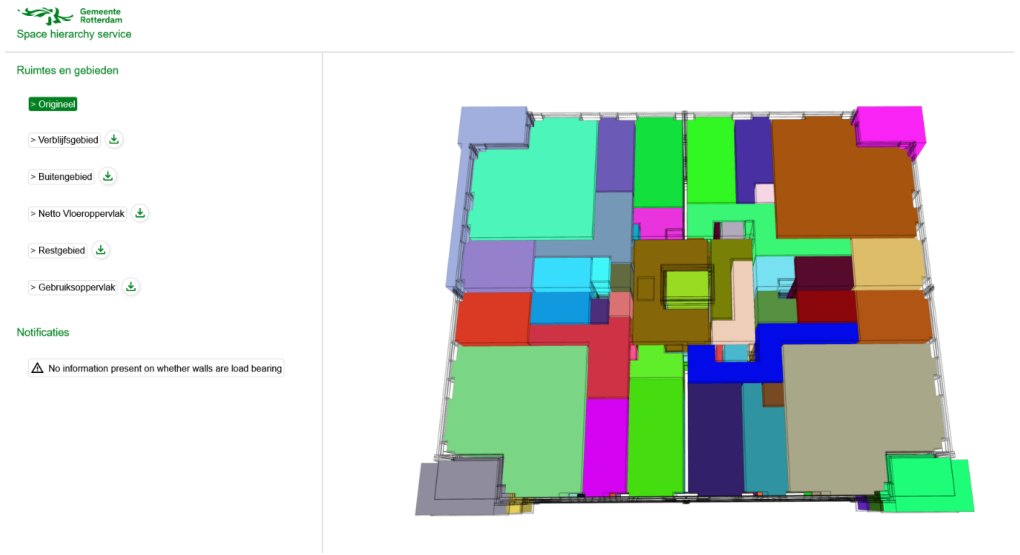
CGAL	– halfspace boolean ops
IfcOpenShell	– ifc parsing and mapping to polyhedra
rdflib	- RDF querying
python	- glue language
C++	- main implementation language

From spaces to zones using halfspaces

```
select ?i1 ?i2 ?e1 ?e2 ?w ?wi1 ?wi2 where {
    ?elem a <http://example.org/classes/Element> .
    ?elem <http://example.org/classes/ifcType> "IfcWall" .
    ?elem <http://example.org/classes/LoadBearing> FALSE .

    ?elem <http://example.org/classes/boundedBy> ?p1 .
    ?elem <http://example.org/classes/boundedBy> ?p2 .

    ?p1 <http://example.org/classes/opposite> ?p2 .

    ?p1 <http://example.org/classes/touches> ?q .
    ?p2 <http://example.org/classes/touches> ?r .

    ?sp1 <http://example.org/classes/ifcType> "IfcSpace" .
    ?sp2 <http://example.org/classes/ifcType> "IfcSpace" .
    ?sp1 <http://example.org/classes/boundedBy> ?q .
    ?sp2 <http://example.org/classes/boundedBy> ?r .

    ?q <http://example.org/classes/hasEquation> ?eq1 .
    ?r <http://example.org/classes/hasEquation> ?eq2 .

    ?sp1 <http://example.org/classes/hasIndex> ?i1 .
    ?sp2 <http://example.org/classes/hasIndex> ?i2 .
    ?p1 <http://example.org/classes/hasIndex> ?wi1 .
    ?p2 <http://example.org/classes/hasIndex> ?wi2 .
    ?elem <http://example.org/classes/hasIndex> ?w .
    ?q <http://example.org/classes/hasIndex>   ?e1 .
    ?r <http://example.org/classes/hasIndex>   ?e2 .

    filter(?p1 != ?p2)
}
```

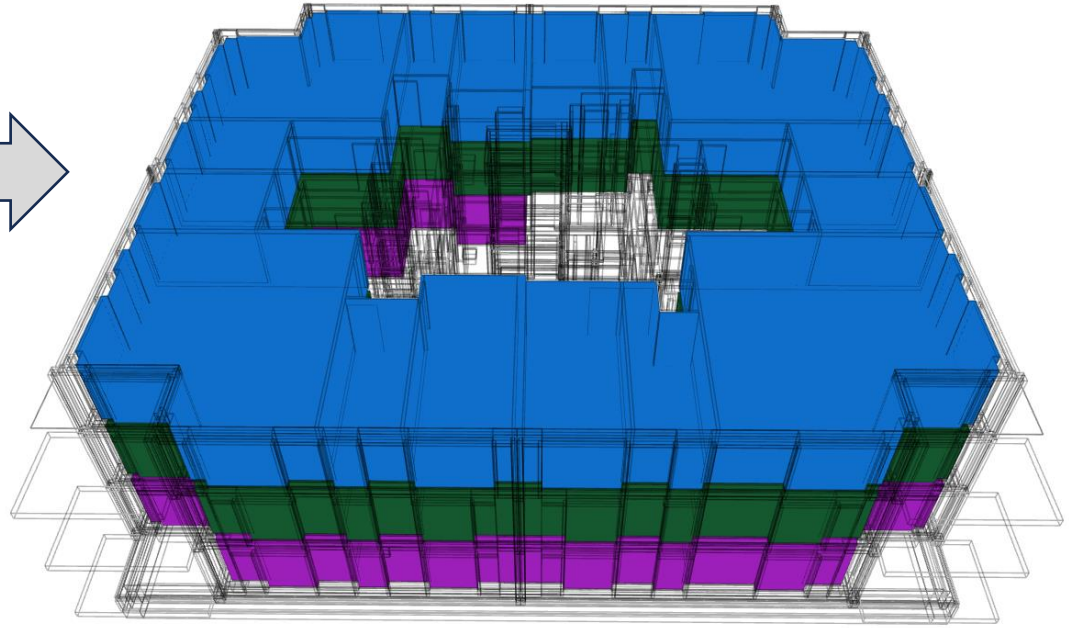
Embed runtime-queryable semantic filters

From spaces to zones using halfspaces

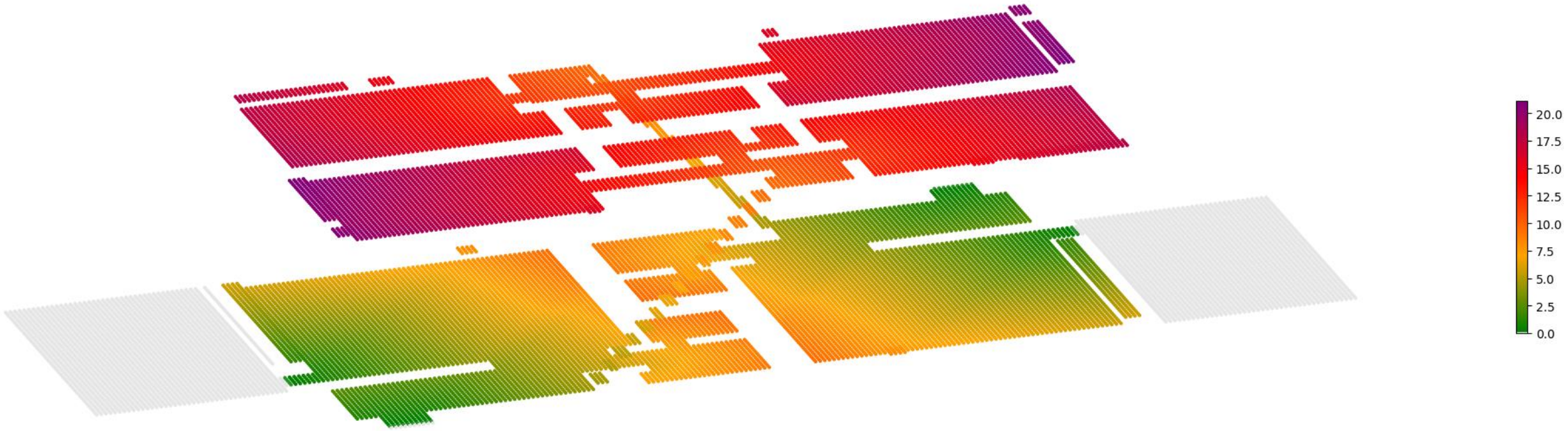


Individual spaces

Aggregated interior spaces joined accross non-loadbearing partitions



Voxels evacuation analysis

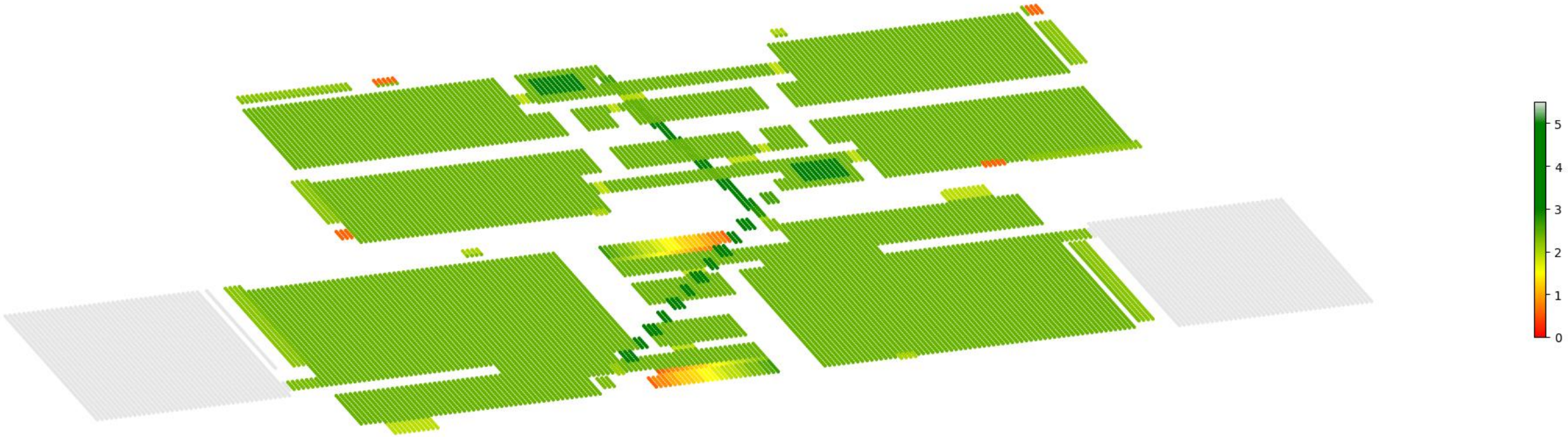


https://github.com/opensourceBIM/voxelization_toolkit

C++ - main implementation language

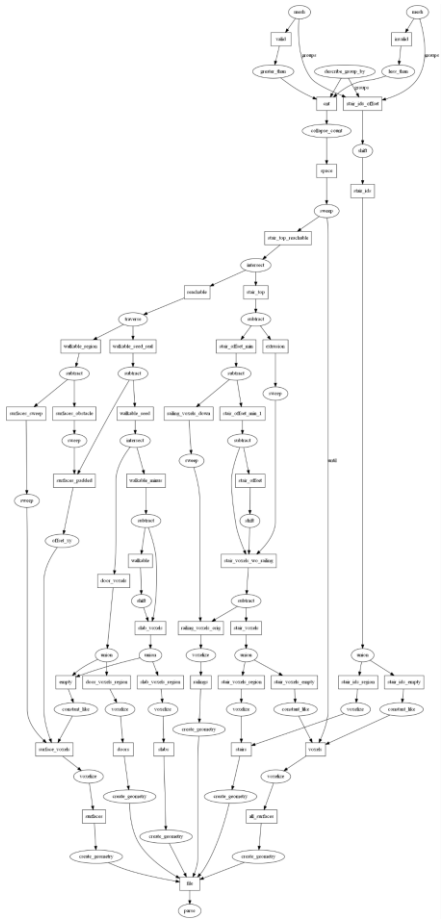
python - data visualization

Voxels headroom analysis



https://github.com/opensourceBIM/voxelization_toolkit

voxel analysis implementation language



```
file = parse("*.ifc")
all_surfaces = create_geometry(file, exclude={"IfcSpace", "IfcOpeningElement", …})
voxels = voxelize(all_surfaces)

stairs = create_geometry(file, include={"IfcStair"})
stair_ids_region = voxelize(stairs, type="uint", method="surface")
stair_ids_empty = constant_like(voxels, 0, type="uint")
stair_ids = union(stair_ids_region, stair_ids_empty)
stair_ids_offset = shift(stair_ids, dx=0, dy=0, dz=1)

stair_voxels_region = voxelize(stairs)
stair_voxels_empty = constant_like(voxels, 0)
stair_voxels = union(stair_voxels_region, stair_voxels_empty)

railings = create_geometry(file, include={"IfcRailing"}, optional=1)
railing_voxels_orig = voxelize(railings)
railing_voxels_down = sweep(railing_voxels_orig, dx=0.0, dy=0.0, dz=-1.0)
stair_voxels_wo_railing = subtract(stair_voxels, railing_voxels_orig)

stair_offset = shift(stair_voxels_wo_railing, dx=0, dy=0, dz=1)
stair_offset_min_1 = subtract(stair_offset, stair_voxels_wo_railing)
stair_offset_min = subtract(stair_offset_min_1, railing_voxels_down)
extrusion = sweep(stair_voxels_wo_railing, dx=0.0, dy=0.0, dz=-0.4)
stair_top = subtract(stair_offset_min, extrusion)

surfaces = create_geometry(file, exclude={"IfcOpeningElement", "IfcDoor", "IfcSpace", …})
…
```

voxelization

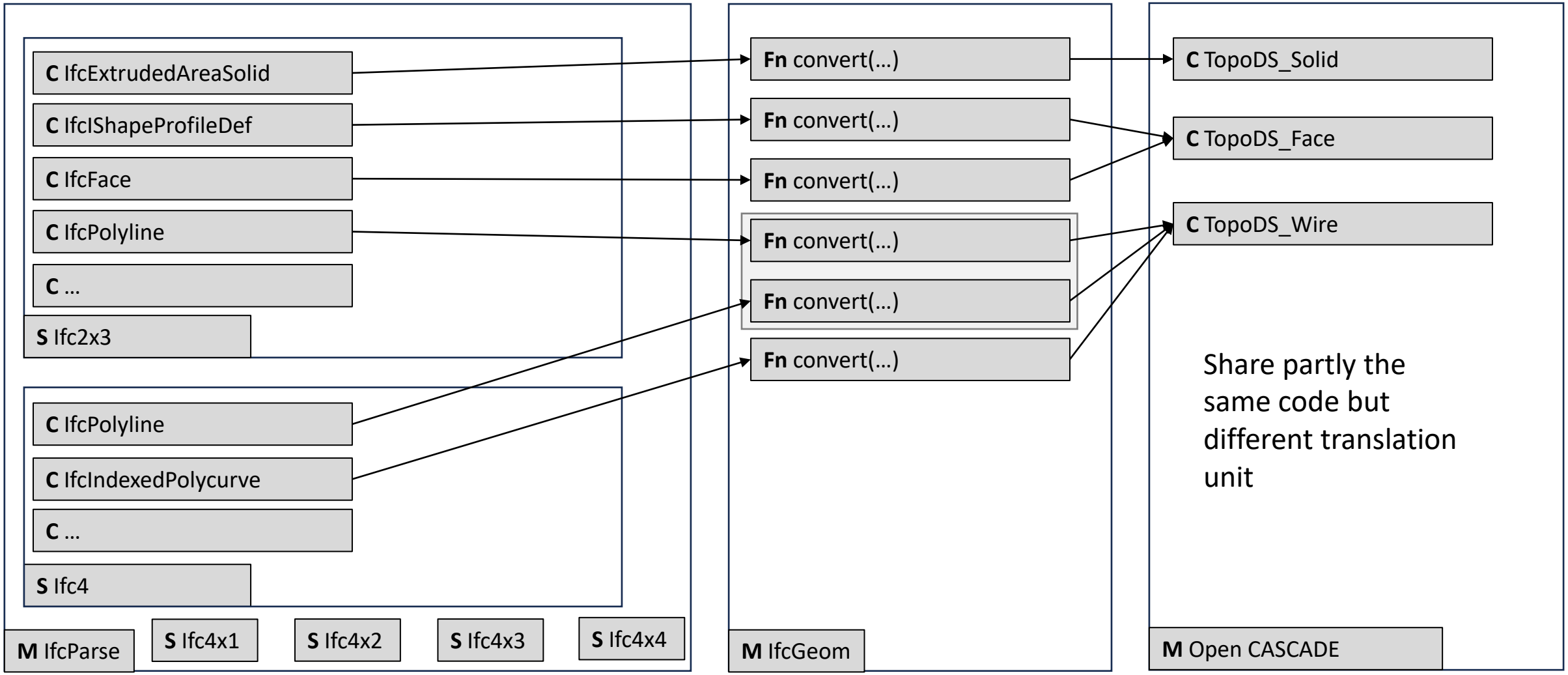
scalar/vector fields

robust and trivial boolean operations

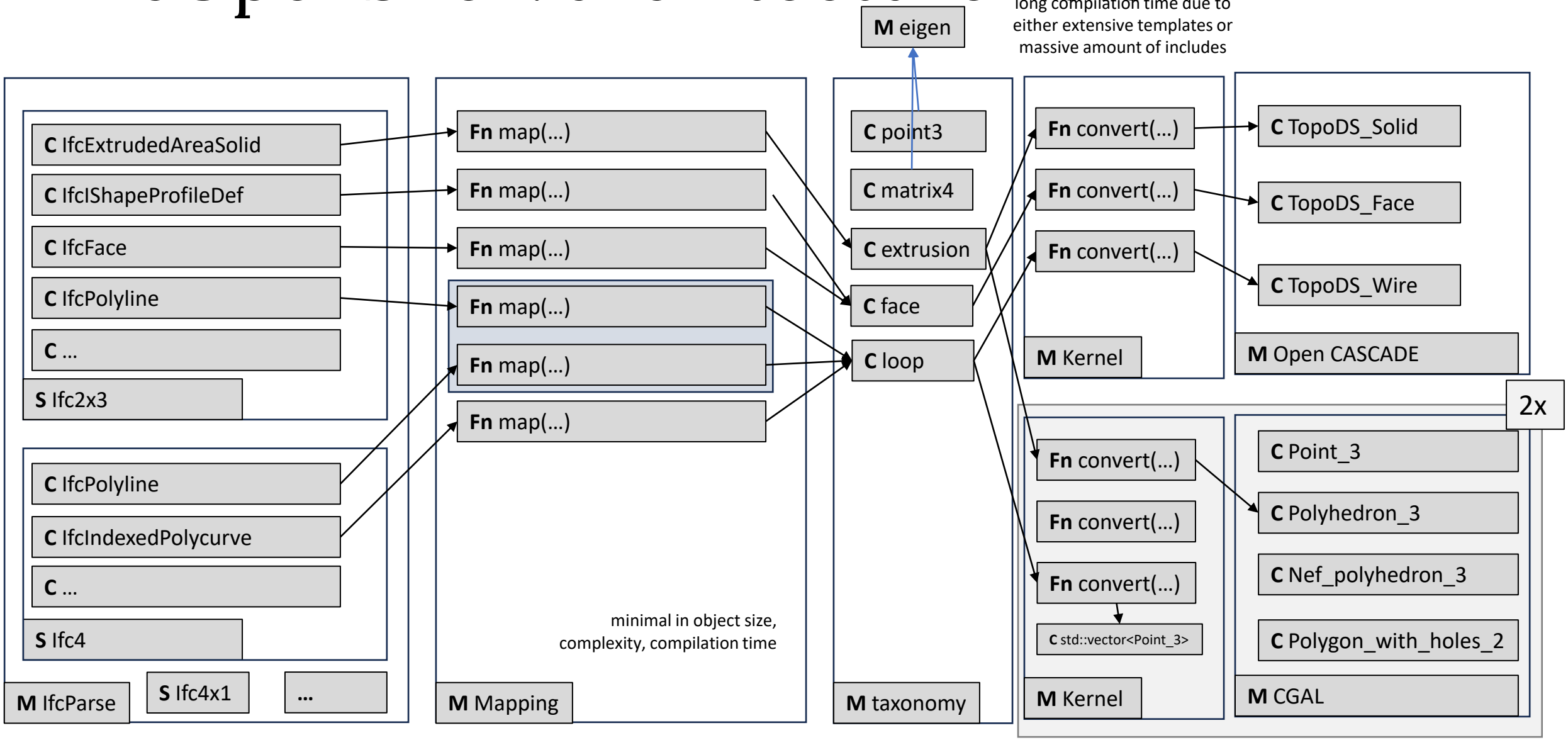
efficient and trivial distance calculation on superimposed grids

closes gaps due to modelling issues, precision issues or intentional gaps

IfcOpenShell: architecture v0.7



IfcOpenShell: architecture v0.8



CGAL

- Predominantly only polyhedra
- Exact rational number type
- Machine native interval for performance, fallback to exact when uncertain
- Friendly documentation, but chaotic packages
- Rather academic, not a focus on CAD

Open CASCADE

- BRep data model
- Cryptic, but consistent API and data model
- Tolerance and fuzziness
- Many CAD operations implemented

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