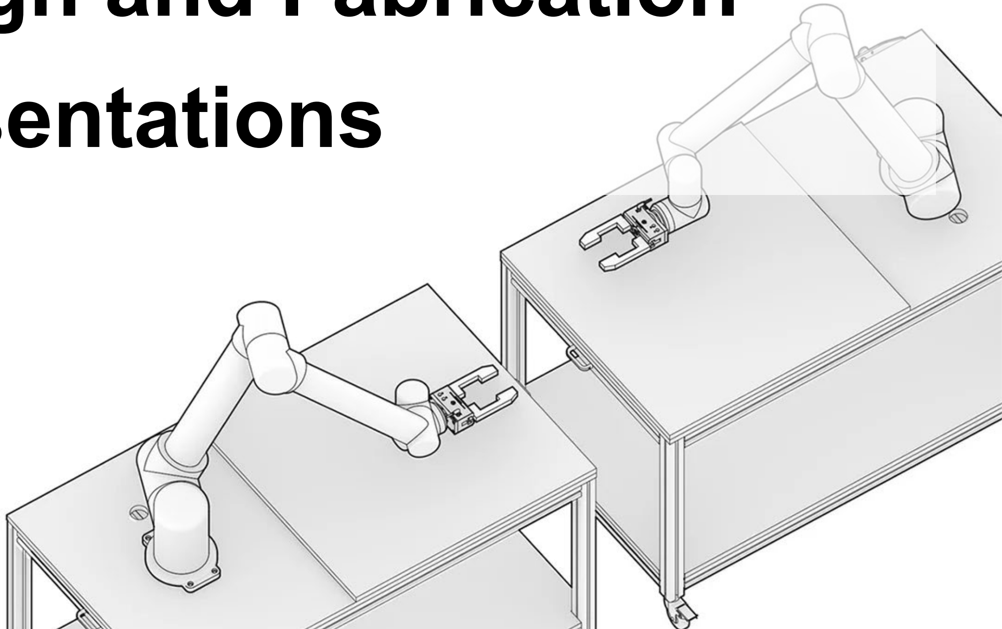
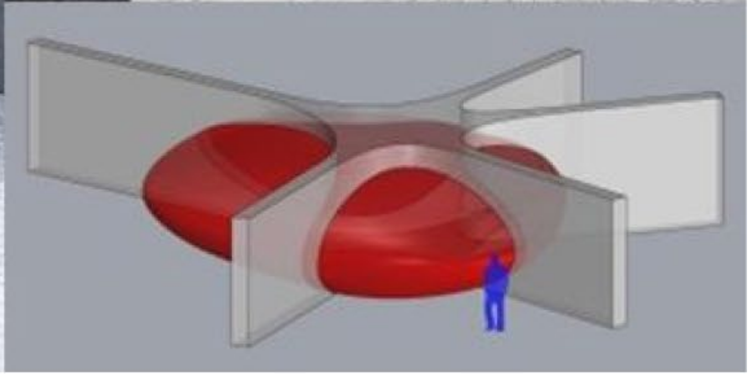
Integrated Design and Fabrication

Representations

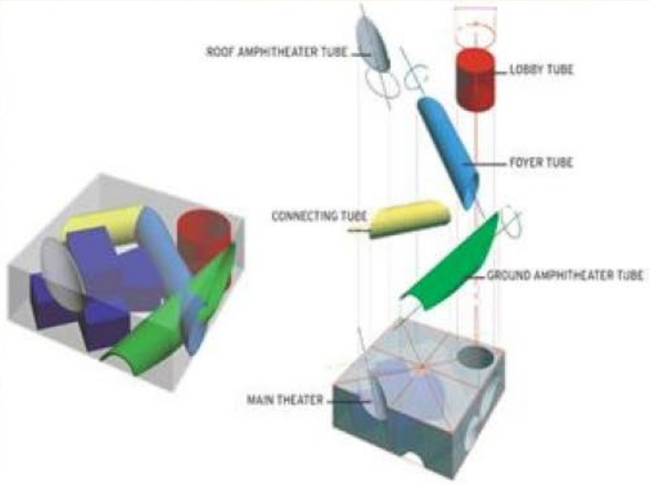


Architecture and Geometry



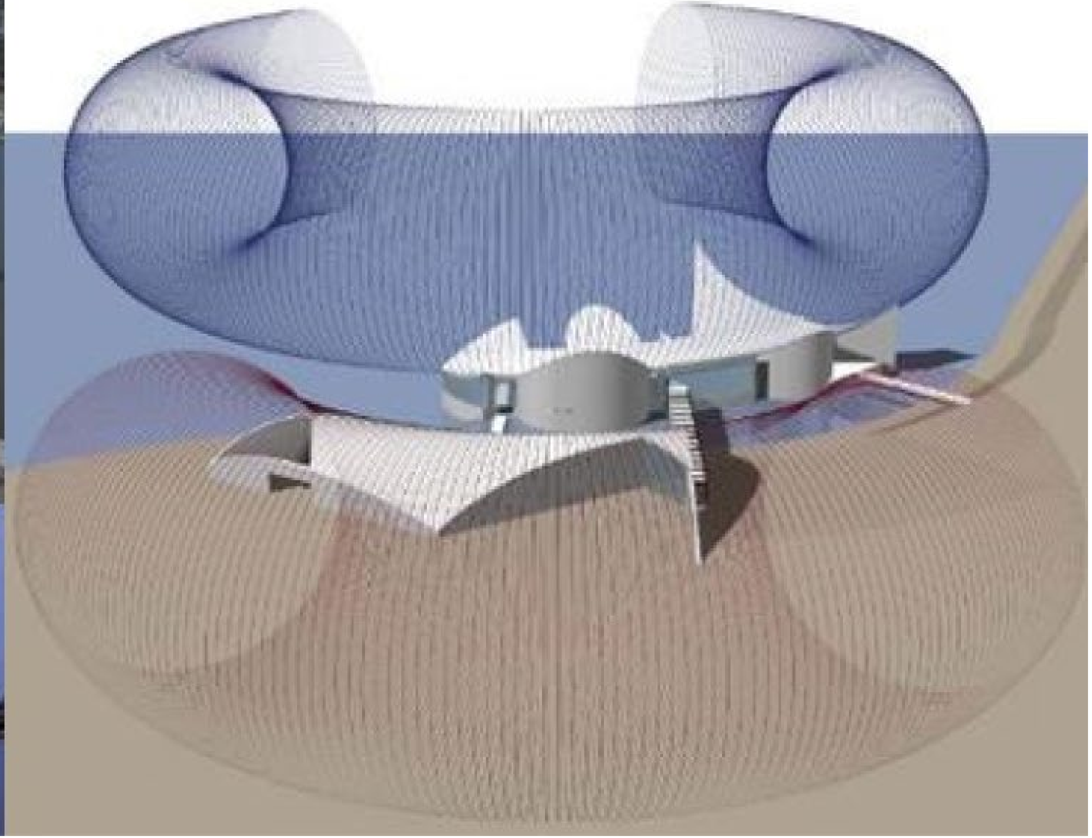
Sean Collier Memorial at MIT, 2000

Architecture and Geometry



Poly Grand, Shanghai, Tadao Ando, 2015

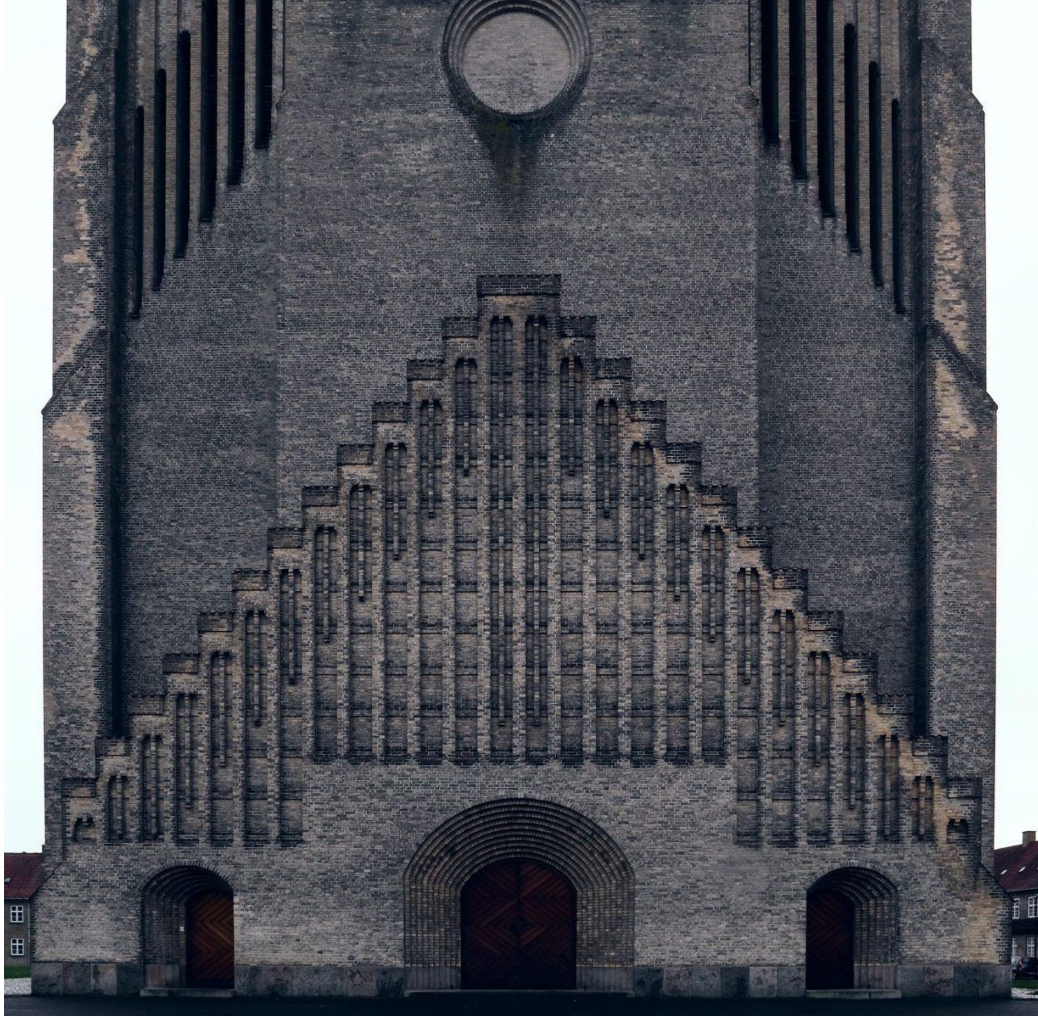
Architecture and Geometry



Exploration Place, Moshe Safdie, 2000

Material-aware Design

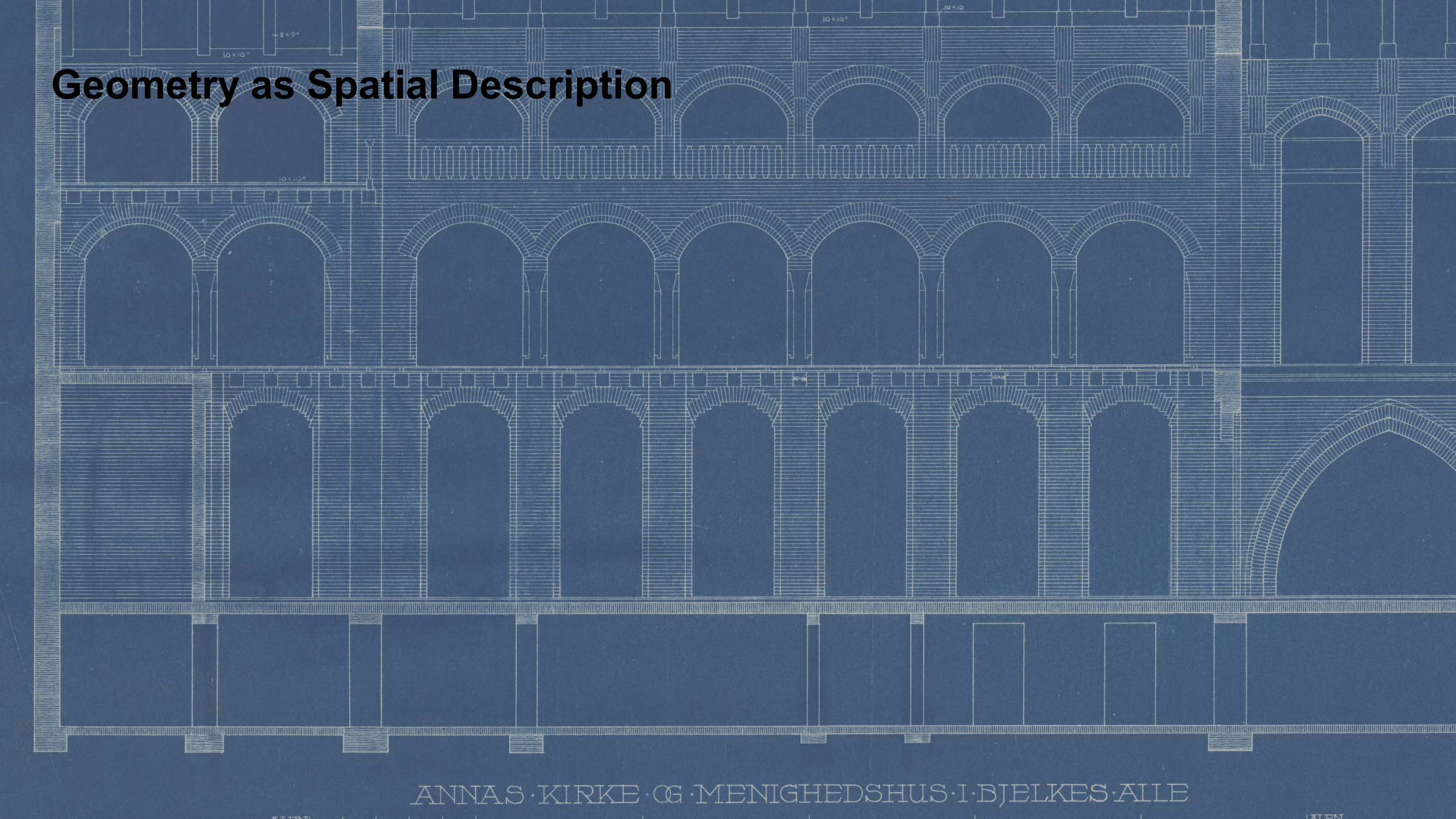
Grundtvig’s Church in Copenhagen, Denmark, Peder Vilhelm Jensen-Klint, 1940



Computational Design and Fabrication 1

Grundtvig's Church in Copenhagen, Denmark, Peder Vilhelm Jensen-Klint, 1940

Geometry as Spatial Description



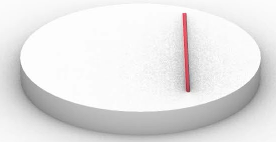
Geometry for Procedural Description

Advanced Representations for Computable Processes

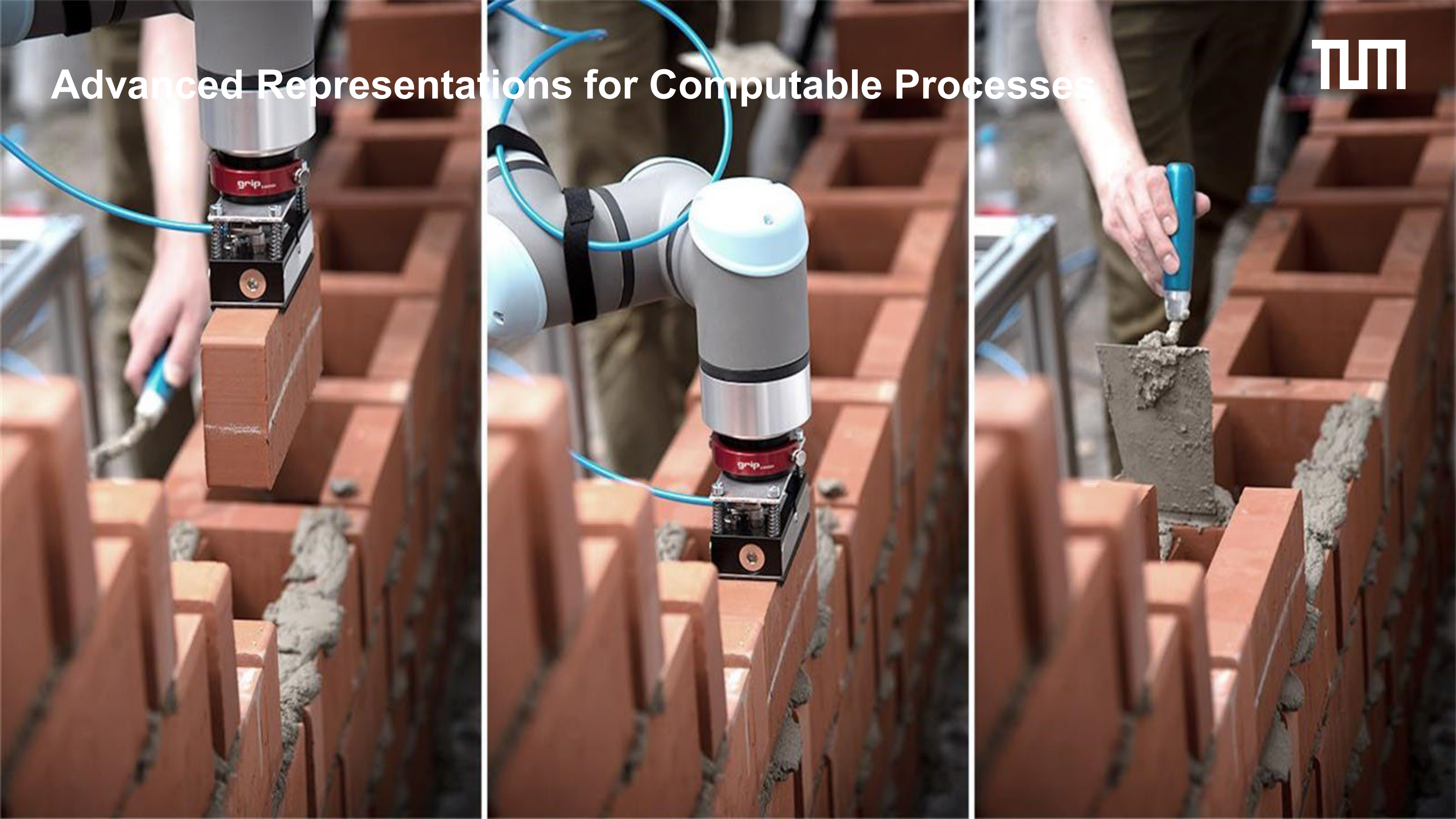
BUILT TOTAL:
0

BUILT BY HUMAN:

BUILT BY ROBOT:



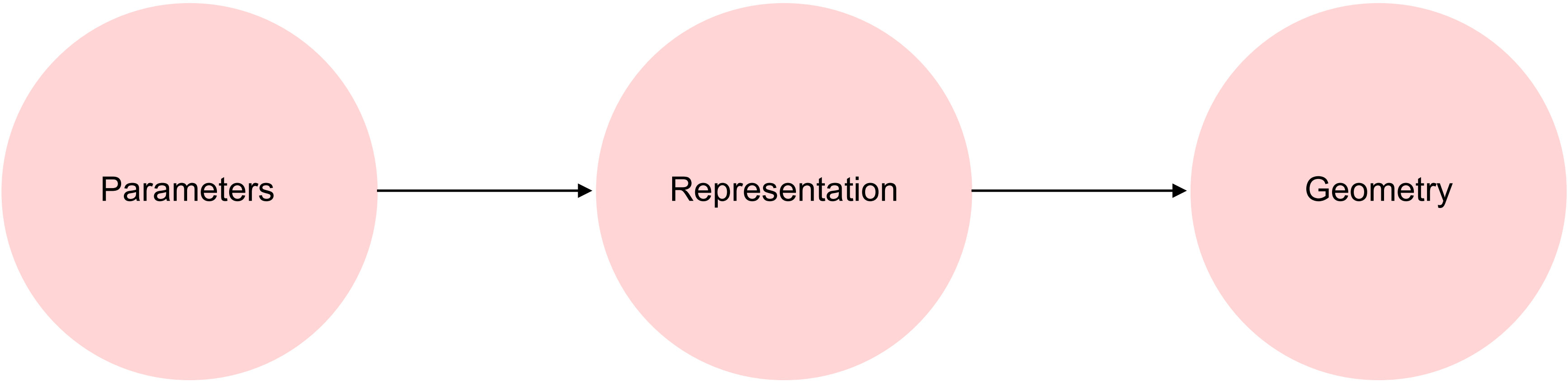
Advanced Representations for Computable Processes




Robotnik


Robotnik

Geometry Representation

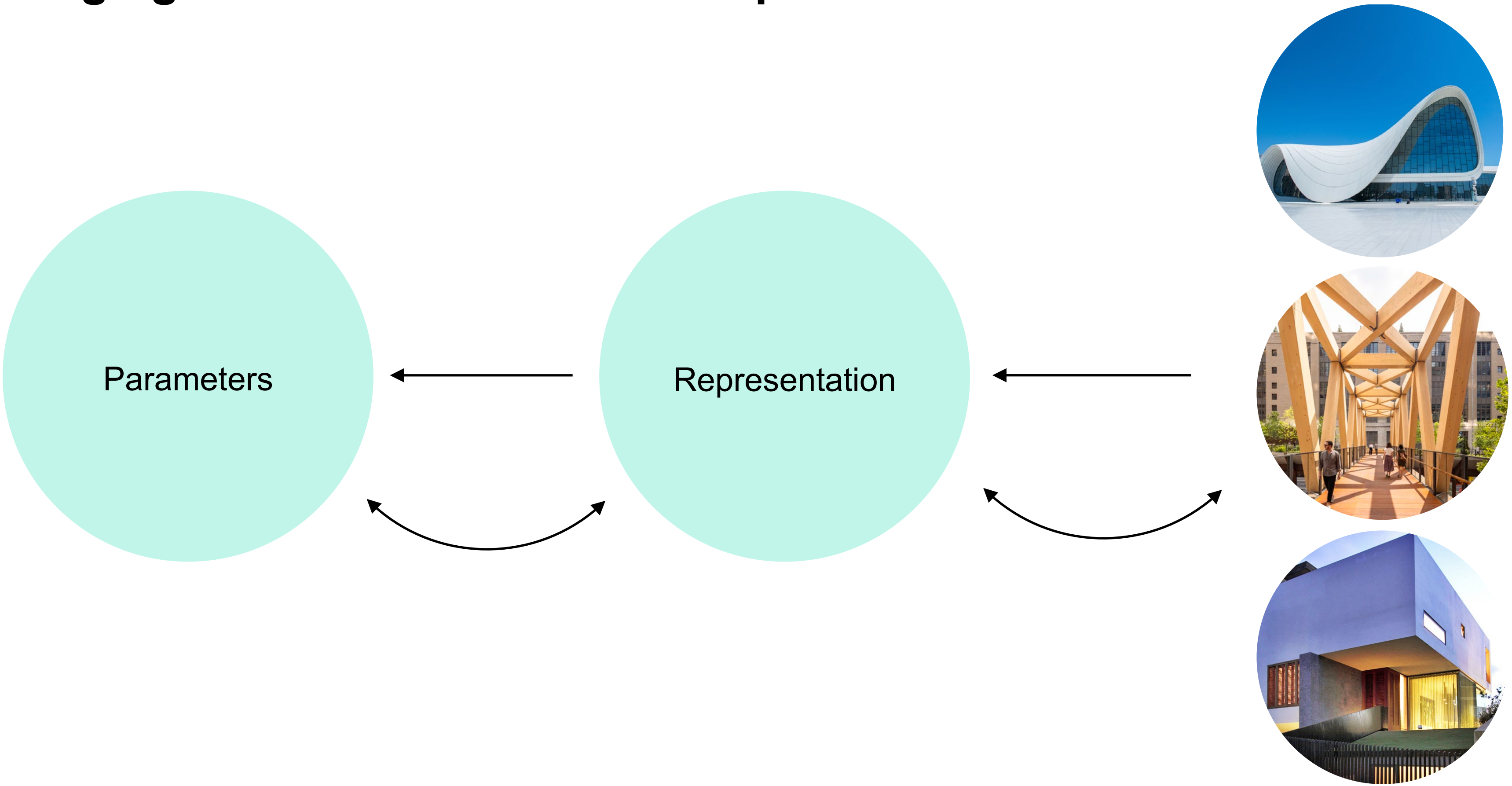


Some numbers and variables

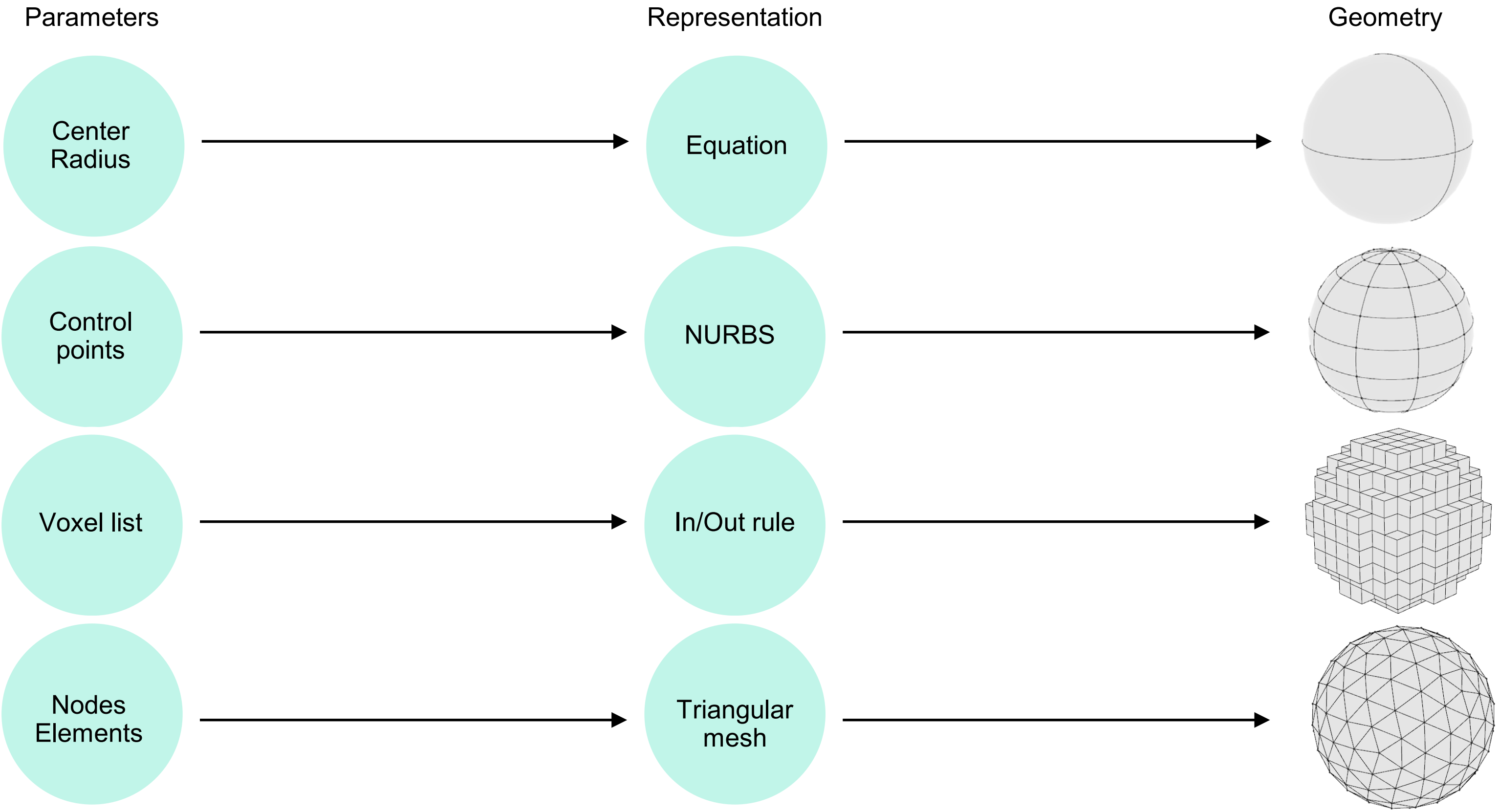
A logic linking numbers to shapes

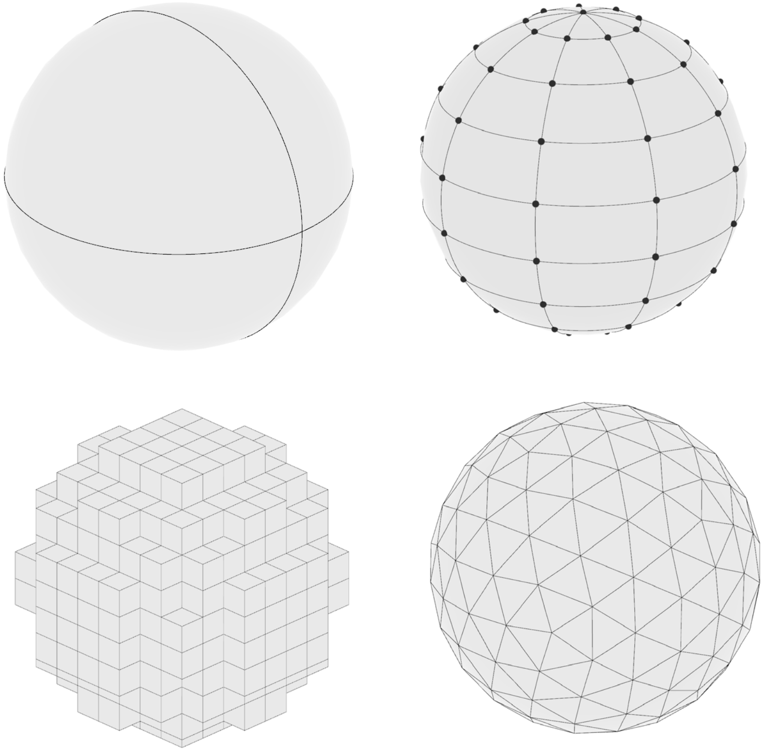
Some shape, used for …

Design goal defines the suitable representation



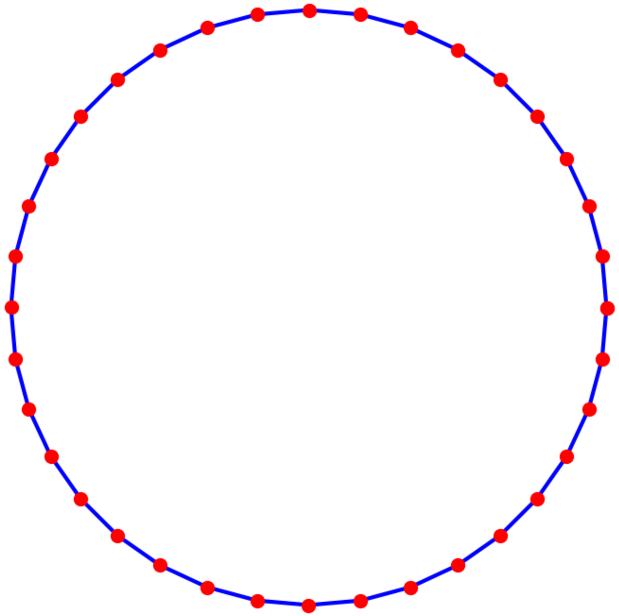
Example: Sphere





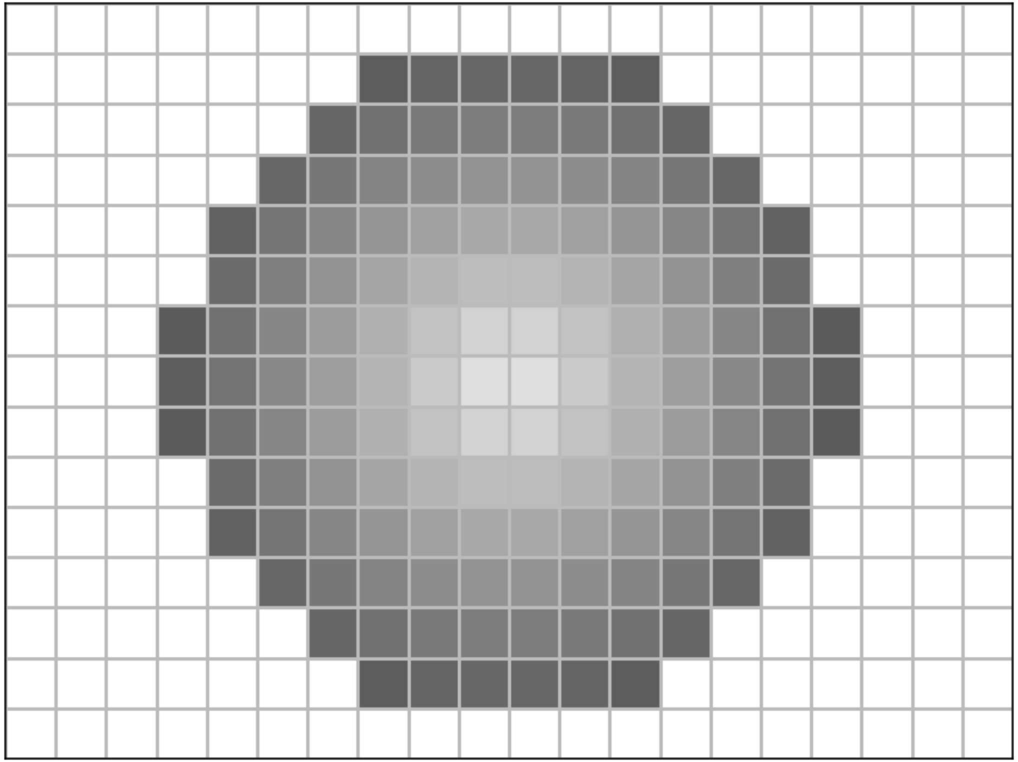
Example: Sphere

Mesh based

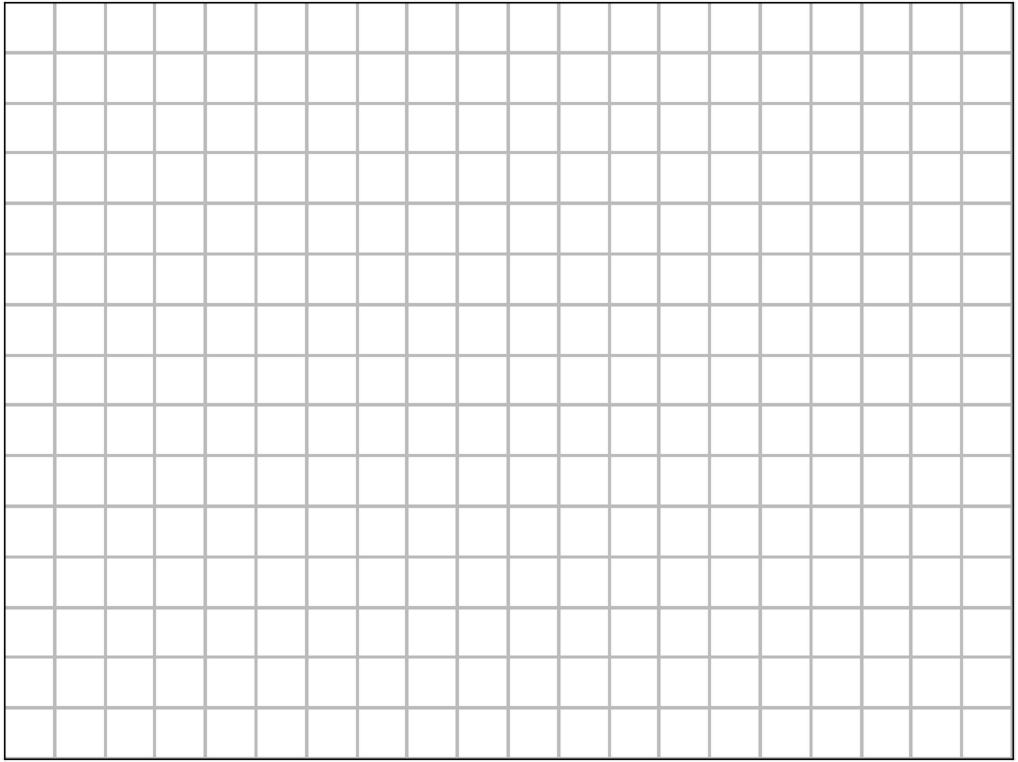


Mesh based

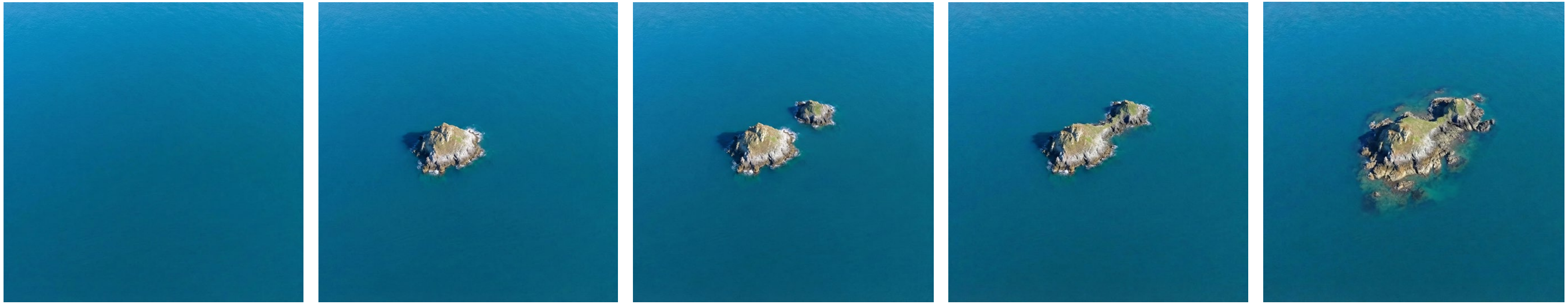
Pixel based (implicit)



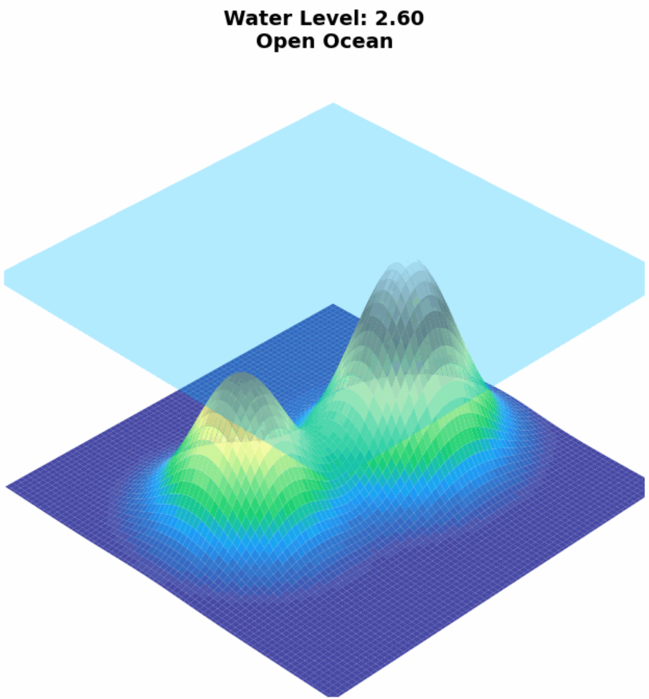
Pixel based (implicit)



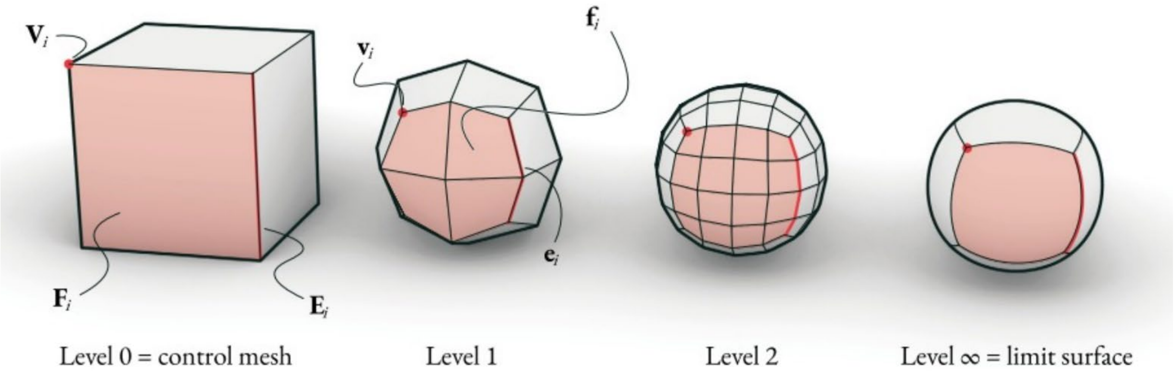
More examples: Level-Set Method



Level-Set method

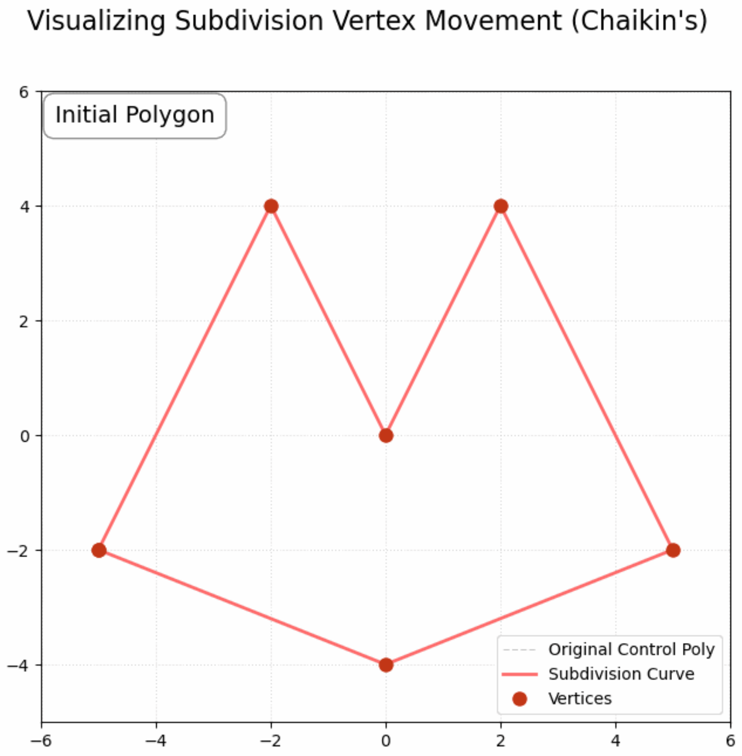


More examples: Sub-Division Surfaces

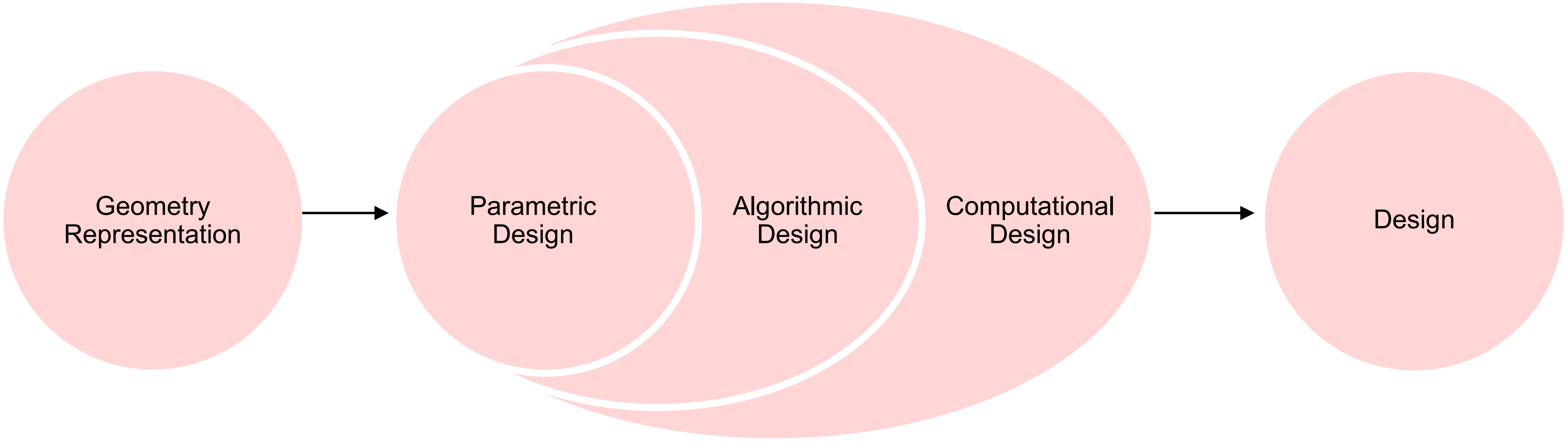


Source: Oberbichler, T. and Bletzinger, K.U., 2022 CAD-integrated form-finding of structural membranes using extended catmull–clark subdivision surfaces

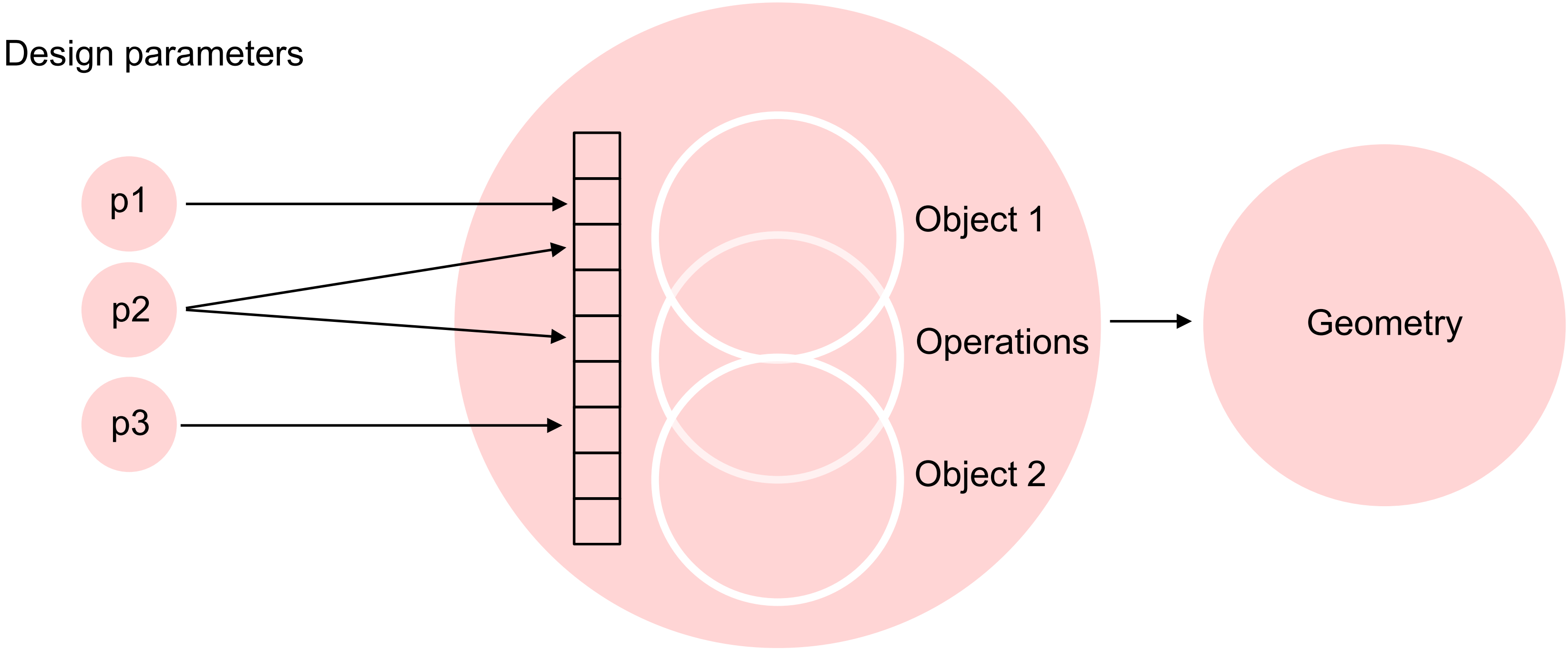
Sub-Division



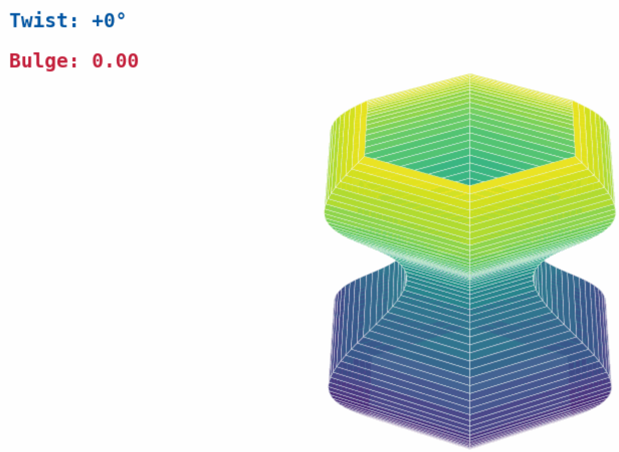
Representation is the core of Computational Design



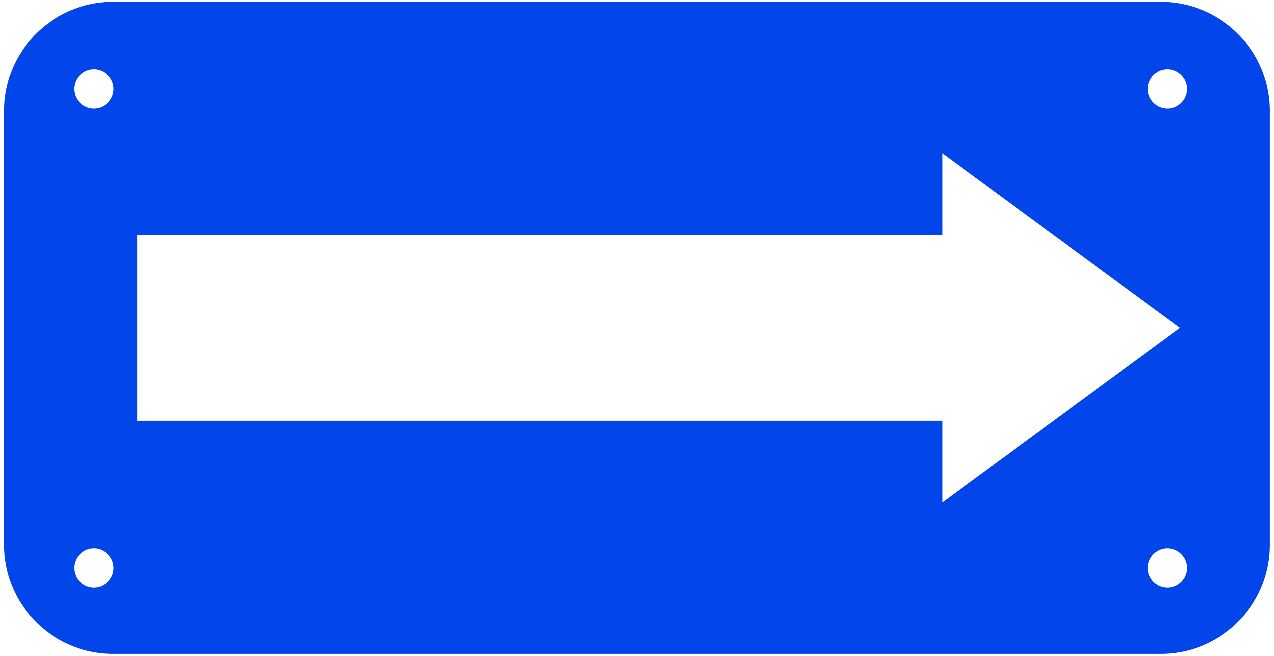
Parametric Design



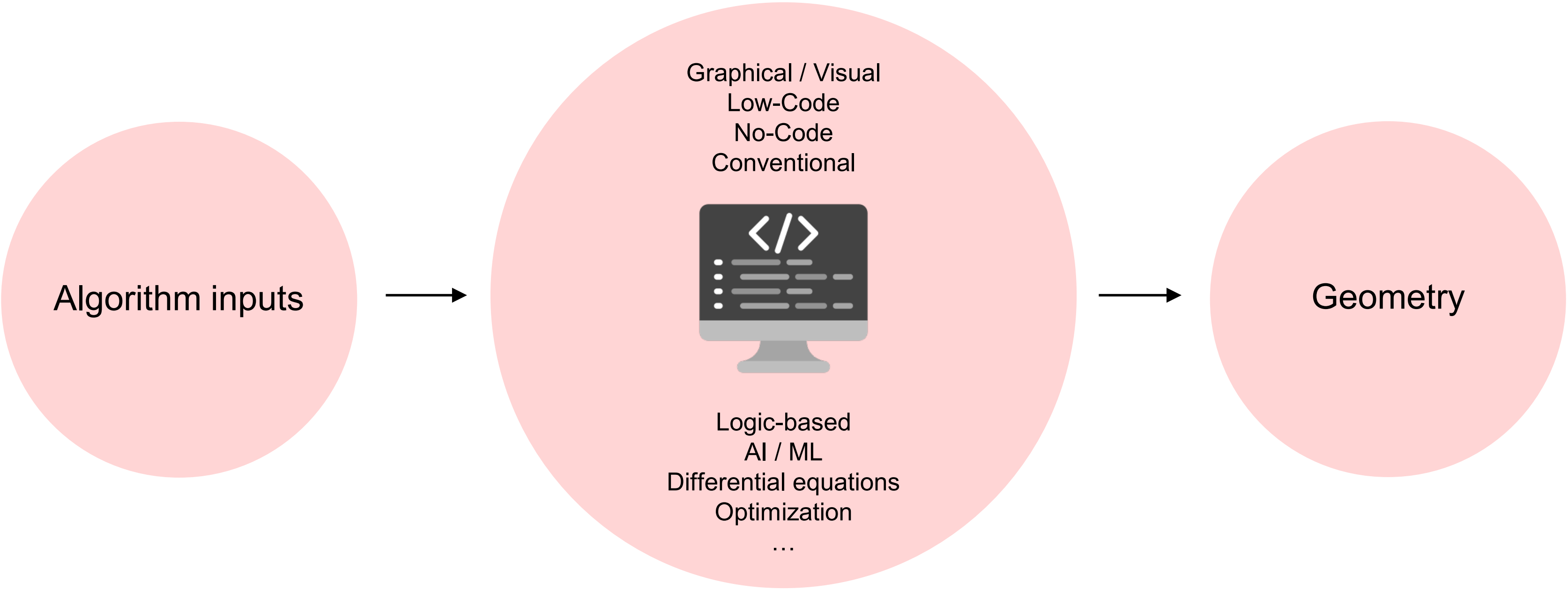
Parametric Design



Example:



Algorithmic design

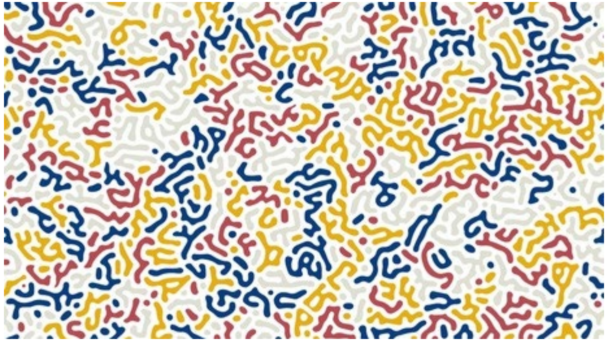


But you still need a Geometry Representation!

Some examples of design algorithms

Geometrically motivated

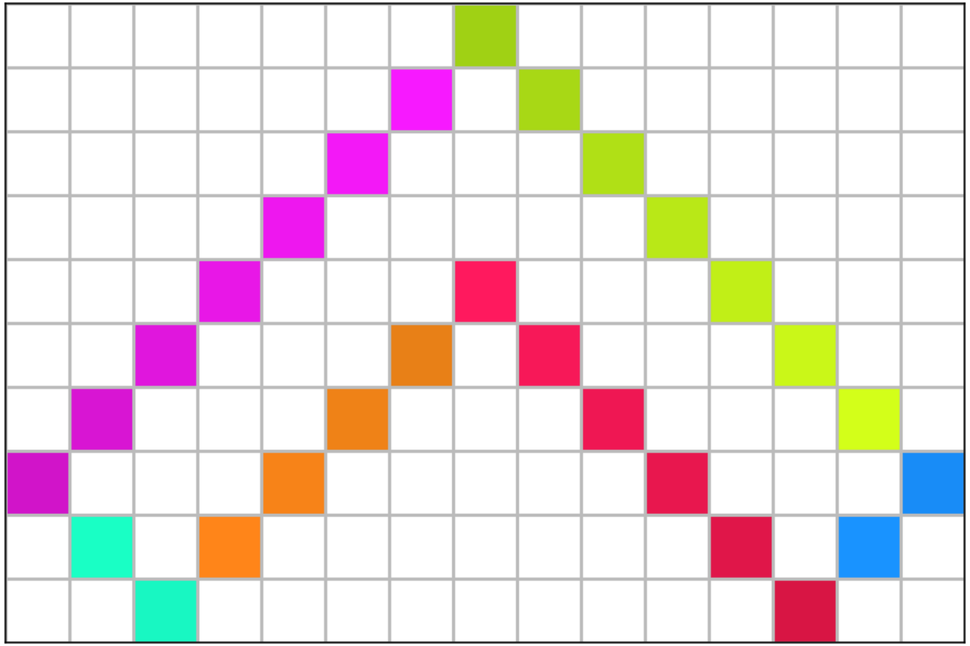
Physically motivated



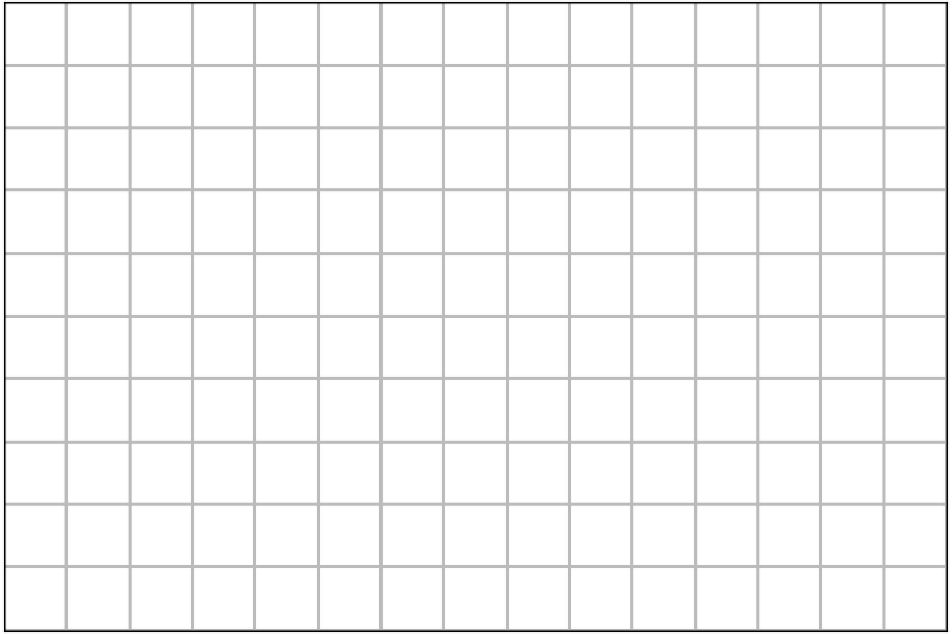
Generative

Optimization

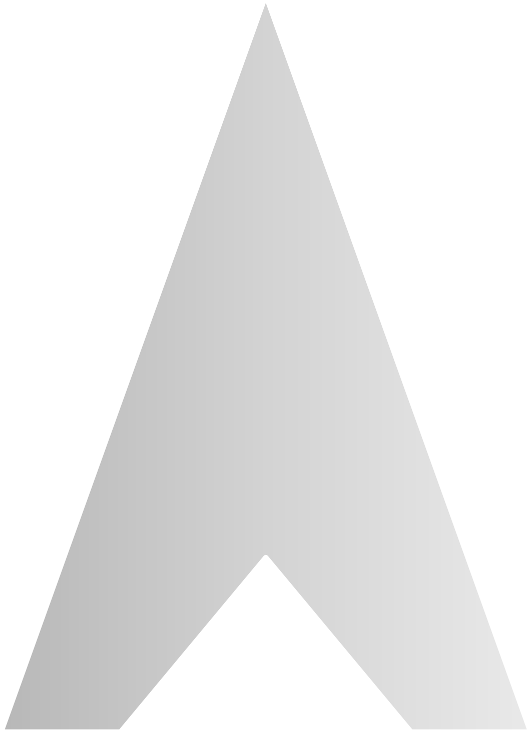
Example

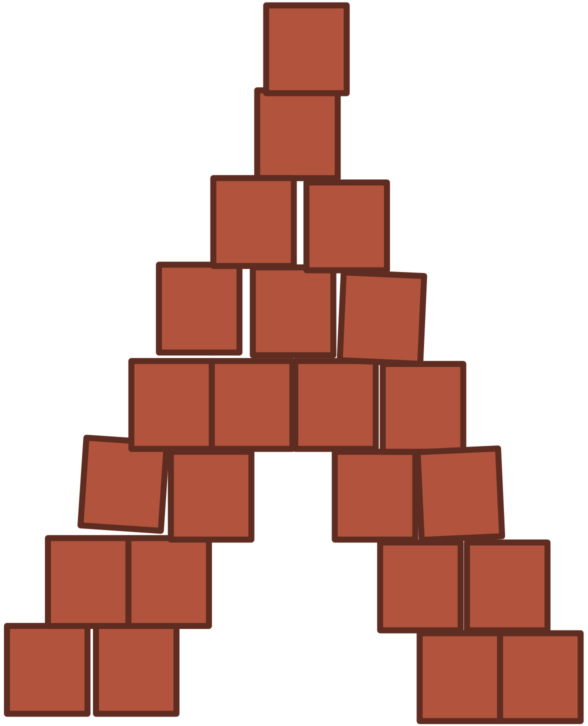


Example

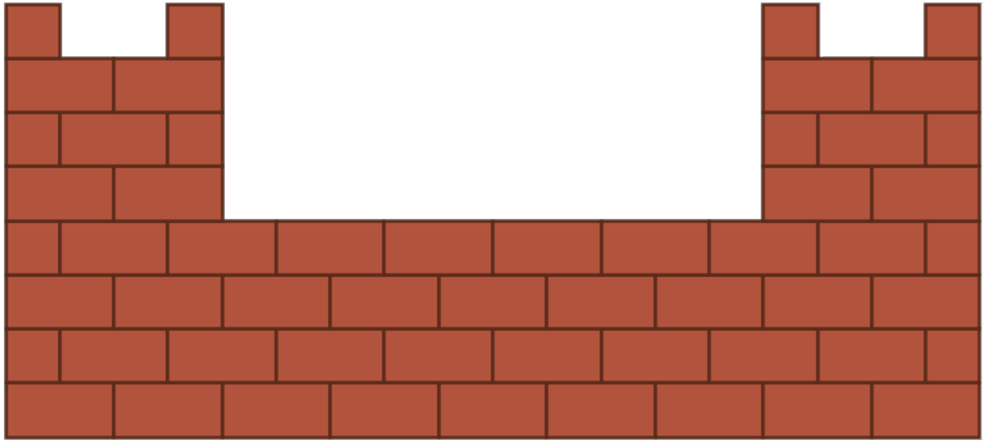


Thinking in materials.

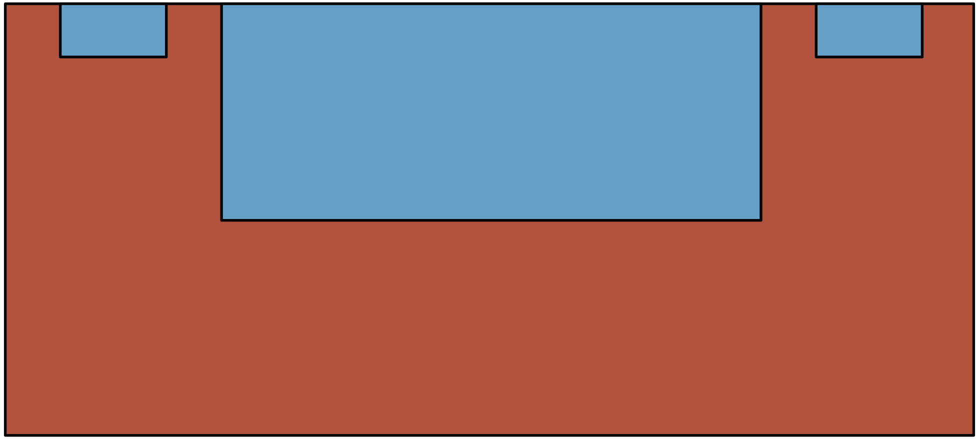




Computational Design of a Castle

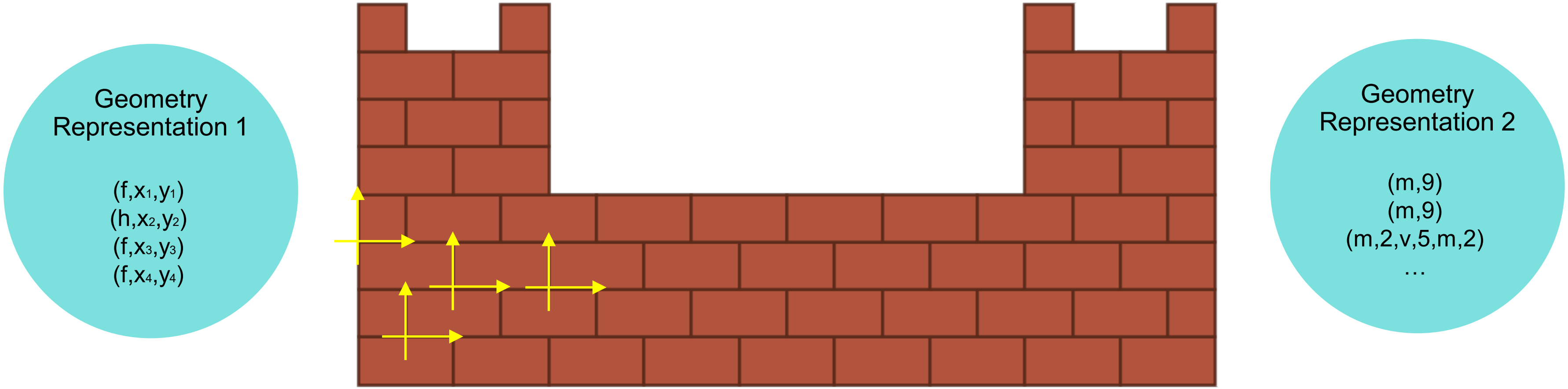


Boolean Operators

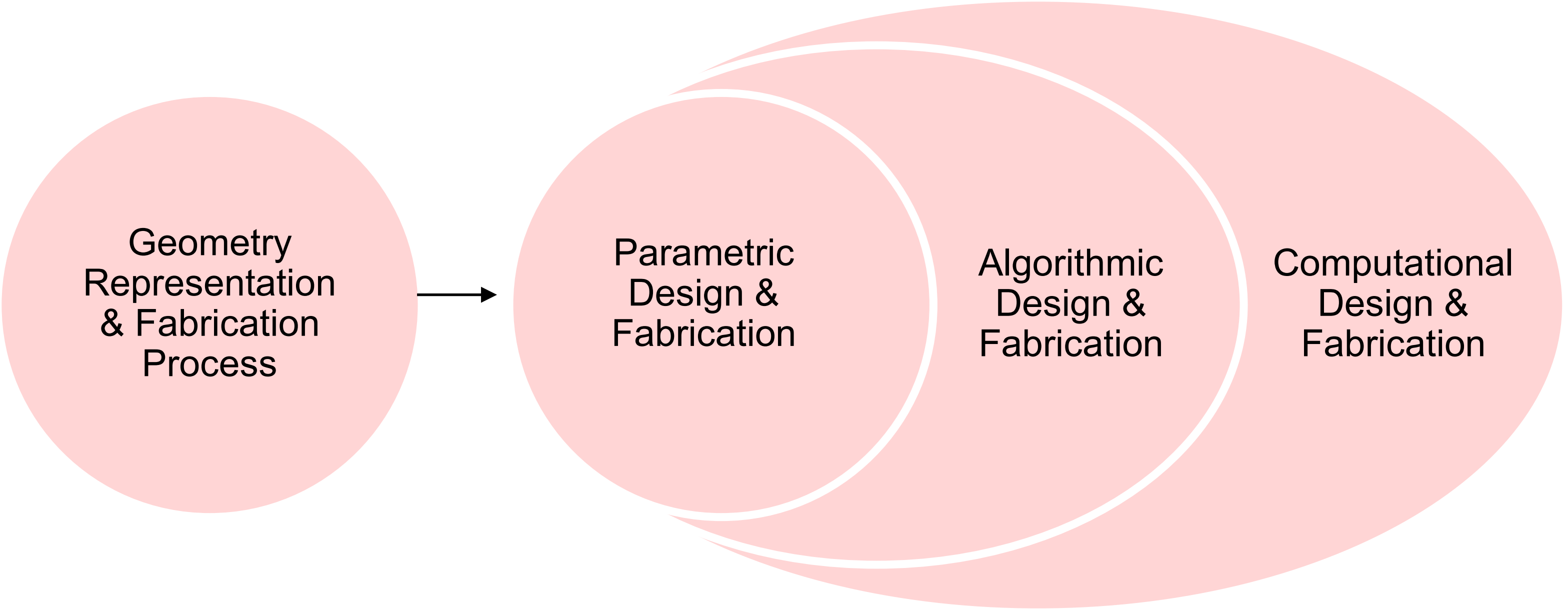


„Brick“ representation

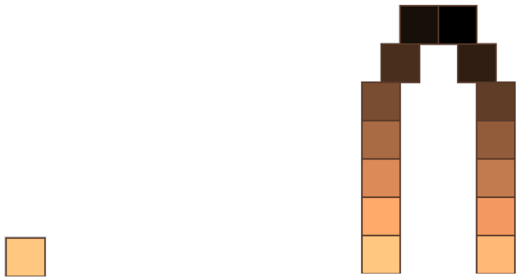
Computational Design of a Castle

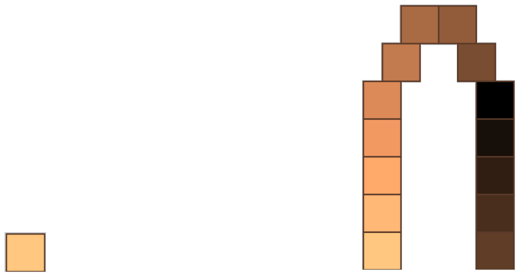


Fabrication Process

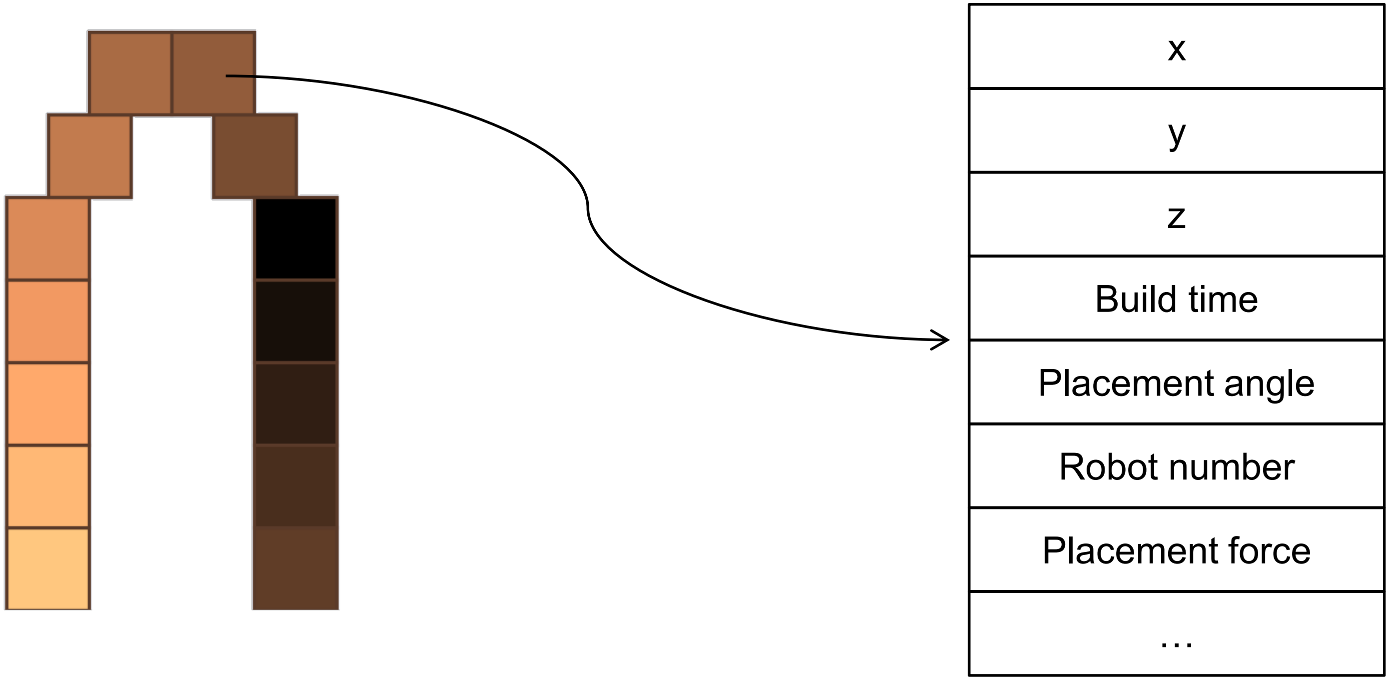


Example: build sequence



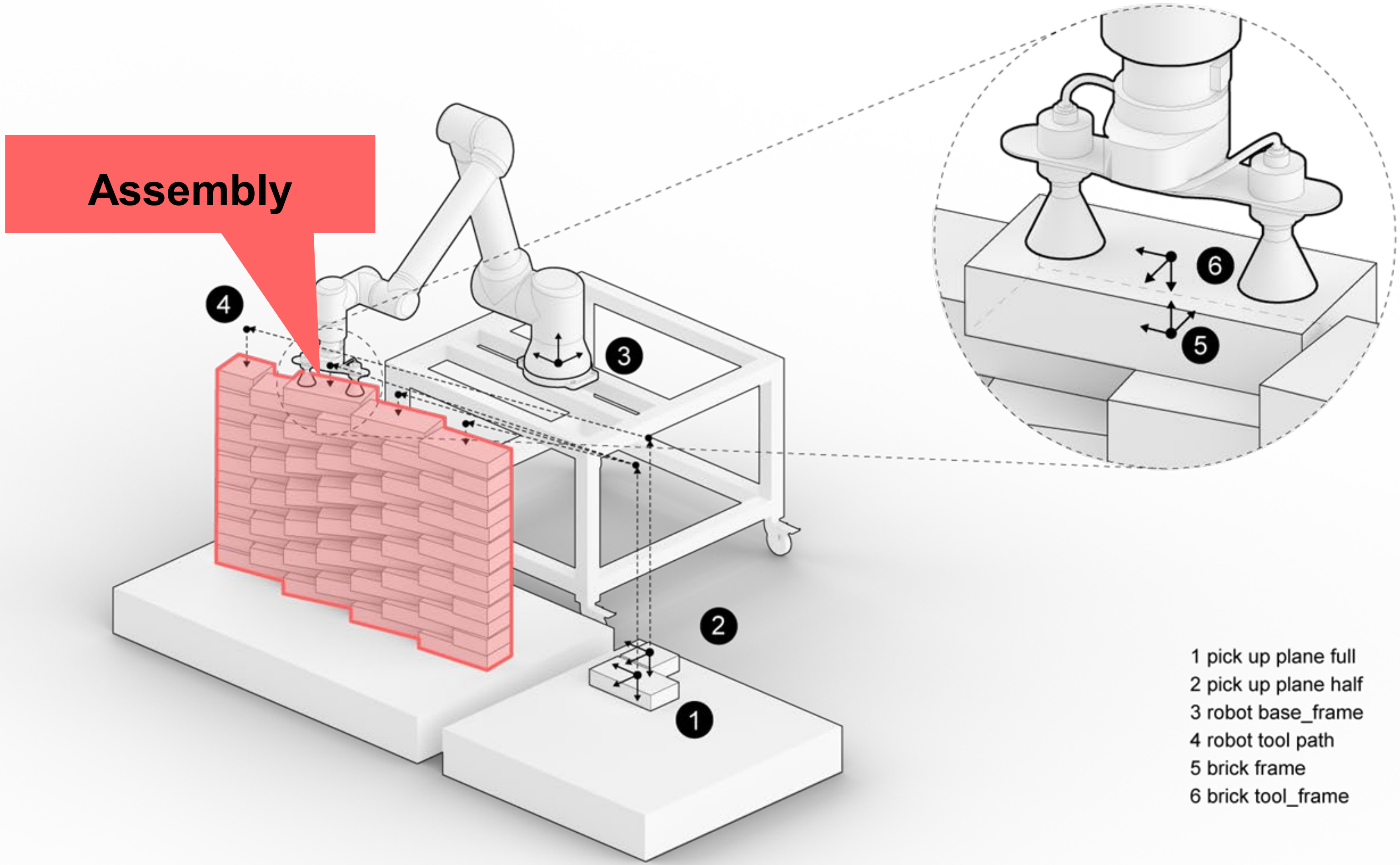


There are more dimensions….

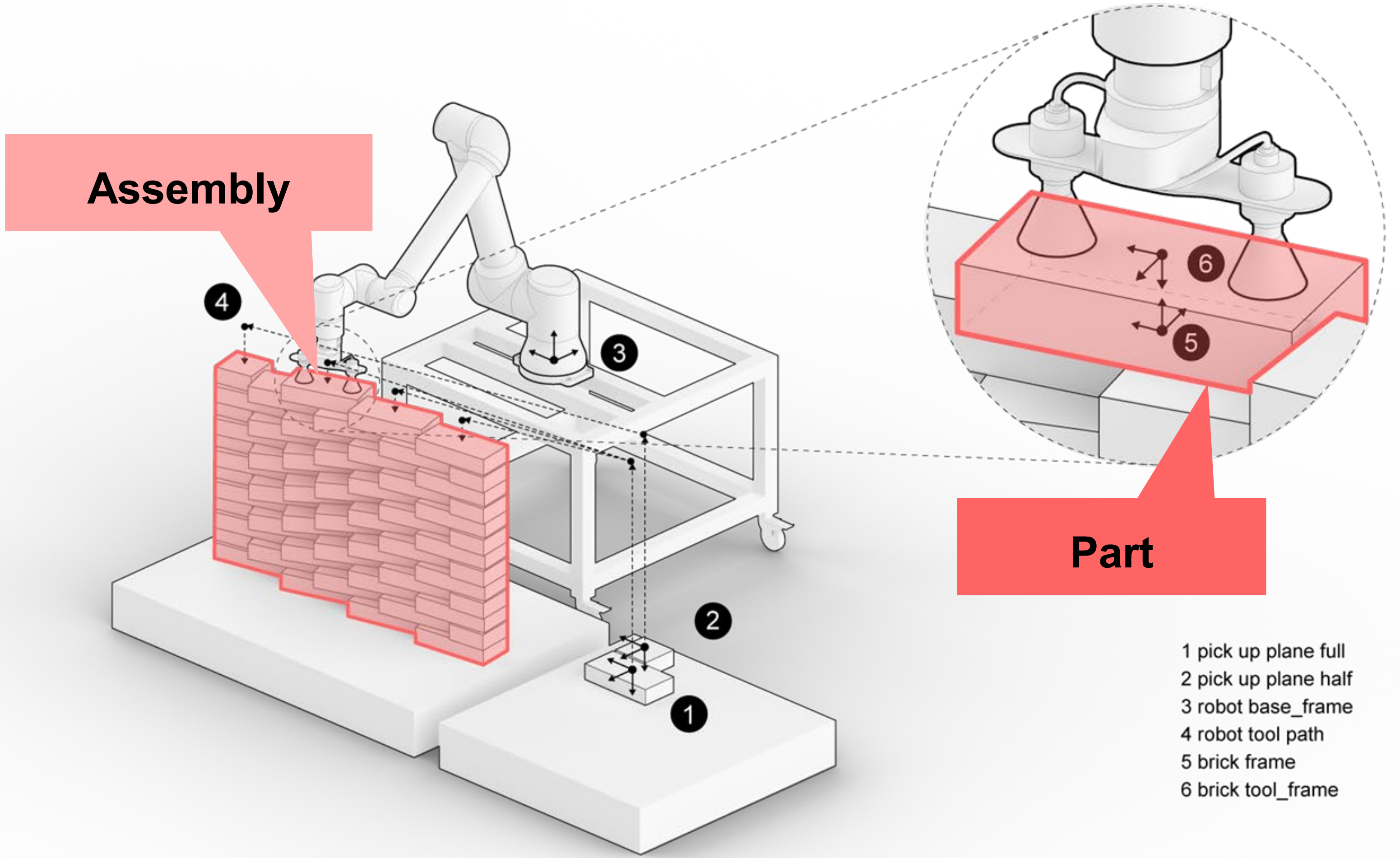


Assembly Model

An Assembly Model refers to an **advanced computational representation** that stores the **detailed geometry** of a building structure, enriched with **topological relationships** (e.g., adjacency, connectivity), **sequencing logic** (order of operations), and **fabrication-related attributes** such as part identifiers, connection types, or material specifications.

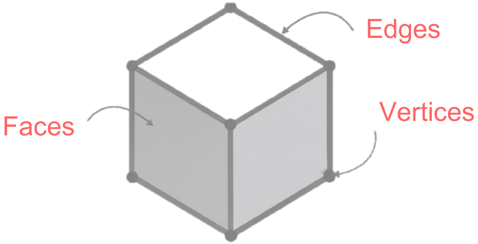


1 pick up plane full
2 pick up plane half
3 robot base_frame
4 robot tool path
5 brick frame
6 brick tool_frame


Assembly
4
3
2
1
6
5
Part
1 pick up plane full
2 pick up plane half
3 robot base_frame
4 robot tool path
5 brick frame
6 brick tool_frame

Part: Geometry Attributes (3D Primitives or Meshes)

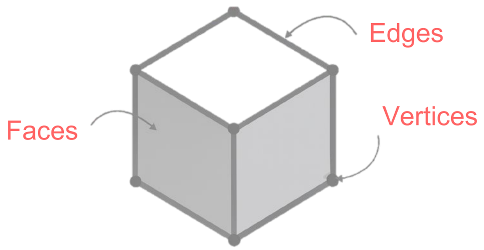
Geometry



A **Part** can integrate a **Mesh** for representing the part‘s geometry.

Part: Geometry Attributes (3D Primitives or Meshes) … and Fabrication-Related Attributes

Geometry

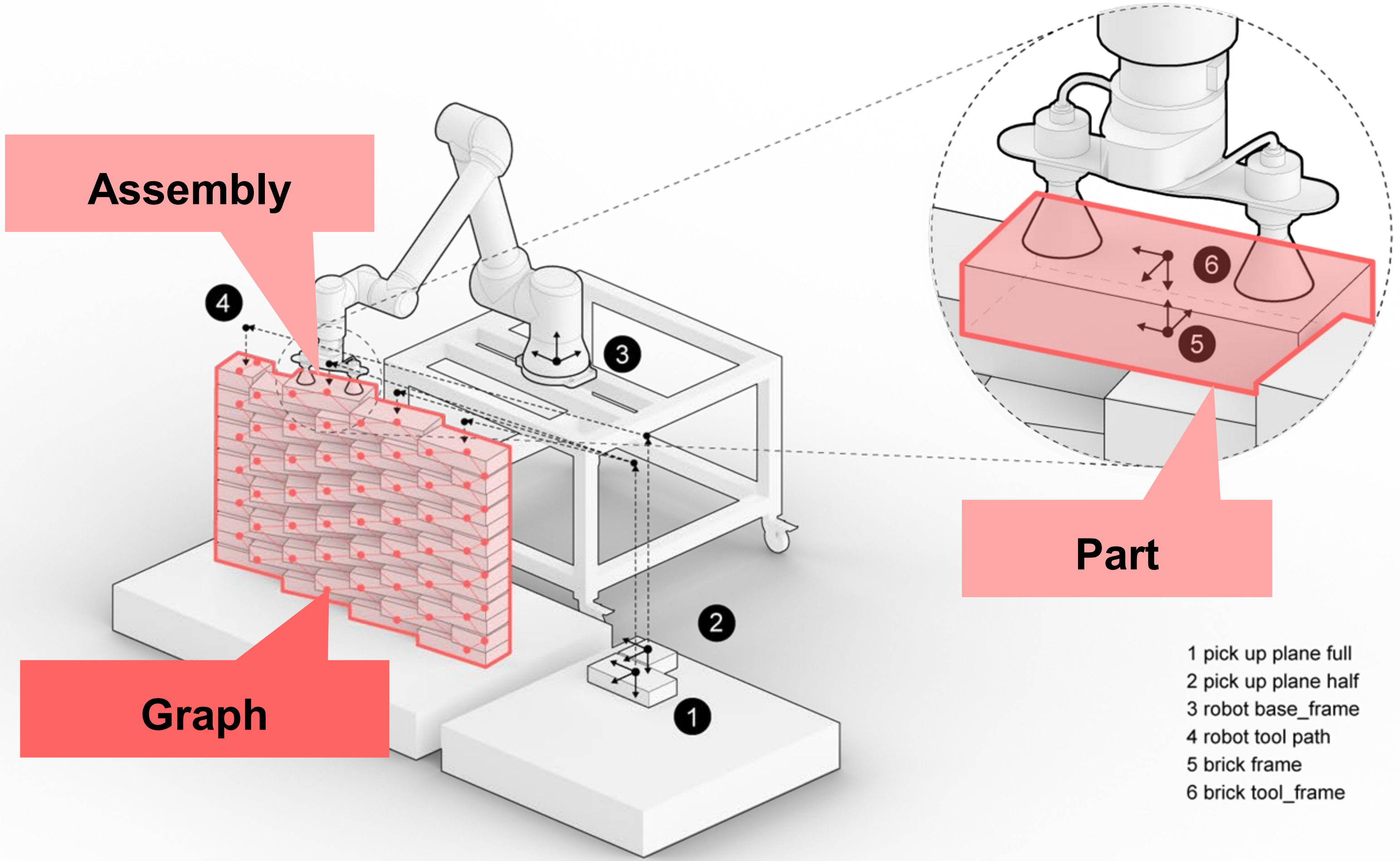


A **Part** can integrate a **Mesh** for representing the part‘s geometry.

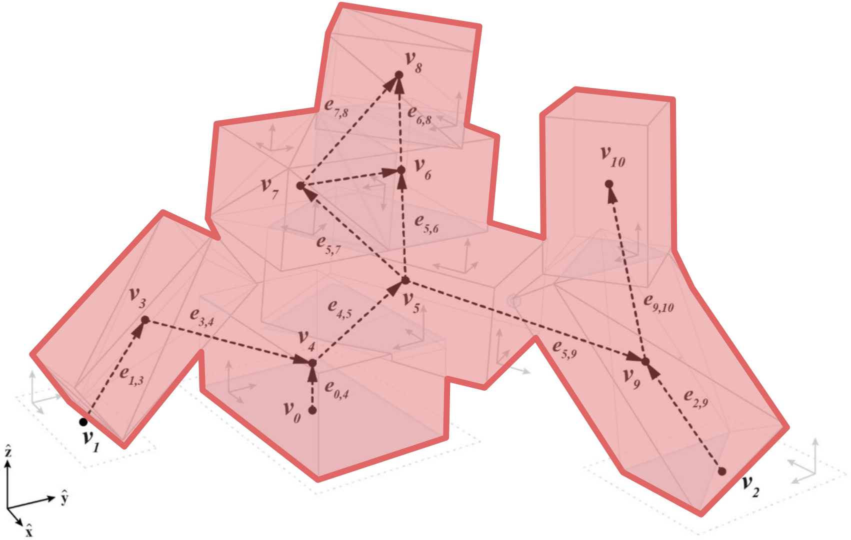
Other Attributes

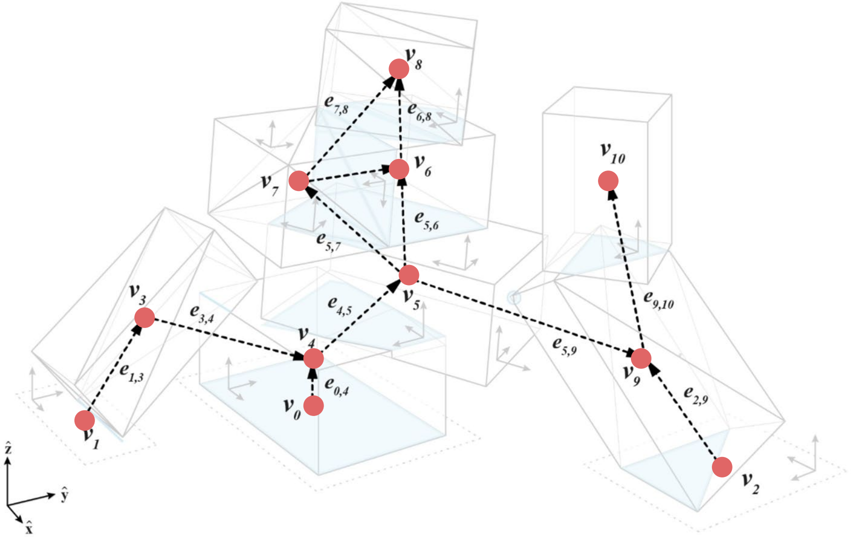
mesh = …
name = …
color = …
….

… such as part identifiers, connection types, or material specifications.


Assembly
4
3
Graph
2
1
6
5
Part
1 pick up plane full
2 pick up plane half
3 robot base_frame
4 robot tool path
5 brick frame
6 brick tool_frame

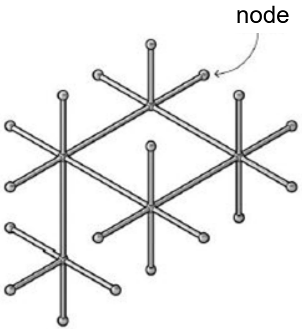
Geometry vs Topology





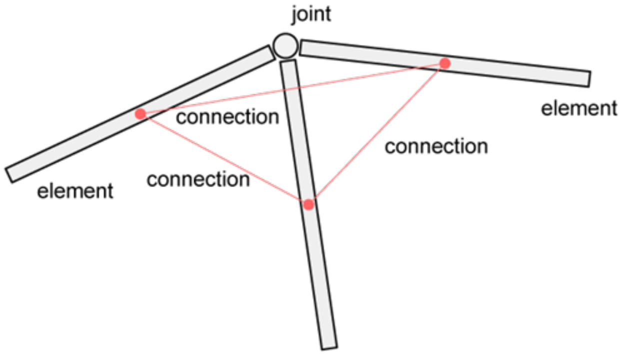
Topology: Represented by a Graph

Graph

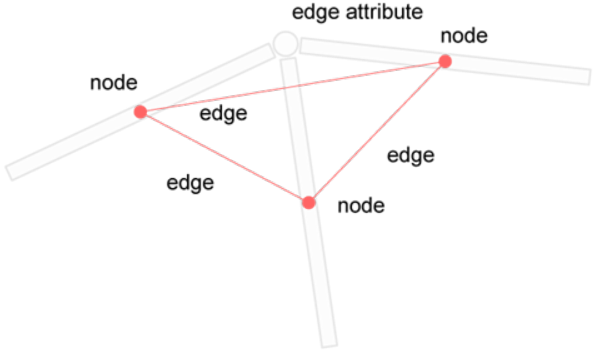


A graph of nodes
with node connectivity defined by
directed edges

Parts as *nodes* + Joints as *connections*

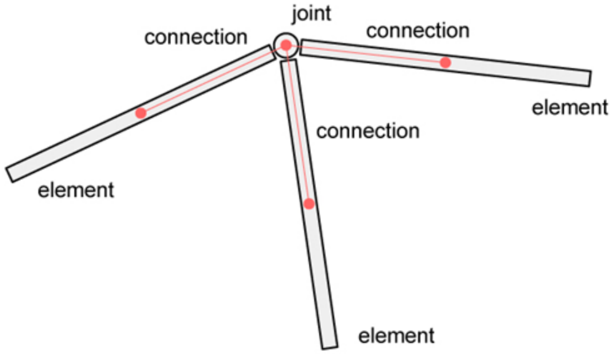


Assembly Model

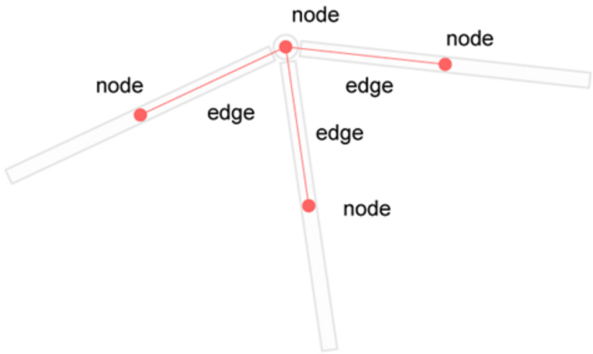


Graph

Parts as *nodes* + Joints as *nodes*

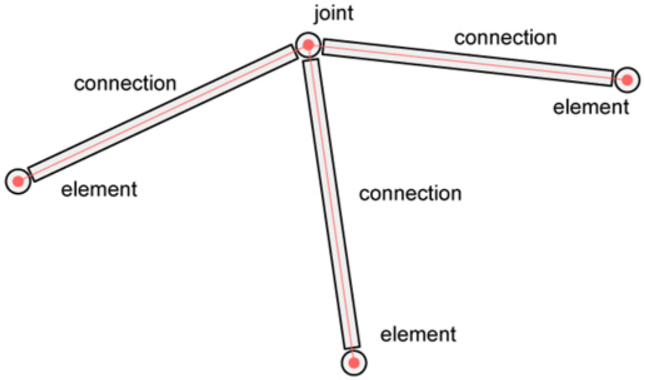


Assembly Model

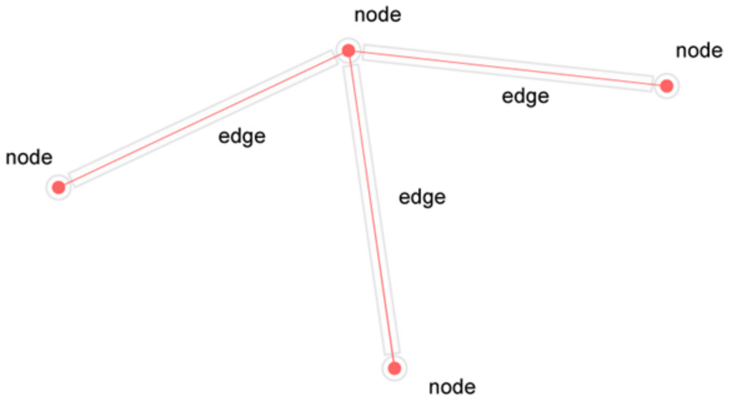


Graph

Parts as *connections* + Joints as *nodes*



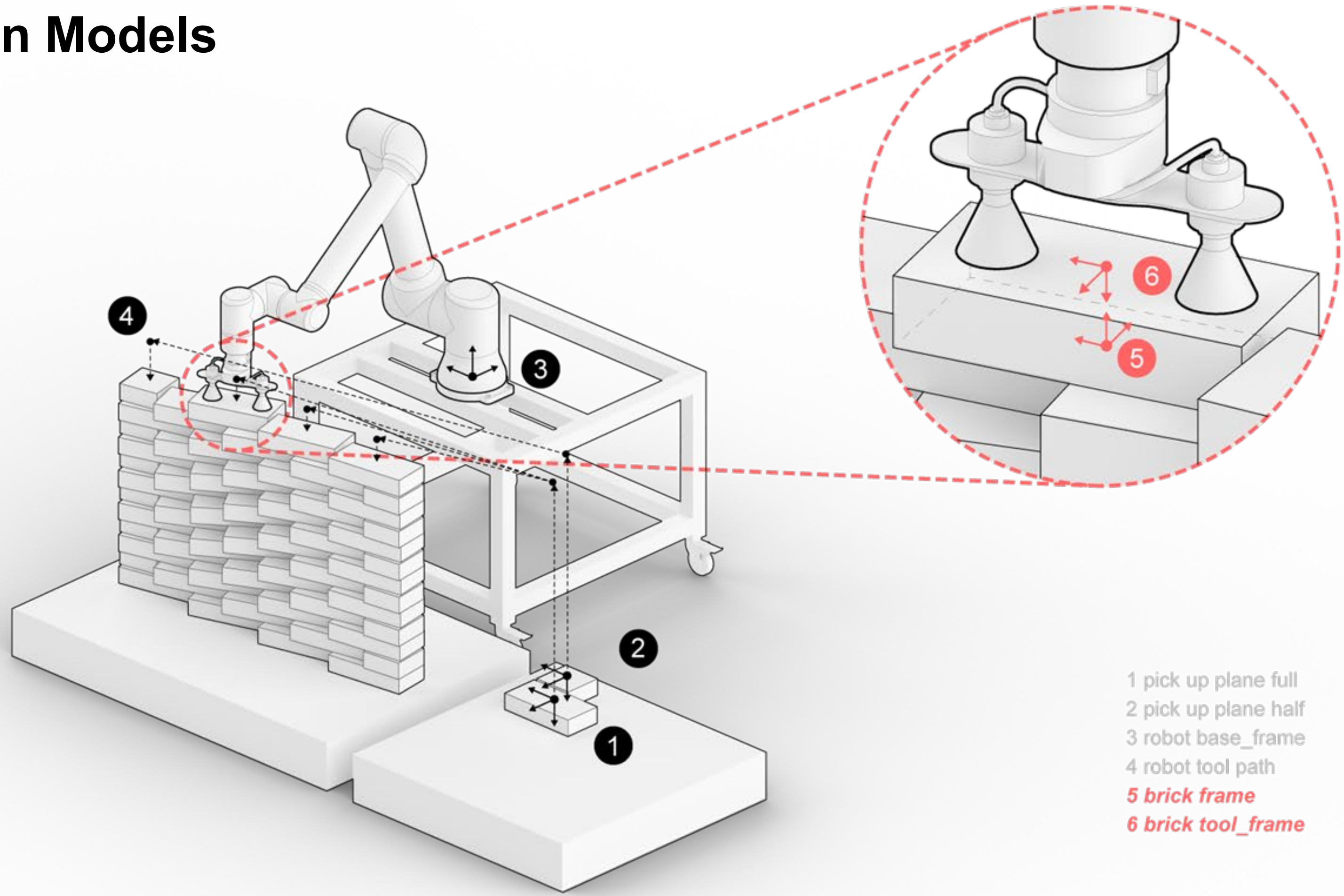
Assembly Model



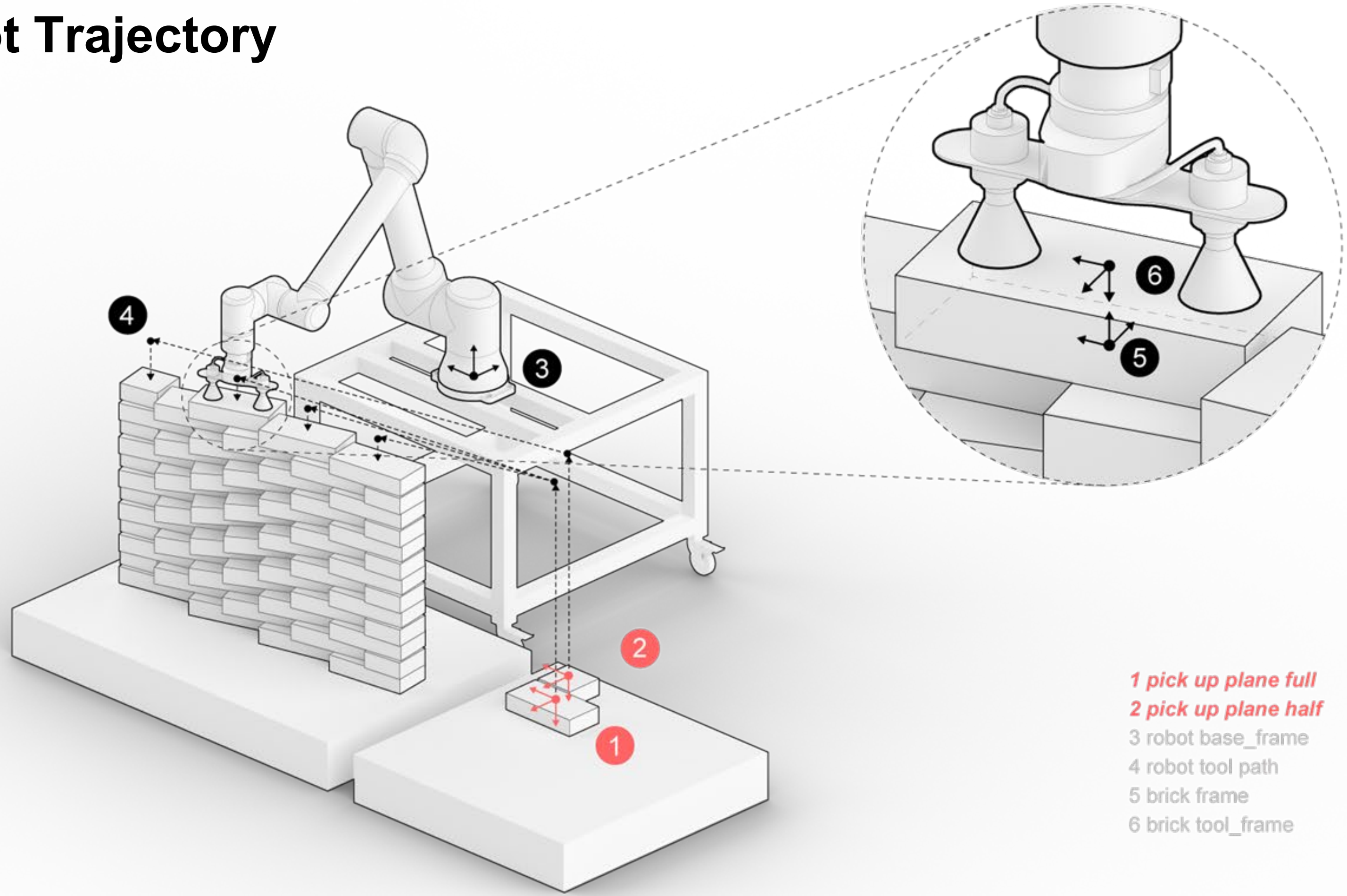
COMPAS Graph

Outlook: From Assembly Models to Action Models

Action Models



Robot Trajectory



1 pick up plane full
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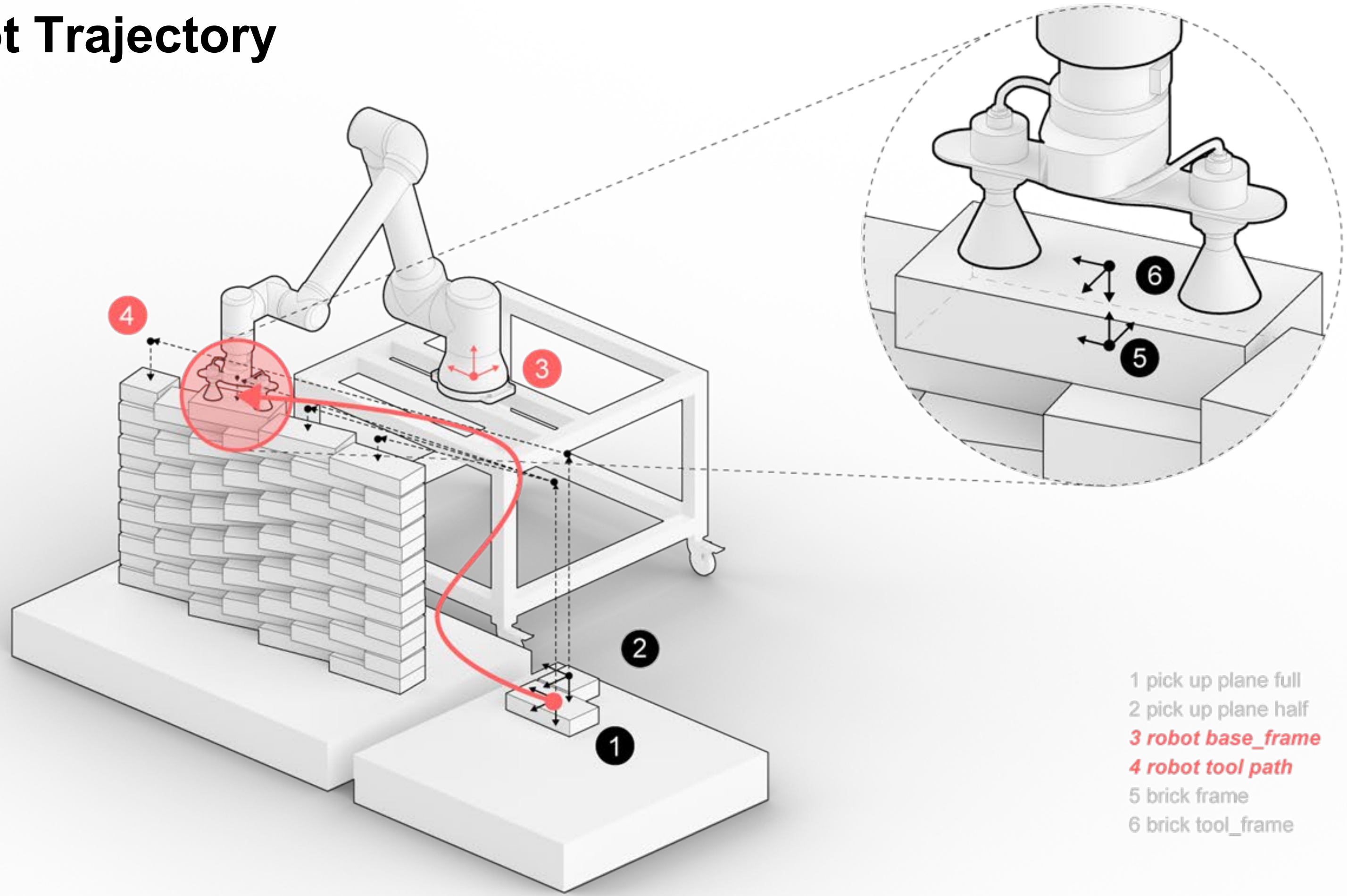
Robot Trajectory



1 pick up plane full
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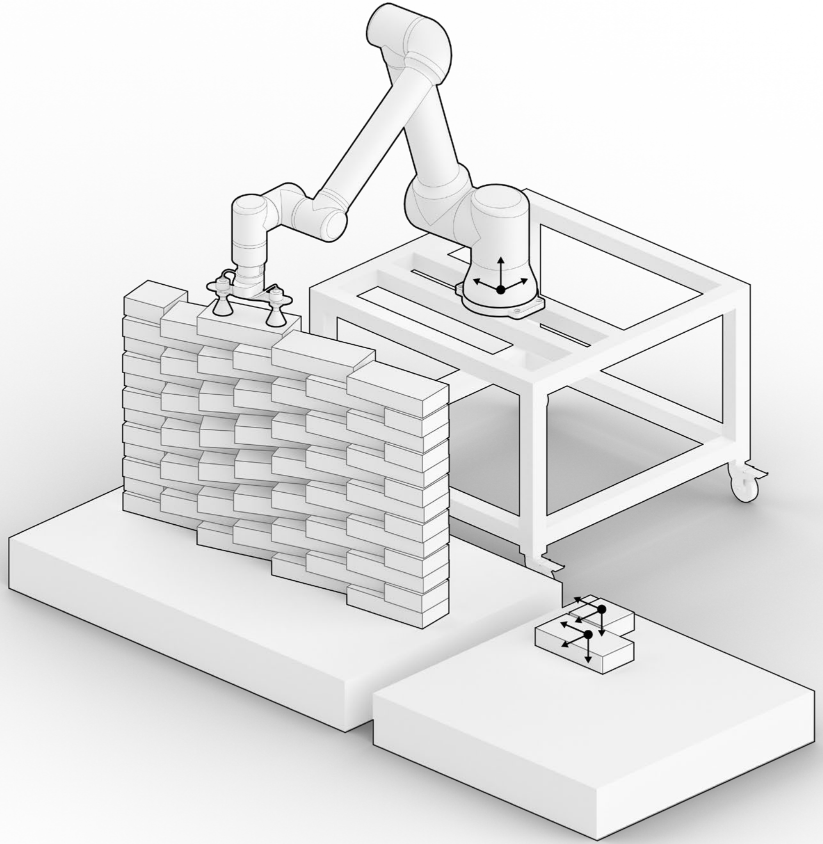
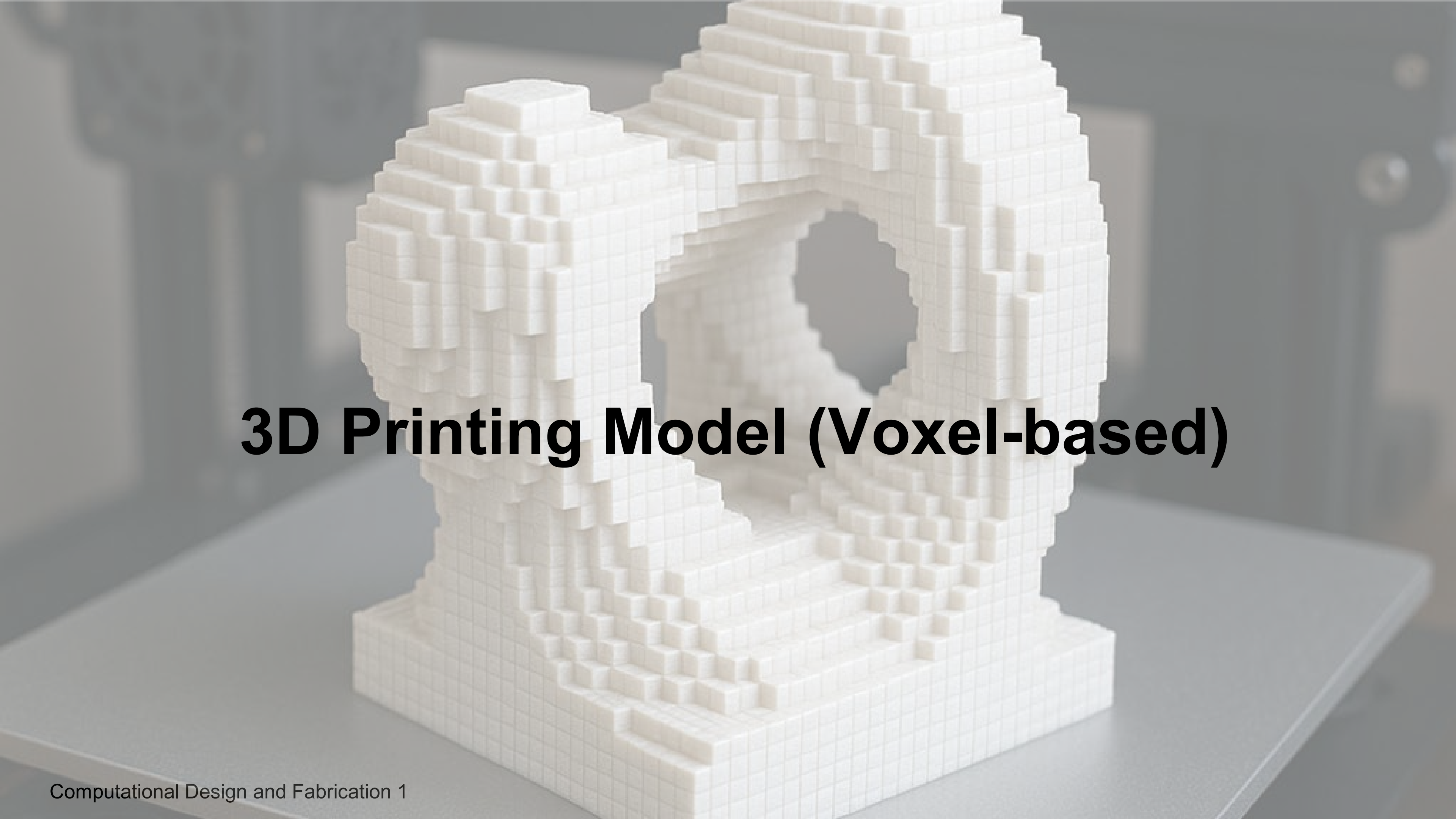


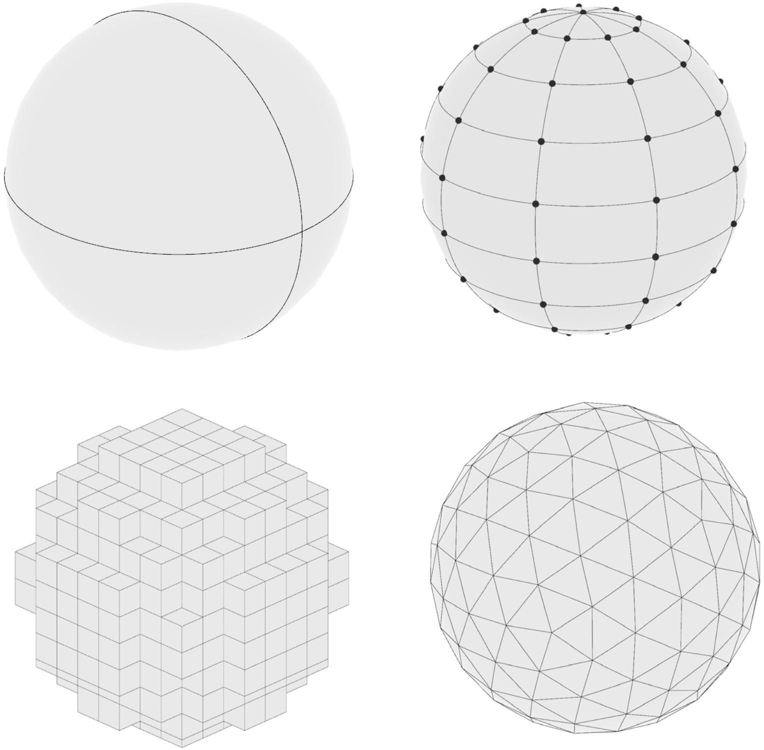
python

COMPAS

3D Printing Model (Surface-based)

3D Printing Model (Voxel-based)



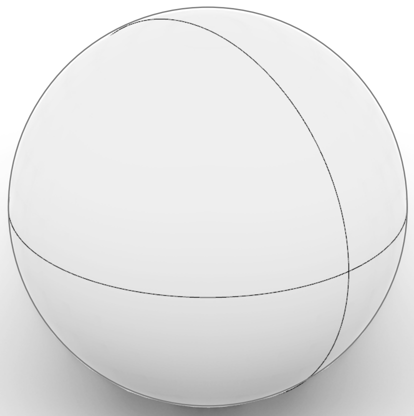


Example: Sphere

Sphere from origin and radius

Learning objectives

1. Constructing an **analytic sphere** from a center point and radius.



Sphere from origin and radius

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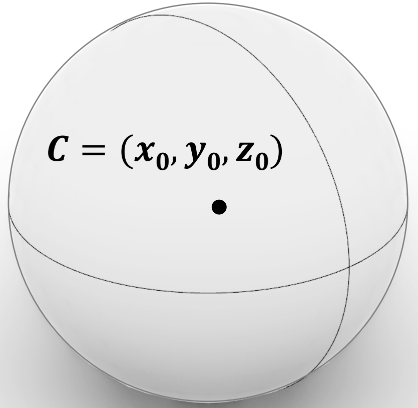


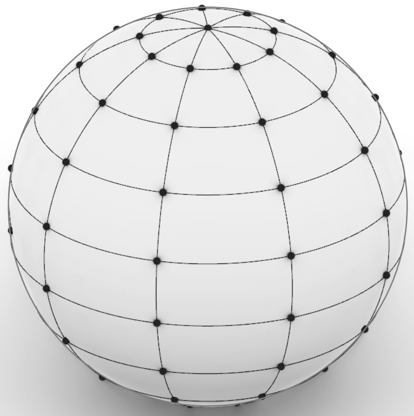
A sphere centered at point C with radius r is defined by the implicit equation:

$$(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2 = r^2$$

Sphere from control points

Learning objectives

1. Constructing a **sphere approximation** by sampling analytic points in spherical coordinates and organizing them in a UV grid.
2. Creating a **NURBS surface** through a structured point grid and generating interpolated U- and V-direction NURBS curves.



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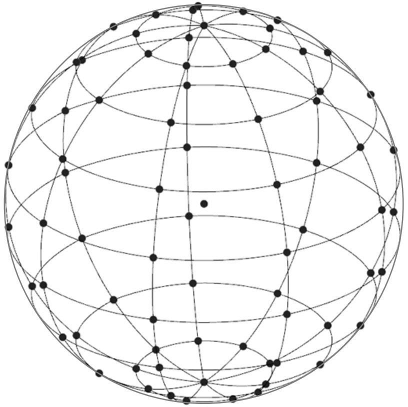
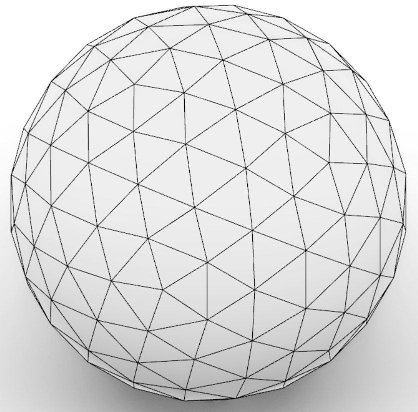


Icosahedron-based sphere mesh (geodesic approximation)

Learning objectives

1. Constructing an **icosahedron-based approximation of a sphere** by normalizing, scaling, and translating vertices.
2. **Refining a triangular mesh** through recursive subdivision and projection onto a sphere.



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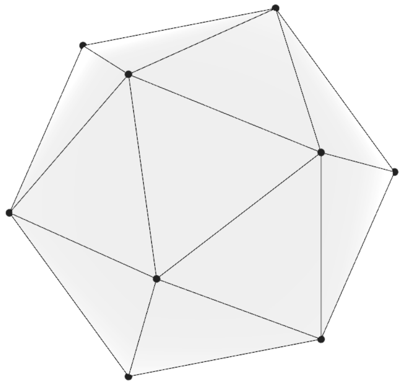

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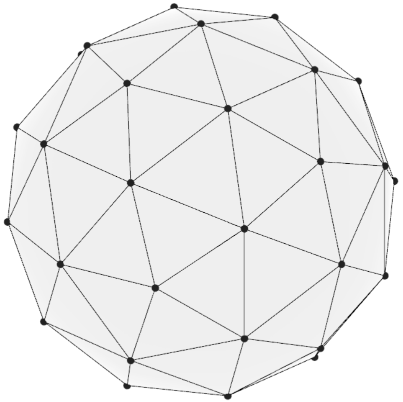
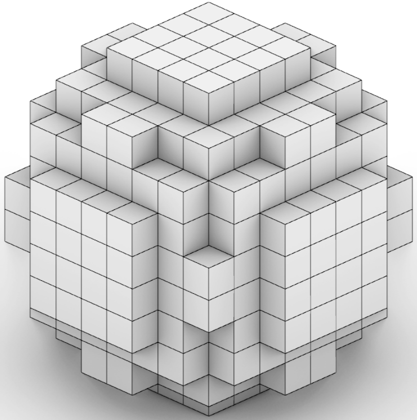


Voxel-based approximation of a sphere

Learning objectives

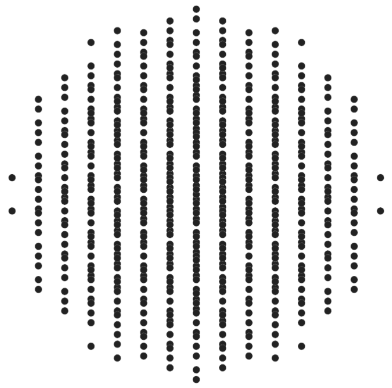
1. Constructing **a voxelized representation of a sphere** by evaluating the implicit sphere equation on a 3D grid.
2. **Generating voxel geometry** and extracting their edges to understand discrete, grid-based spatial representations.

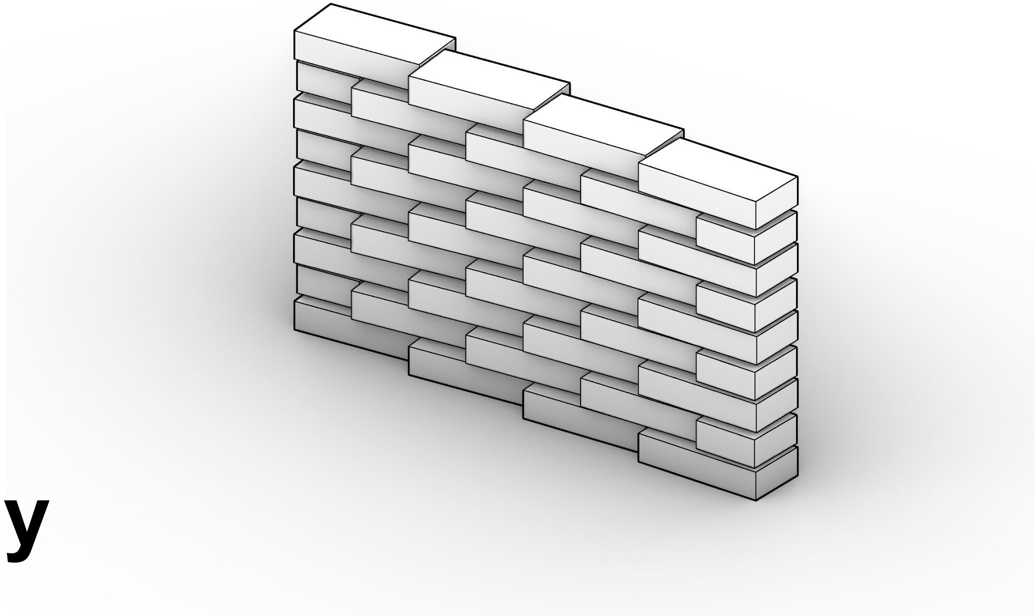


Voxel-based approximation of a sphere

Learning objectives

1. Constructing **a voxelized representation of a sphere** by evaluating the implicit sphere equation on a 3D grid.
2. **Generating voxel geometry** and extracting their edges to understand discrete, grid-based spatial representations.





Example: Assembly