Let's define the function `geneva_wheel(d, r, theta)`:

```
    # Compute exact pose
    psi = atan2(r * sin(theta), d - r * cos(theta)) + pi / 4
    assert abs(theta) <= pi / 4, 'pin out of bounds'
    return bake_keyframe(psi)
```

Geometry as an Executable Specification

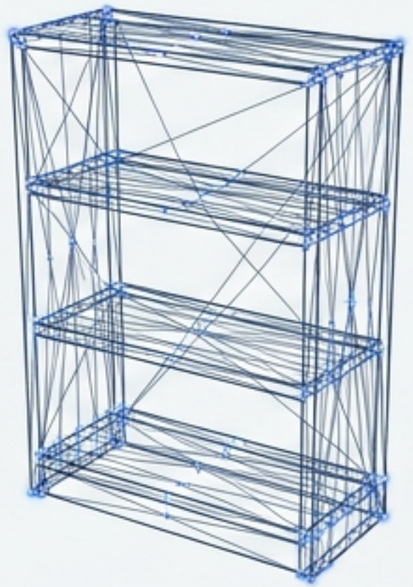
Treating 3D models as verifiable programs rather than static files.



Gemini Notebook

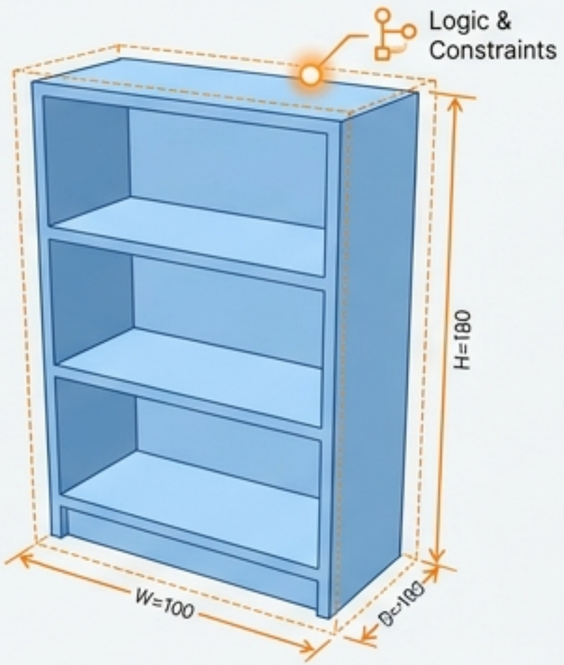
Losing the “Why” of a Shape

Interactive Modeling



- Leaves a shape.
- Artifact is a dead collection of coordinates.
- Human infers design intent; the file does not state it.
- If a shelf is nudged, nothing objects.

Executable Modeling



- Leaves a program.
- Artifact names the quantities that dictate coordinates.
- Rejects inputs that create impossible objects.
- Explicitly tests what it has built.

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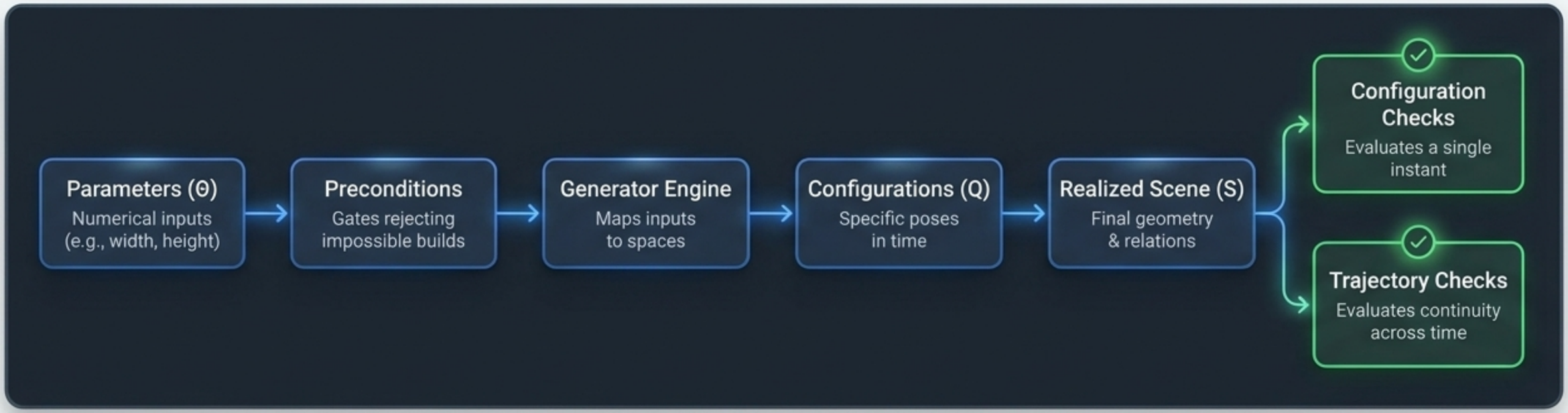
The Anatomy of a Generator



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Phase 1: Mechanisms & The Math of Motion

Repository Scope:

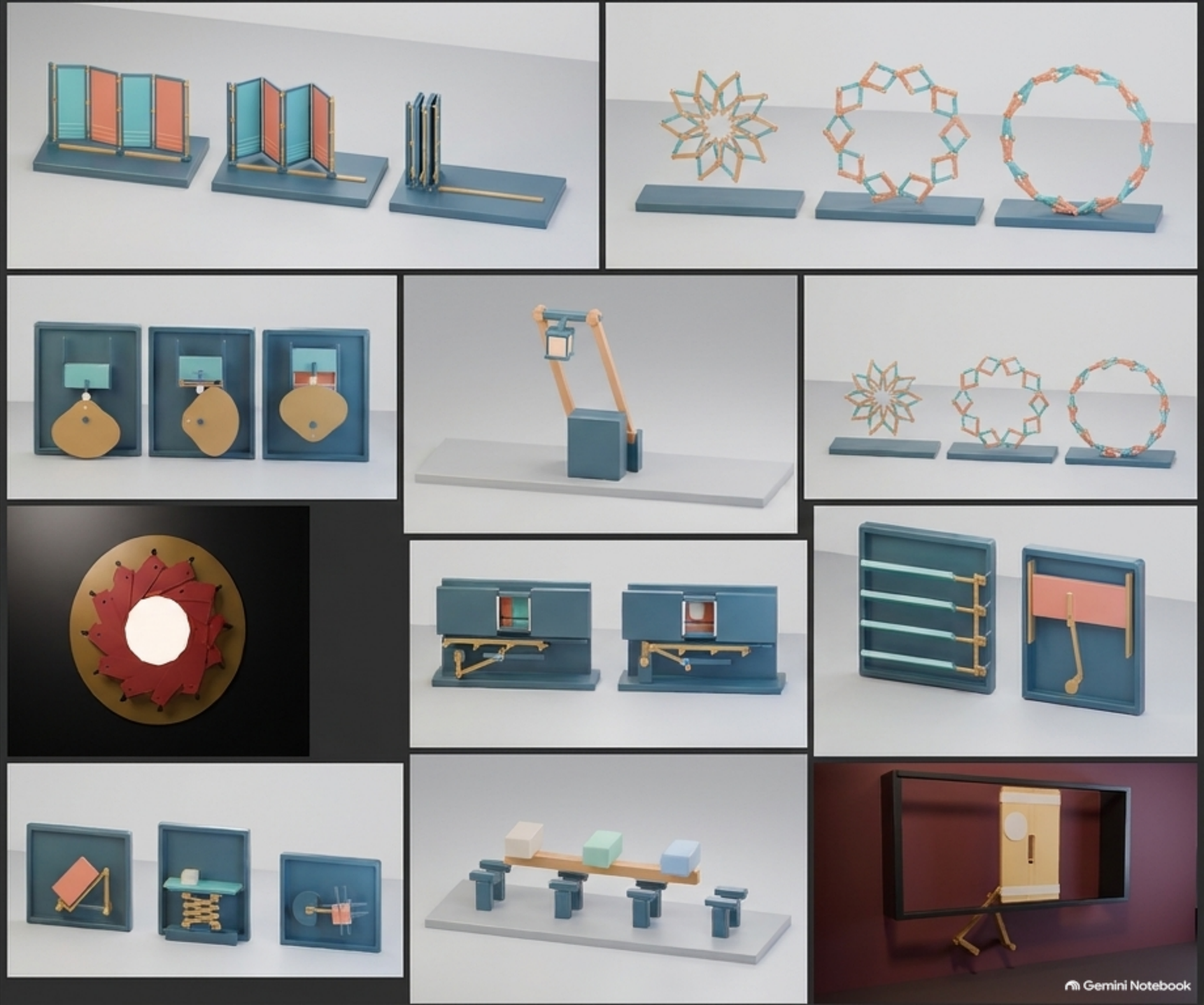
12 scripts
~2,600 lines of Python

Methodology:

No physics engines are used. Scripts compute exact poses from geometry at each sampled instant and bake the results into keyframes.

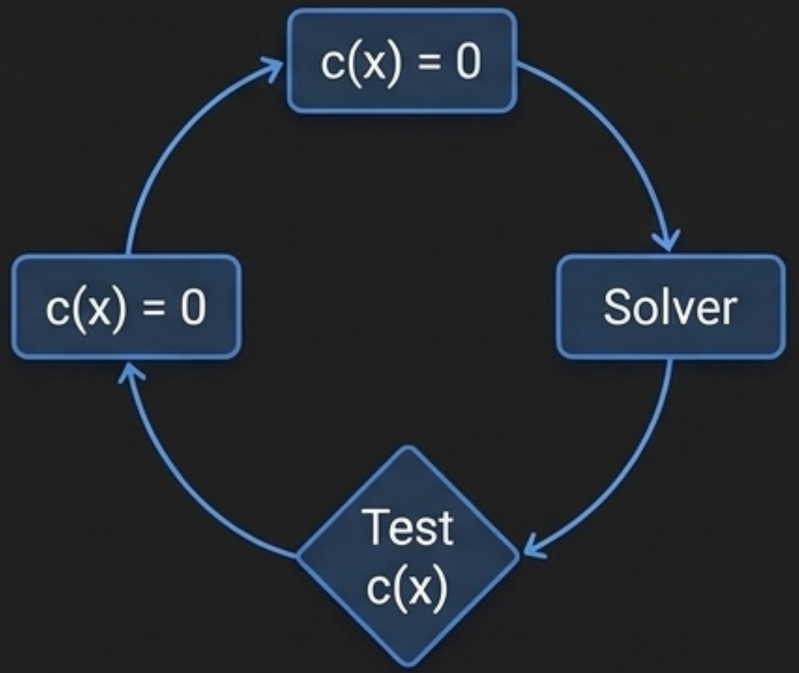
Example Outputs:

Cams, folding screens, expanding rings, iris shutters, intermittent drives, and straight-line linkages.



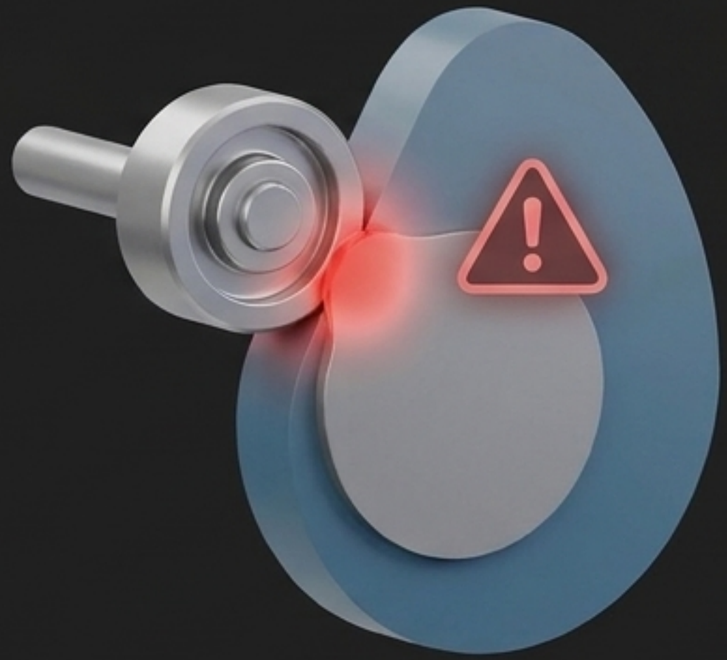
The Illusion of Verification

Restating Construction



If a pose is computed via an equation, testing that equation only proves the arithmetic solver isn't broken. It carries **zero information** about **real-world viability**.

Checking Intent



Math carries zero information about properties left free by the equations—like arbitrary parts colliding. True verification requires testing against **human intent**.

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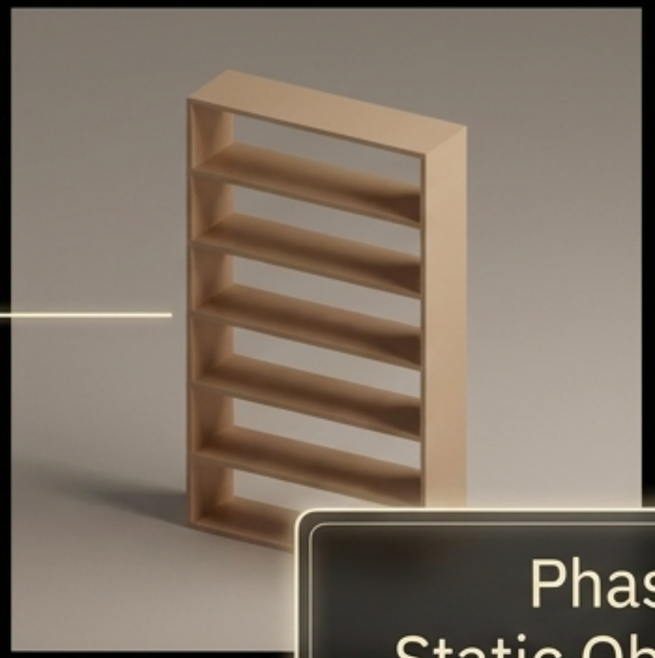
Phase 2: Static Objects are Point Configurations

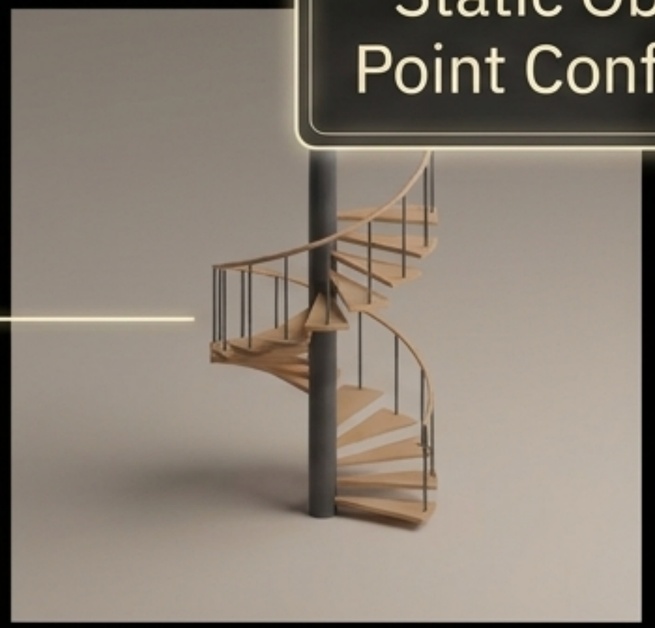
Parametric logic rejects impossible builds (e.g., board thickness exceeding total width).



Changing frequency parameters alters the base. Only specific inputs yield a flat base—a requirement that must be explicitly checked.



Verifies closure and equal rise, but does not guarantee conformity with building codes.



Closed surface mesh volume is verified against analytical volume of 128-sided stacked frusta (agreeing to within 10^{-4}).



Removing time removes the solver, but keeps everything else: parameters, preconditions, construction, and identi

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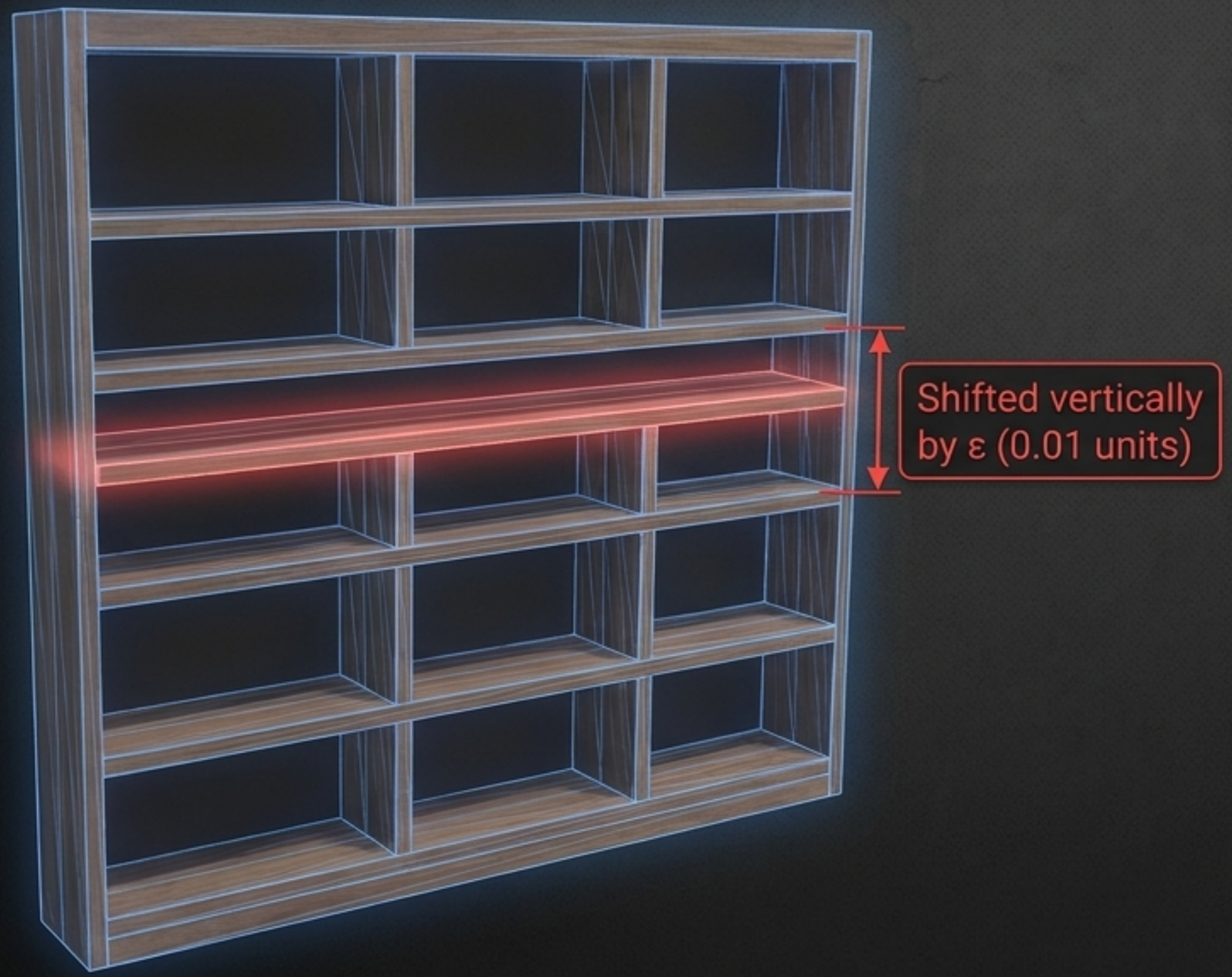
Case Study: The Escaped Defect



Generic Mesh Verification

```
[PASS] Part Count: Remains 7

[PASS] Closure: No holes created

[PASS] Volume: Total mass unchanged

[PASS] Interpenetration: Distance to
neighbors > 0
```

Key Insight: Generic geometric tests are entirely blind to a ruined design because they do not know what the object is supposed to be.

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Encoding Design Intent

```
clear = [b[0][2] - a[1][2] for a, b in zip(boards, boards[1:])]
assert max(clear) - min(clear) < 1e-5, 'uneven shelf spacing'
```

```
[PASS] Part Count
[PASS] Closure

[PASS] Volume

[FAIL] Equal Shelf Spacing (Max delta exceeds 1e-5)
```

The only remedy for the escaped defect is **explicitly** stating the property taken for granted. A library of generators must grow by **encoding the intentions** that generic **tests do not know.**

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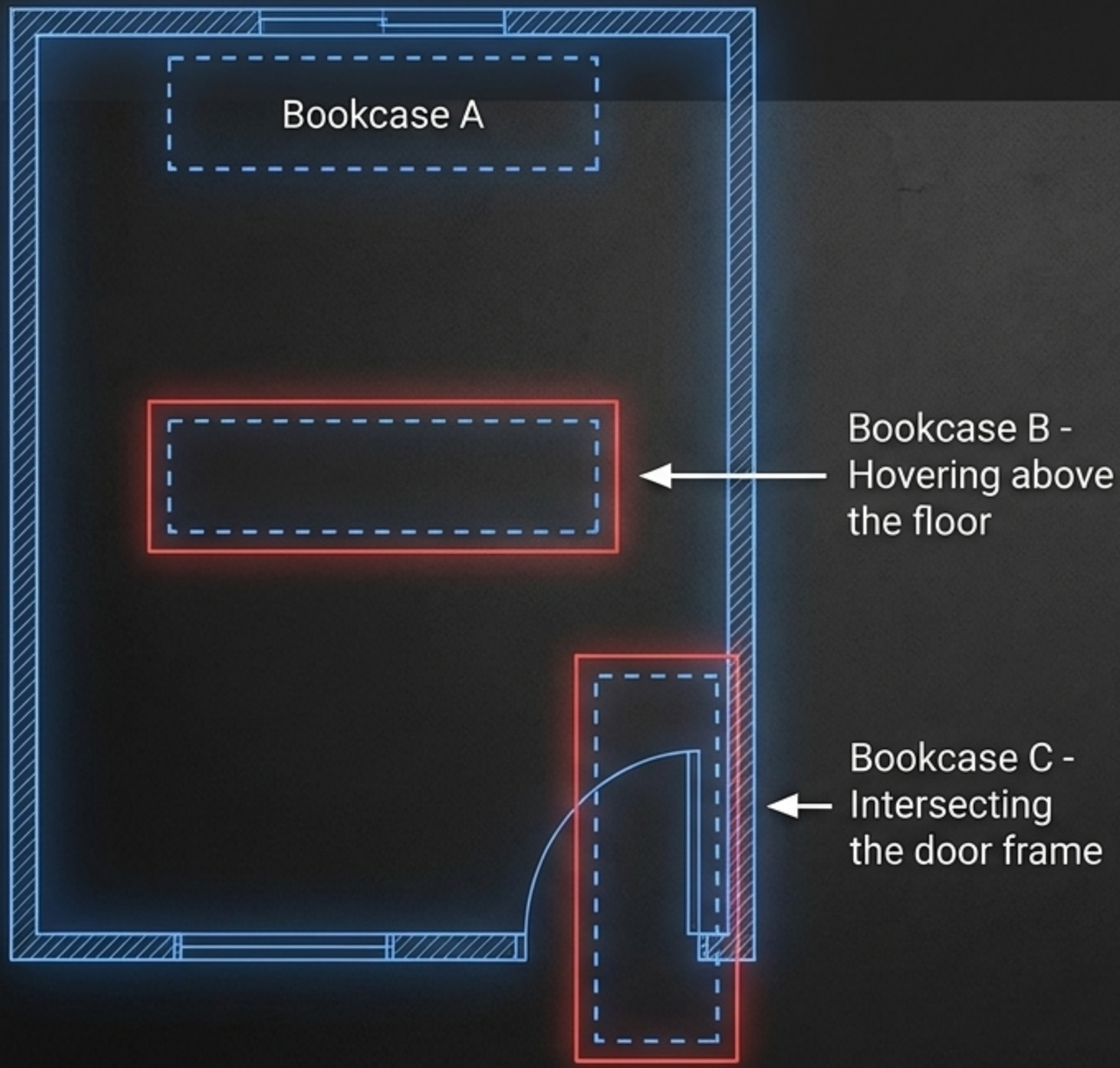
Phase 3: Composable Systems & Invisible Placement



Placement is invisible to unit checks.

A rigidly translated unit will perfectly pass all of its own internal checks even if it floats or blocks a doorway.

Composition adds obligations at each level. Containers (rooms) must test what components (bookcases) **cannot**.

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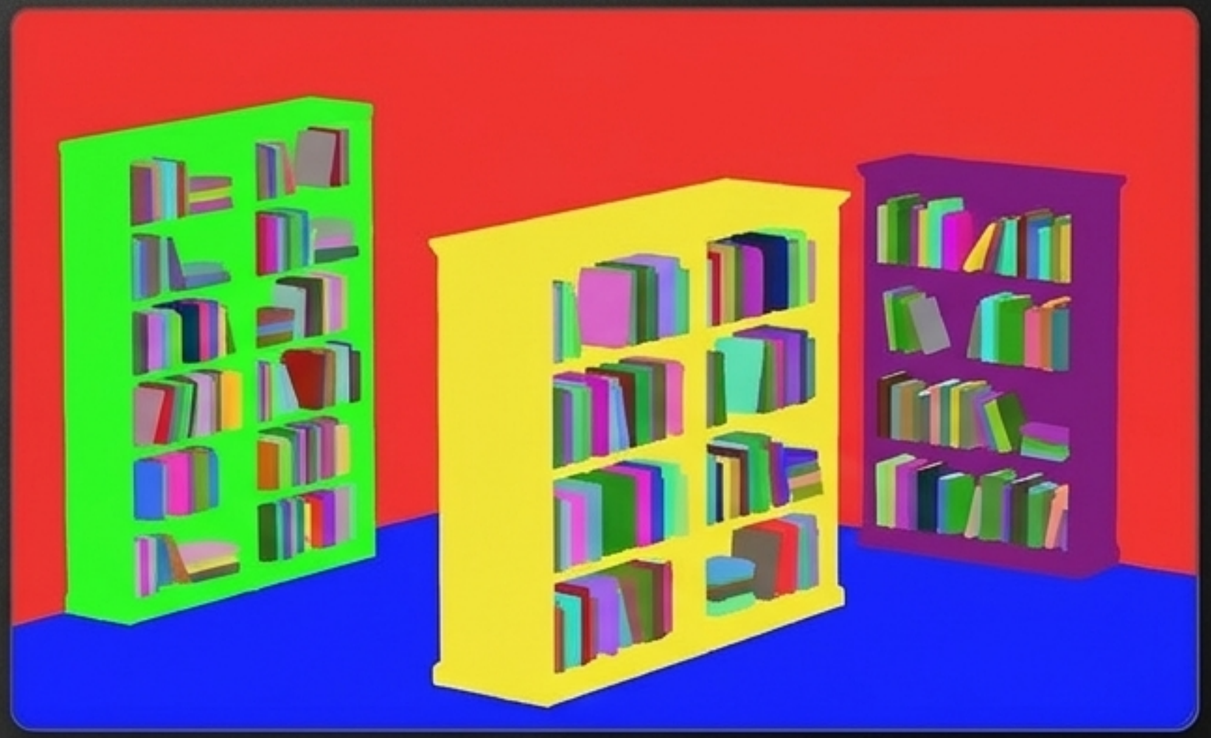
Phase 4: Synthetic Data Generation



Rendered Scene



Self-Labeling Output

Because a generator **mathematically knows what it built** and **exactly where it placed it**, it can **perfectly** output label images, depth arrays, and bounding boxes without requiring any manual human annotation.

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The Two-Route Validation Technique

Route A: Rendered Label

Flat emissive ID levels

Route B: Raycasting

Cast ray through pixel centers

Disagreement Detected: 203,136 of 1,474,560 pixels mismatched.



The Culprit: Blender's default world node tree grey background was recorded as ID 13—the exact same ID number assigned to one of the bookcase boards.

A second computational route to the same label is essential. A single route will report massive errors with complete confidence.

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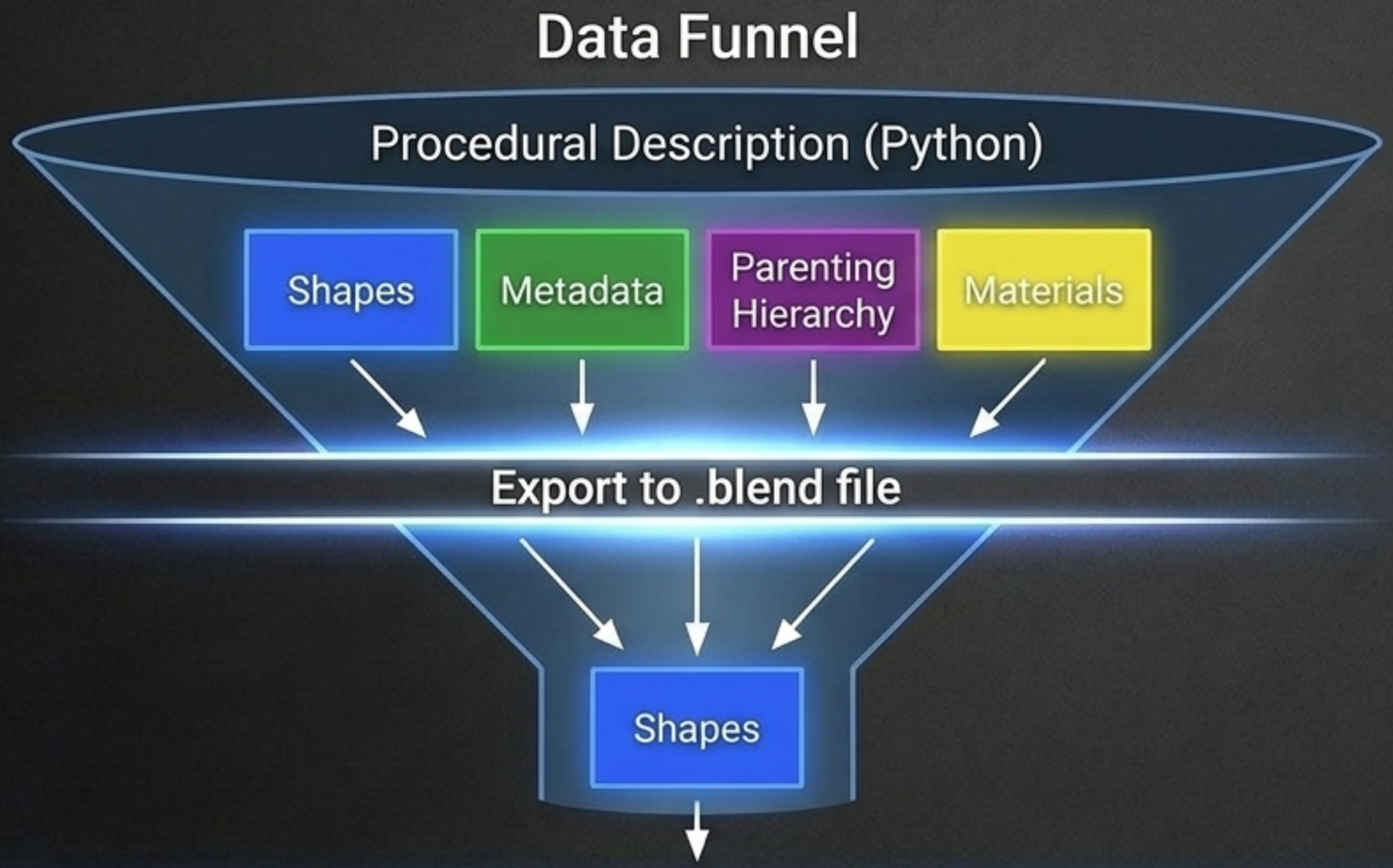
Generative Repositories & The Boundary Problem



Micromegas study

Across 6 generative families
(e.g., "great microscope", 'cosmic necklace')

- ✅ 100% of primitives exported.
- ❌ 0 objects retained parents.
- ❌ 0 objects retained materials.
- ❌ 0 objects retained custom properties.

A **repository of generators preserves the capacity to produce**. A folder of static meshes only preserves dead products stripped of context.

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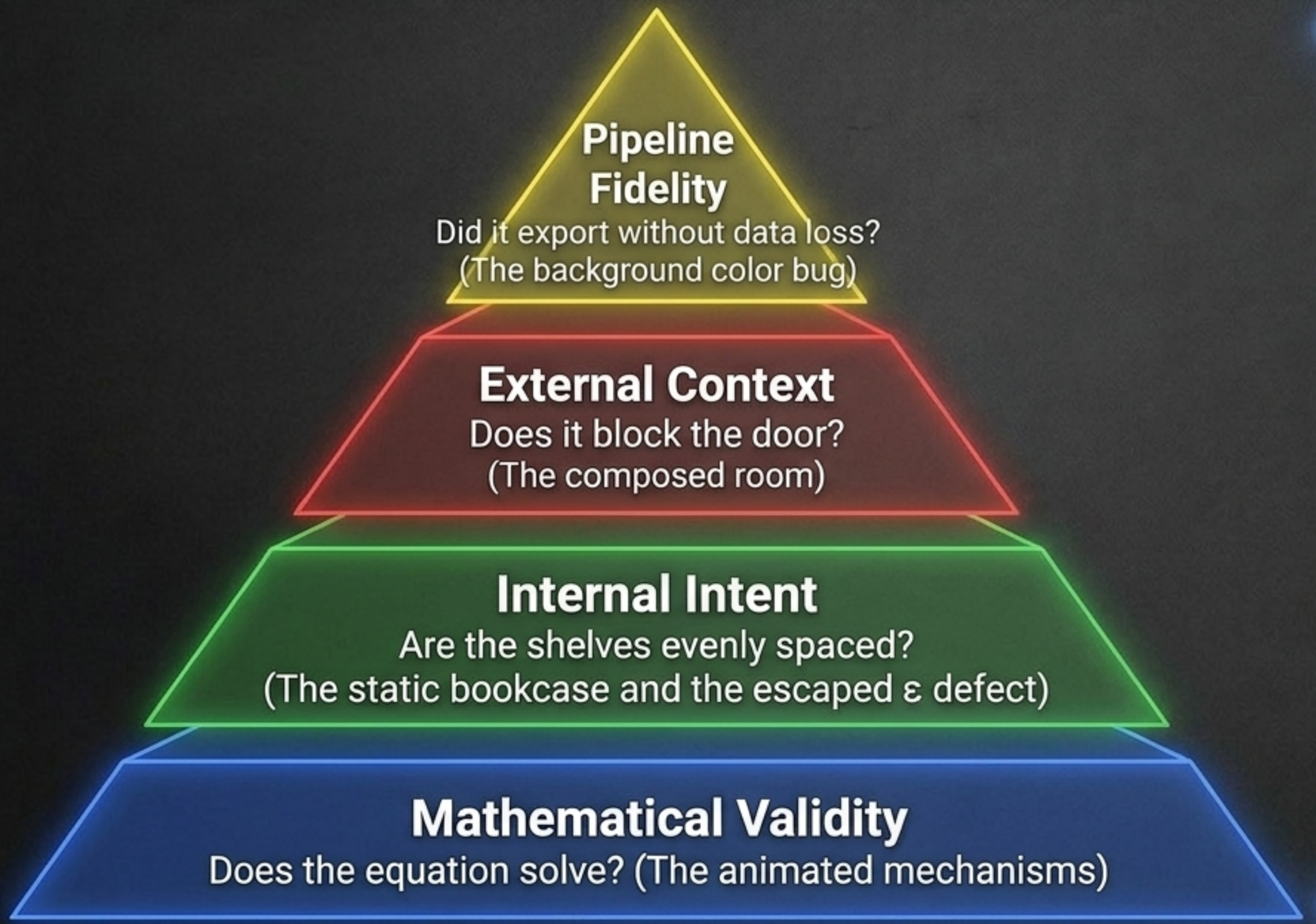
The Escalating Hierarchy of Verification



Passing a test at one layer guarantees nothing about the layer above it. Executable geometry requires asserting correctness at every boundary.

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Headless Geometry as Production Infrastructure



Moving 3D out of the interactive graphical session and into the command line. Scripts accept parameters, perform internal tests, write manifests, and return a pass/fail status to the larger pipeline. A true automated asset factory.

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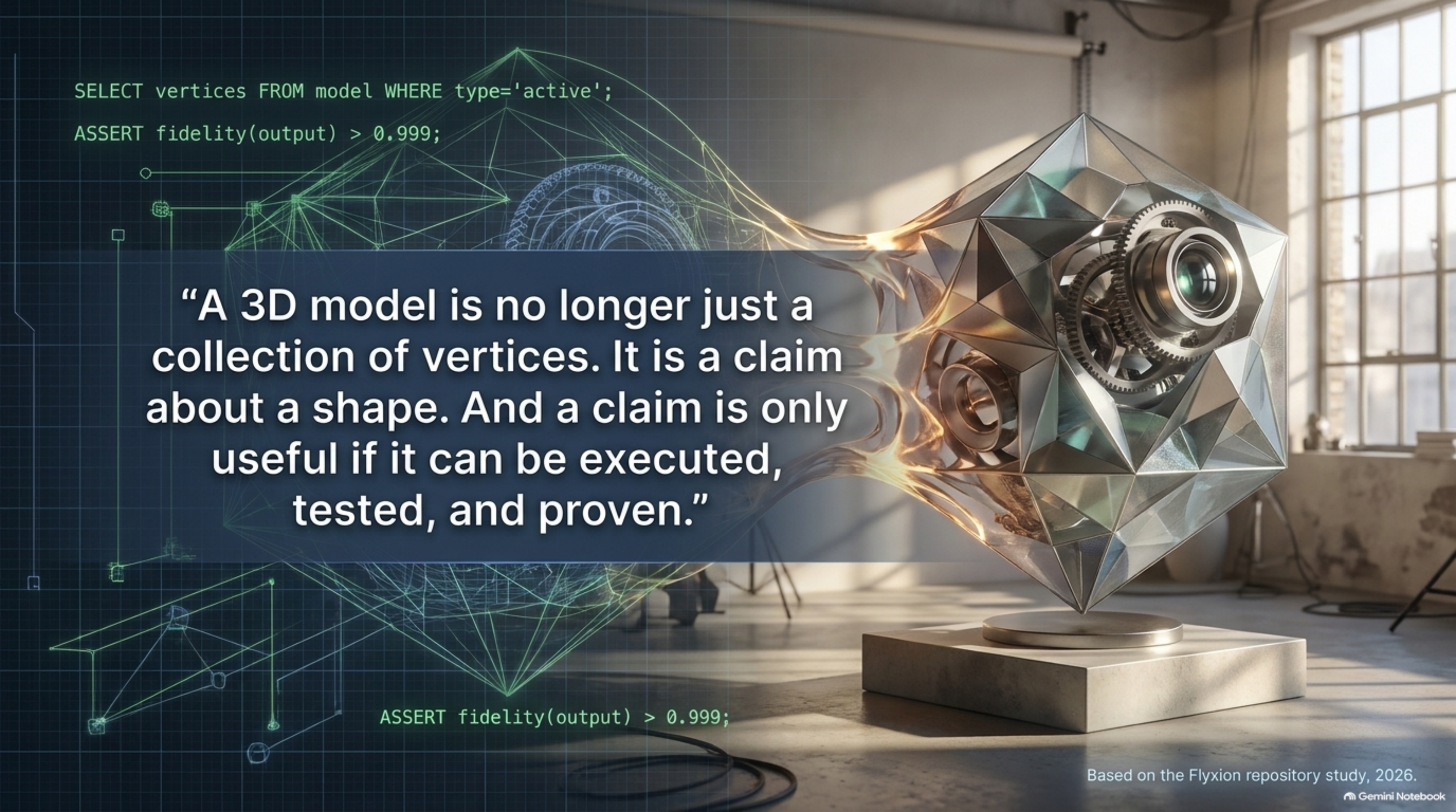
SELECT vertices FROM model WHERE type='active';
ASSERT fidelity(output) > 0.999;
“A 3D model is no longer just a collection of vertices. It is a claim about a shape. And a claim is only useful if it can be executed, tested, and proven.”
ASSERT fidelity(output) > 0.999;
Based on the Flyxion repository study, 2026.
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