

x3d_mcp

A Model Context Protocol Server for AI-Assisted X3D Authoring

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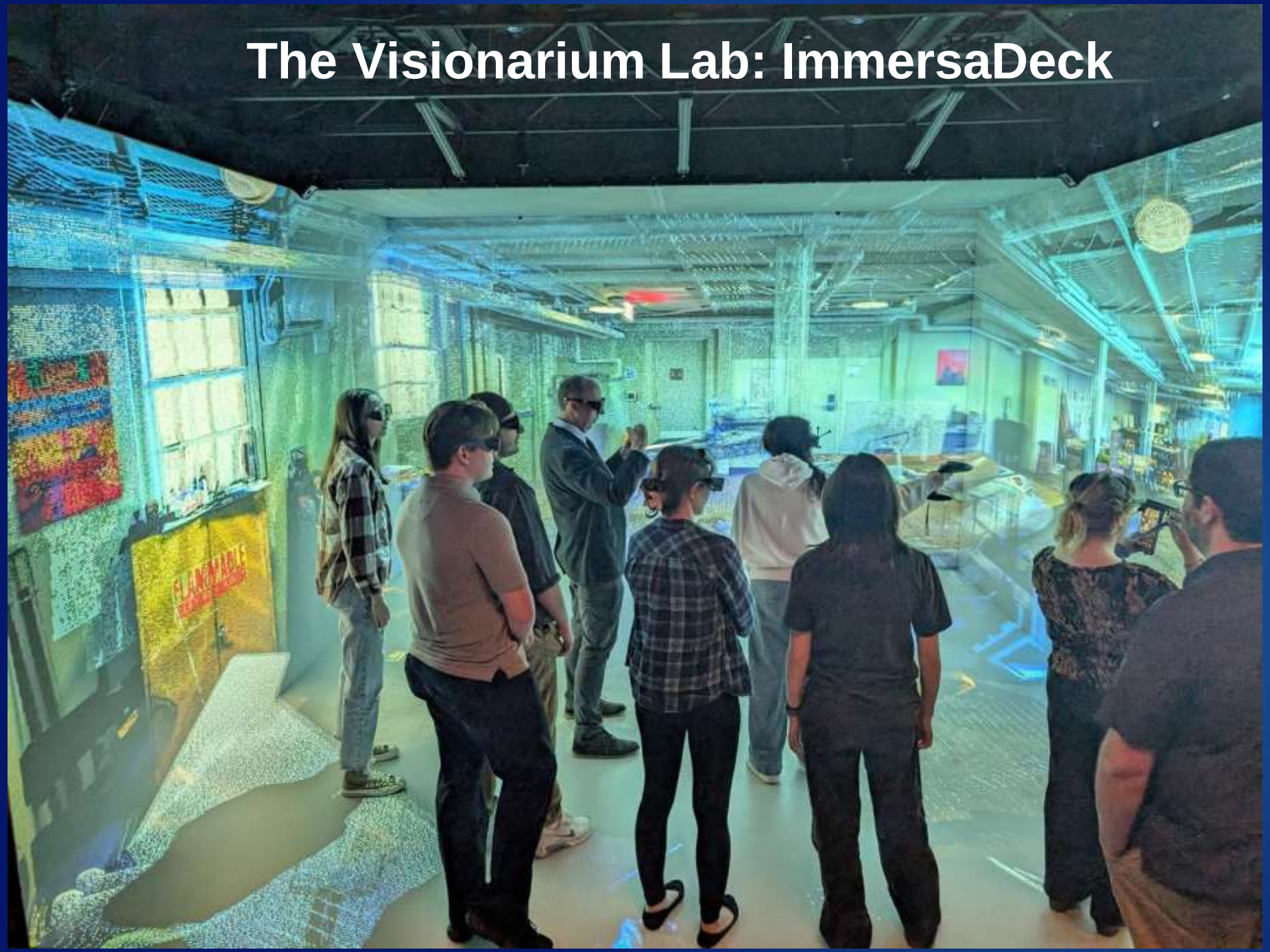
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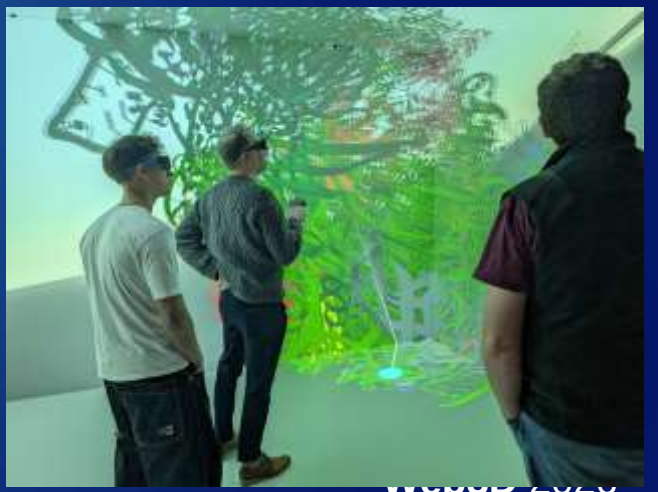
Web3D Consortium
https://www.web3d.org/



The Visionarium Lab: ImmersaDeck







Why Grounding Matters

From plausible markup to specification-valid X3D with any LLM



Raw LLM Failure Modes

- Ungrounded models invent X3D nodes, fields, and incompatible ROUTE connections
- Plausible XML can parse yet fail XSD and semantic validation
- X3D 4.1 adds six nodes beyond typical training familiarity
    - backwards-compatible forwards-compatible evolution continues
- x3d_mcp queries authoritative assets during generation



MCP : Model Context Protocol

- Model Context Protocol (MCP) is an open protocol that lets AI assistants and LLMs interact with external tools, data sources, and services through a standardized interface.

- With MCP, AI can discover available tools, call them with structured inputs, and receive structured results. This makes AI systems more accurate, capable, and connected to authoritative sources.

- For 3D authoring, MCP allows an AI to move beyond "guessing" X3D syntax and instead query specifications, validate models, manipulate scenes, and generate standards-compliant content through dedicated tools.



Rather than embedding all X3D expertise into a model, the expertise is externalized and maintained in the server.

The system provides authoritative schema information, node definitions, hierarchy constraints, and semantic guidance directly to the AI during generation. This addresses a common LLM problem: hallucinating APIs, attributes, or structures that do not actually exist.



Features I

The server supports:

- XML/X3D schema validation
- Structural hierarchy checking
- DEF/USE consistency checking
- ROUTE validation
- Semantic scene validation

Detection of authoring mistakes that schemas alone cannot catch



Features II

Exposes the X3D Unified Object Model and related resources as AI-accessible tools, enabling:

- Node lookup
- Field lookup
- Type constraints
- Inheritance inspection
- Parent/child relationship checking
- Component and profile exploration

This effectively turns the X3D specification into an interactive knowledge base for AI.

Features III

The system does more than answer questions. It supports:

- Generating X3D scenes
- Editing existing scenes
- Node insertion/removal
- Scene conversion
- Browser rendering workflows
- Animation generation

This shifts MCP from a documentation-access tool into a practical authoring environment.



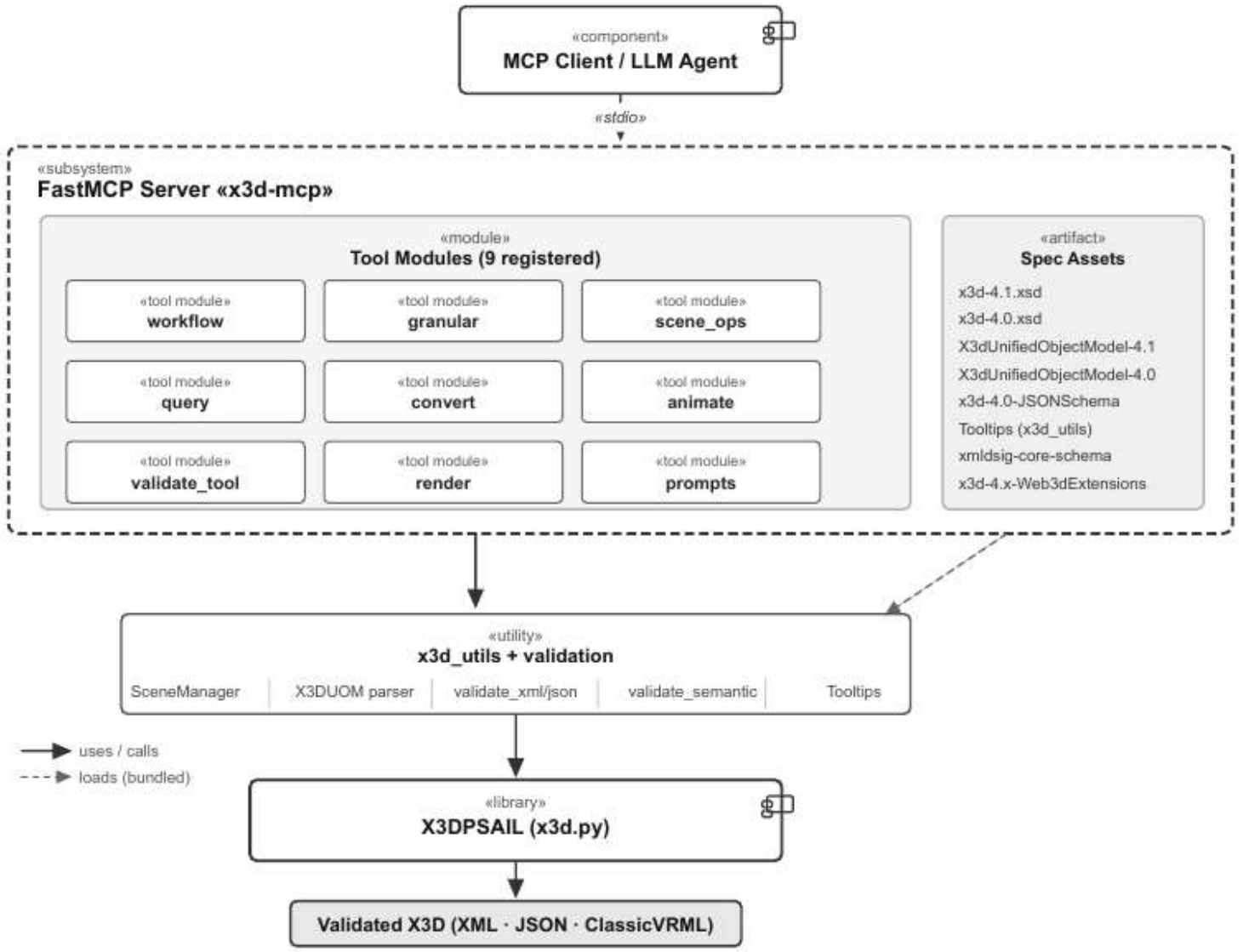
Features IV

Supports automatic generation of X3D animation structures such as:

- TimeSensor
- Interpolators
- ROUTE networks

The server helps construct correct animation pipelines automatically rather than requiring manual assembly.

Grounded Server Architecture



FastMCP is a common MCP approach.

x3d_mcp dispatches nine modules.

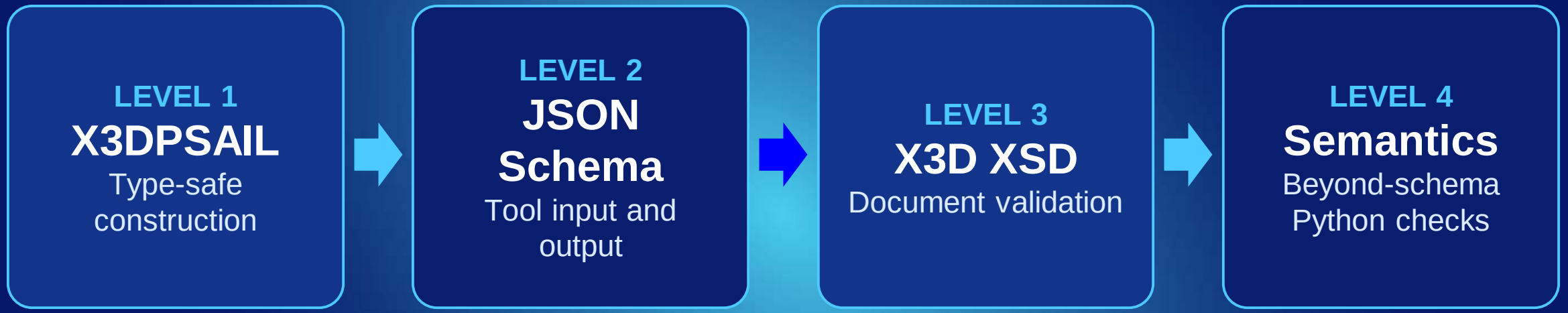
X3DPSAIL x3d.py returns validated X3D.

Authoritative X3D Stack

- X3DUOM indexes roughly 265 X3D concrete nodes with inheritance
- X3D 4.0 and draft 4.1 schemas ship bundled
- X3D-Edit's X3D Tooltips add maintained authoring guidance for each node and field
- X3DPSAIL builds type-safe Python scene graphs
  - Easy to create a valid X3D model, hard to create an invalid X3D model
- More assets are being incorporated: X3D Schematron, X3D Regular Expressions (regex)
  - Each improvement is tracked as part of **x3d_mcp issues**



Four Validation Levels



Each level catches errors the previous level cannot.

Fifteen-Fault Ablation

Key: ✓ caught, ○ passes, — not reachable at that level.

Fault class	L1	L2	L3	L4
Invented node type	✓	—	—	—
Wrong field value type	✓	—	—	—
Invented field name	✓	—	—	—
Out-of-range field value	✓	—	—	—
Malformed tool payload	—	✓	—	—
Missing required tool parameter	—	✓	—	—
Unknown element	—	—	✓	✓
Illegal parent for geometry	—	—	✓	✓
Malformed attribute value	—	—	✓	✓
Duplicate DEF	—	—	✓	✓
USE without DEF	—	—	○	✓
Shape missing geometry	—	—	○	✓
Empty grouping node	—	—	○	✓
ROUTE type mismatch	—	—	○	✓
ROUTE to missing DEF	—	—	○	✓

15/15

corpus faults caught

5

fault classes pass XSD and require Level 4

Duplicate DEF is XSD-visible.
Dangling USE is not IDREF.

Nine-Module Tool Surface

28 tools and 4 guided prompts

Module	Lifecycle phase	Representative tools
query	Discovery	list_nodes, describe_node, list_components, list_profiles
workflow	Synthesis	create_scene, create_geometry, compose_scene
granular	Stateful synthesis	create_node, set_field, add_child, add_route
scene_ops	Editing	modify_x3d_node, remove_x3d_node, move_x3d_node
animate	Animation	animate_x3d_node, add_x3d_route, x3d_animation_info
validate	Validation	validate_x3d, validate_current_scene, validate_semantic
convert	Encoding	convert_x3d across XML, ClassicVRML, and JSON
render	Output	x3dom_page, x3dom_starter
prompts	Guided	build_scene, audit_scene, animate_scene, convert_to_x3dom_html

More tools continue to be added to this excellent repertoire



Dual Authoring Modes

- **Workflow tools** return validated scenes in one roundtrip
- **Granular tools** support stateful, incremental scene construction
- Stateless scene operations edit existing DEF-targeted nodes
- Both modes converge on identical validated output encodings



Primitive to Composition

Workflow 1: Red sphere

Listing 2: Generated X3D 4.0 document.

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE X3D PUBLIC "ISO//Web3D//DTD X3D 4.0//E
  "https://www.web3d.org/specifications/x3d-4.0.
      dtd">
<X3D profile='Interchange' version='4.0'>
  <Scene>
    <Shape>
      <Appearance>
        <Material diffuseColor='0.9 0.1 0.1'/>
      </Appearance>
      <Sphere radius='1.5'/>
    </Shape>
  </Scene>
</X3D>
```

Workflow 2: Table scene

Listing 3: compose_scene call for the table scene (abridged).

```
{
  "objects": [
    {"shape":"box",      "size":[2,0.15,1.5],
     "color":[0.55,0.27,0.07], "def_name":"
         TableTop"},
    {"shape":"cylinder", "size":[0.06,1],
     "color":[0.45,0.22,0.05],
     "translation":[0.7,-0.57,0.5], "def_name":"
         Leg1"},
    // Leg2..Leg4 omitted for brevity
    {"shape":"sphere",   "size":[0.25],
     "color":[0.85,0.1,0.1],
     "translation":[0.4,0.35,0.2], "def_name":"
         Apple"},
    {"shape":"cylinder", "size":[0.12,0.35],
     "color":[0.15,0.4,0.85],
     "translation":[-0.35,0.25,-0.1],"def_name":"
         Mug"}
  ],
  "viewpoint": {"position":[3,2,4],
```

Published tool calls and generated output

Iterative Solar System (Granular)

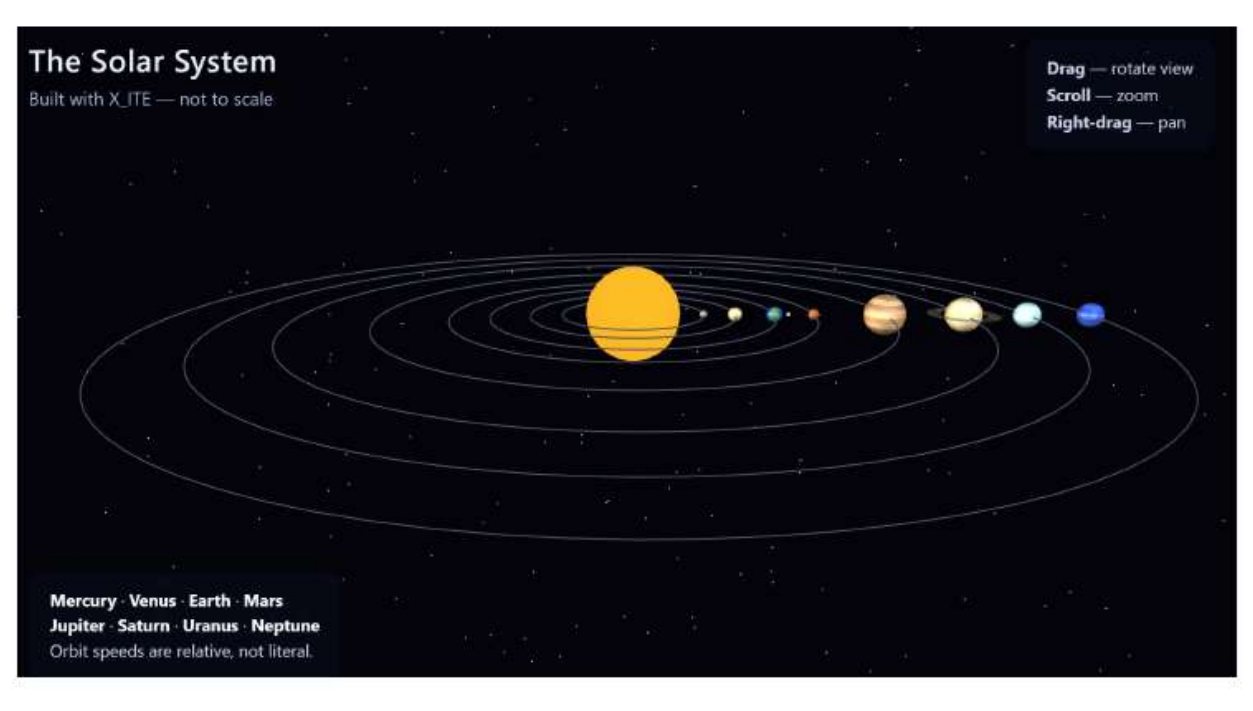


Figure 2: X_ITE render after three iterative turns

- compose_scene placed the Sun and eight planets
- animate_x3d_node selected OrientationInterpolator from SFRotation
- Named DEFs persisted across three conversational turns
- XSD and semantic validation passed every turn



demo video

Workflow Mode

Evaluation Boundary

- Completed ablation injects 15 structural fault classes
- Controlled MCP-versus-baseline X3D-model generation study remains in progress
- Full draft X3D 4.1 node coverage remains incomplete
- X_ITE tooling and multimodal feedback remain future work
- New work possible using X3D Examples Archive (issue 31)
    - improve models and validation tools, tease out X3D design patterns, etc. etc.
    - publish model archives similarly to other HuggingFace-described archives



Live Doha Scene

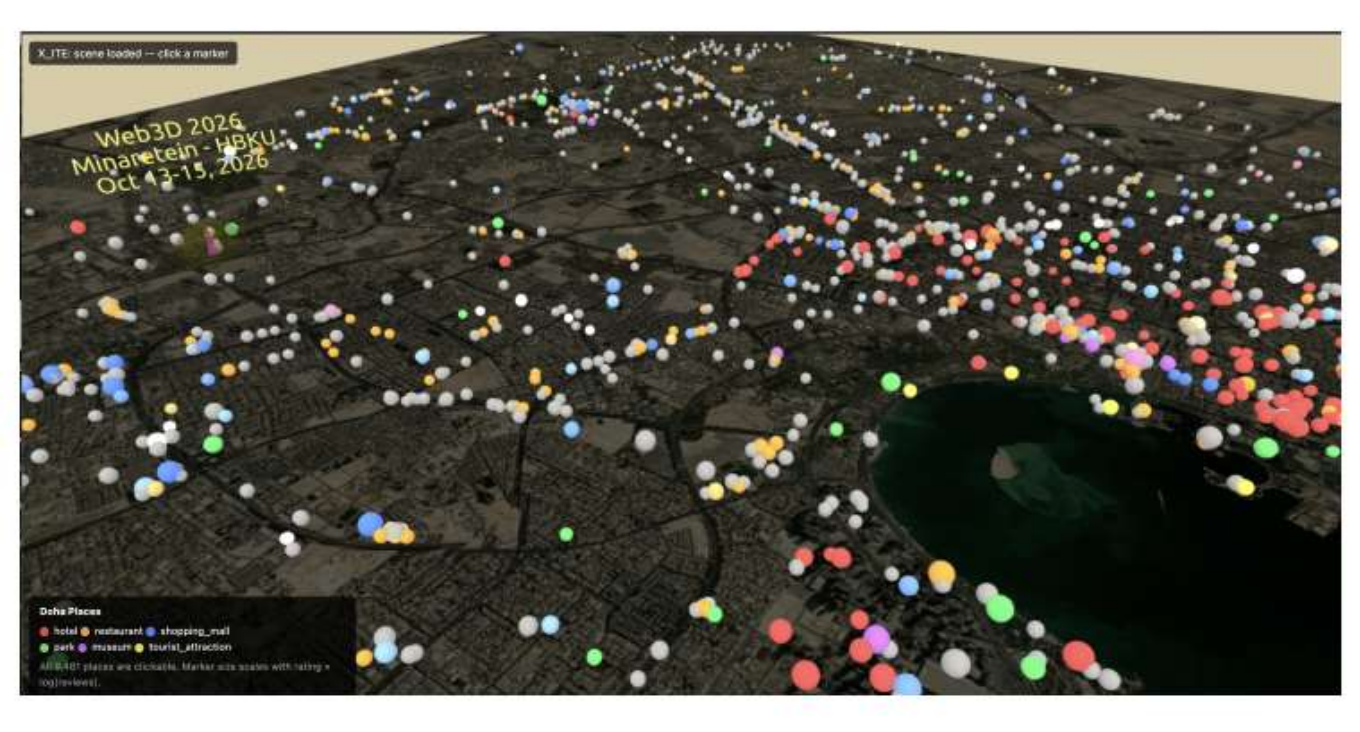


Figure 3: X_ITE render using live Google data

- Google Elevation API supplied terrain samples
- Google Places returned 4,361 locations across six categories
- Ratings control marker color and size
- XSD and semantic validation returned no errors

x3d_mcp Summary

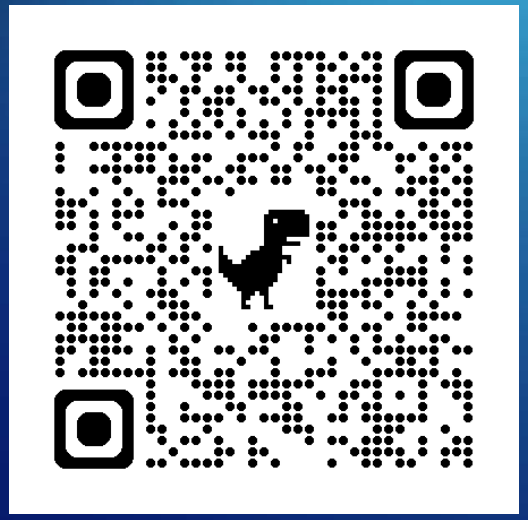
Our core innovation is using MCP as a standards-grounded middleware layer between LLMs and the X3D specification, allowing AI systems to author, validate, edit, and reason about X3D scenes with far greater reliability than prompt-only approaches. It offers a path toward:

- More reliable AI-generated 3D content
- Lower barriers to X3D authoring
- Standards-compliant scene generation
- AI-assisted editing and maintenance of complex 3D worlds



Thank You!

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