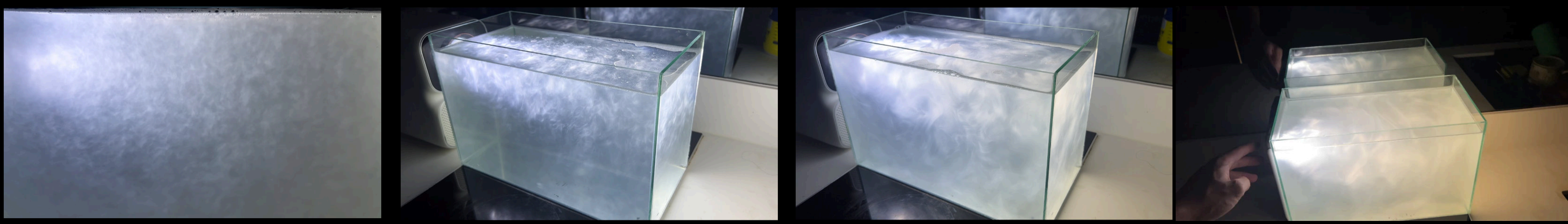
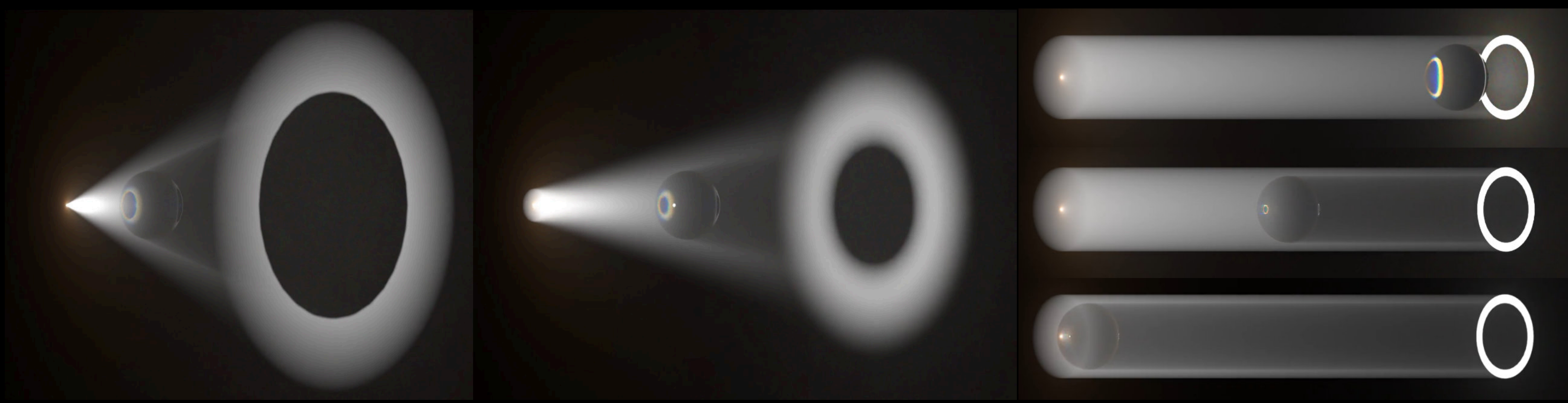
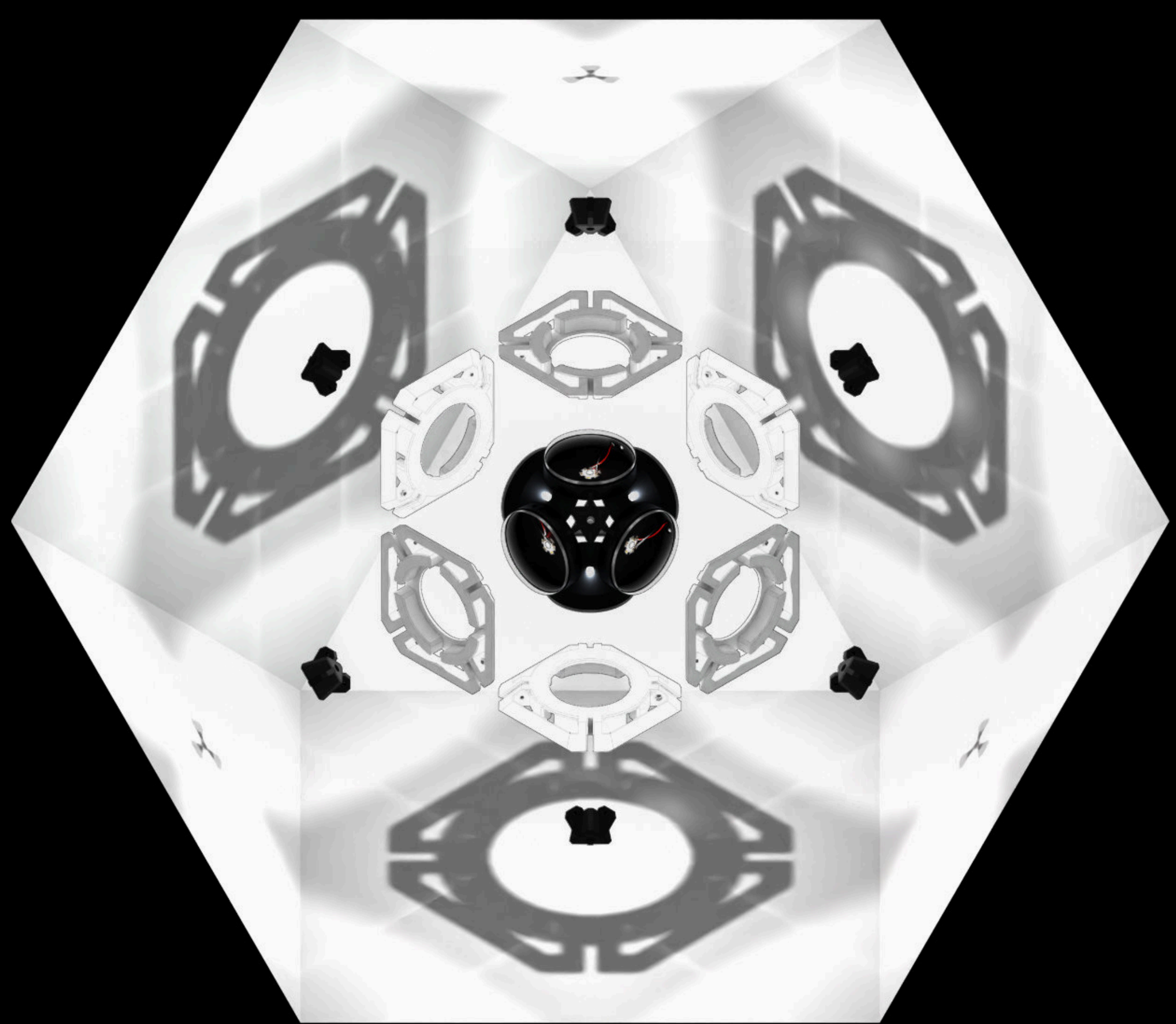
RAYLEIGH SCATTERING

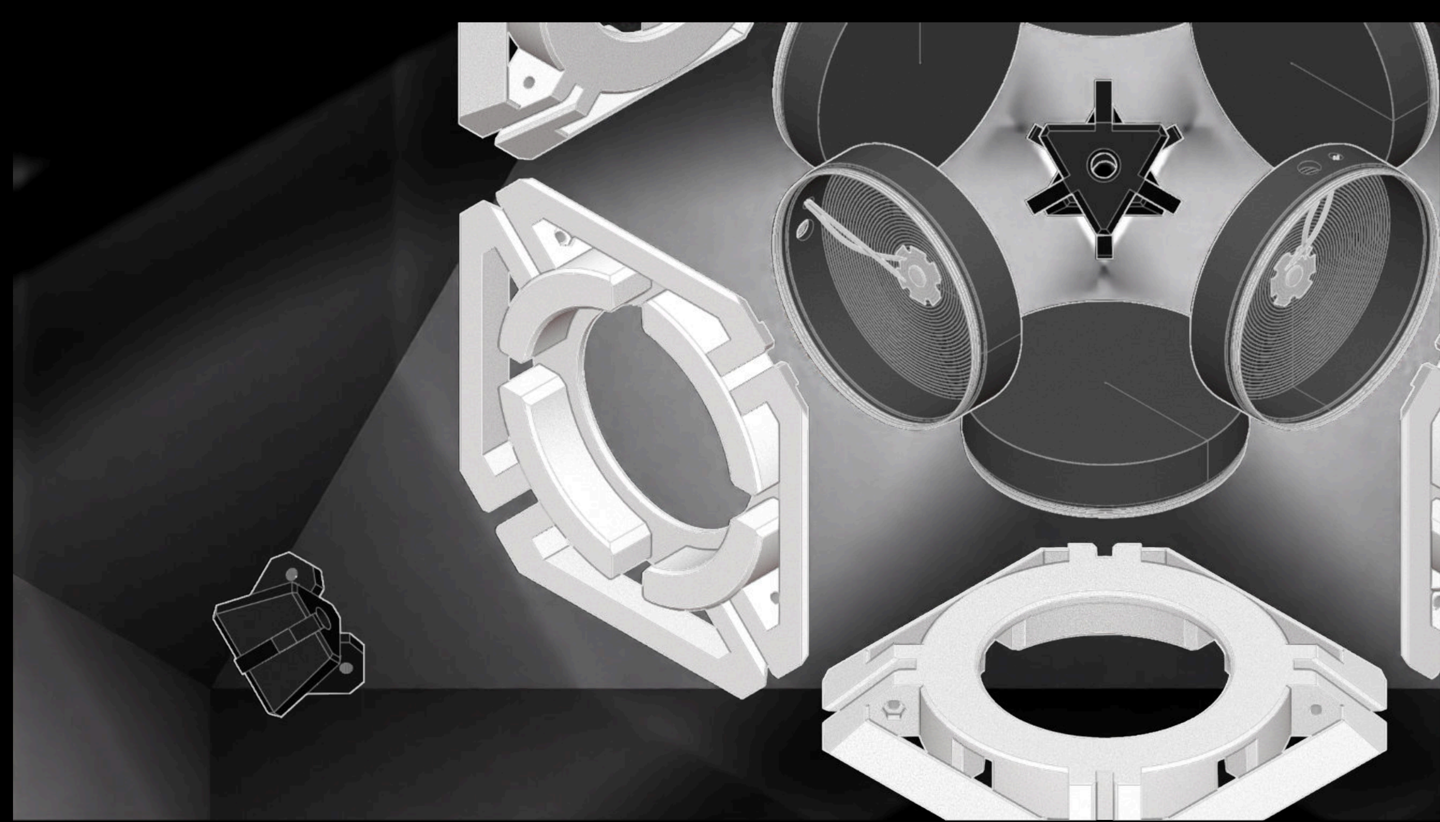


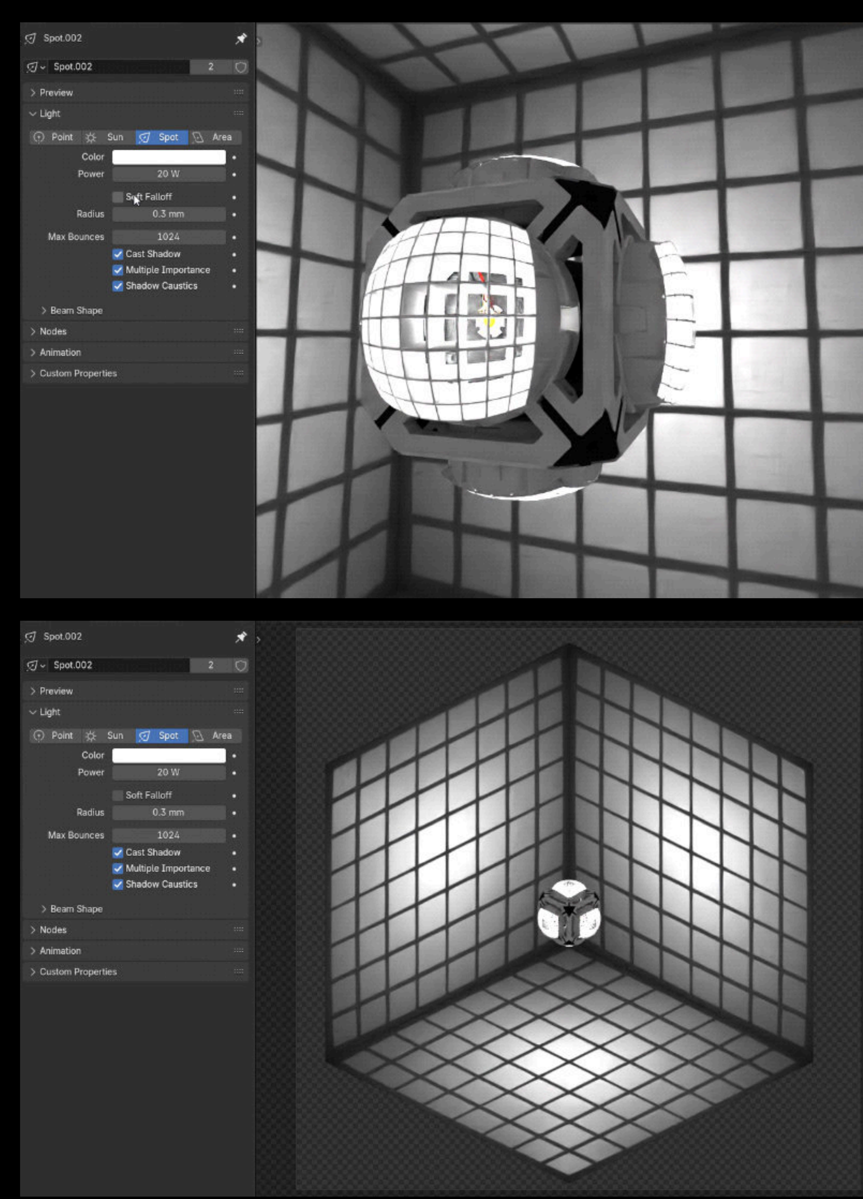
SHADOW SHARPNESS



The shadow sharpness experiments were conducted using a custom 3D simulation tool. These tests focused on three key variables: the radius of the point light , the distance between the light source and the shadow-casting object, and the distance from the object to the projection surface. The findings revealed that the smaller the LED radius, the sharper the shadow edges–mimicking the behavior of an ideal point light. Conversely, larger radius produced penumbras, creating blurrier, more diffused shadows. Additionally, increasing the distance between the light source and the shadow caster enhanced the definition and scale of the shadow pattern, but also reduced brightness intensity. Lastly, the proximity of the shadow-casting object to the projection surface proved crucial: closer objects yielded sharper, smaller shadows, while increased distance resulted in larger, softer silhouettes. These calibrated variables allowed the design of a system capable of fine-tuning shadow resolution to match spatial and narrative requirements.





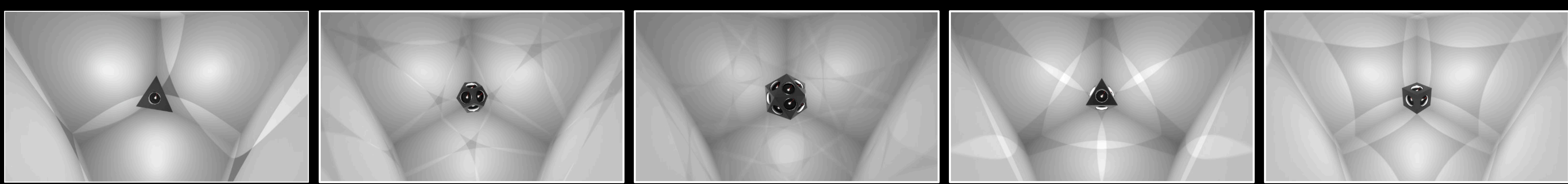


SHADOW PROJECTION DEVICE

A custom-designed apparatus engineered to cast intricate shadow patterns by projecting light through interchangeable pattern modules. The core structure features six high-intensity CREE LEDs arranged symmetrically on a 3D-printed frame, each directed through a magnifier lens and a patterned filter. To optimize the design, a custom 3D simulation software was developed to compute and visualize how light interacts with the geometry of the shadow maker.

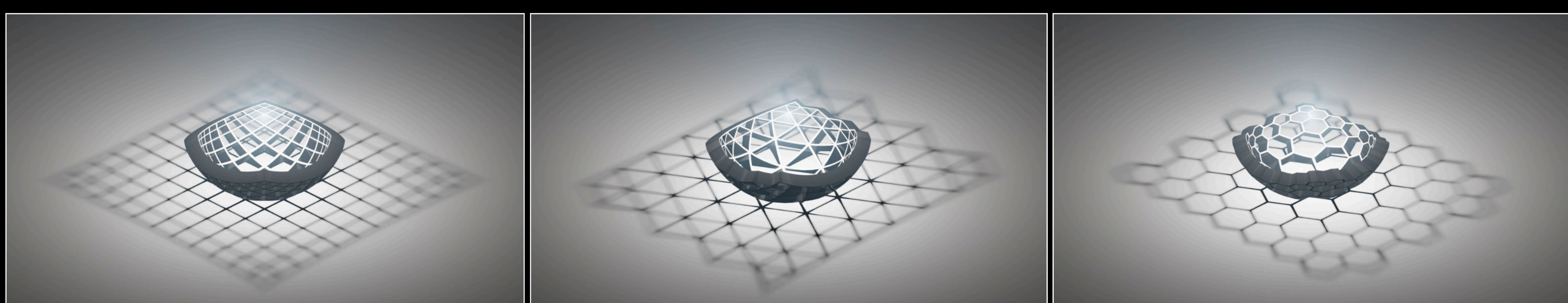
This tool enabled precise calculation of projection behavior, allowing real-time adjustments to the orientation, scale, and curvature of components. The simulation also revealed how the LED beam radius directly affects the sharpness of the projected shadows – a narrower beam creates sharper, more defined edges, while a wider beam softens the patterns. This dynamic control is essential for tailoring the visual outcome to specific spatial contexts or narrative intentions.

LIGHT OVERLAPPING

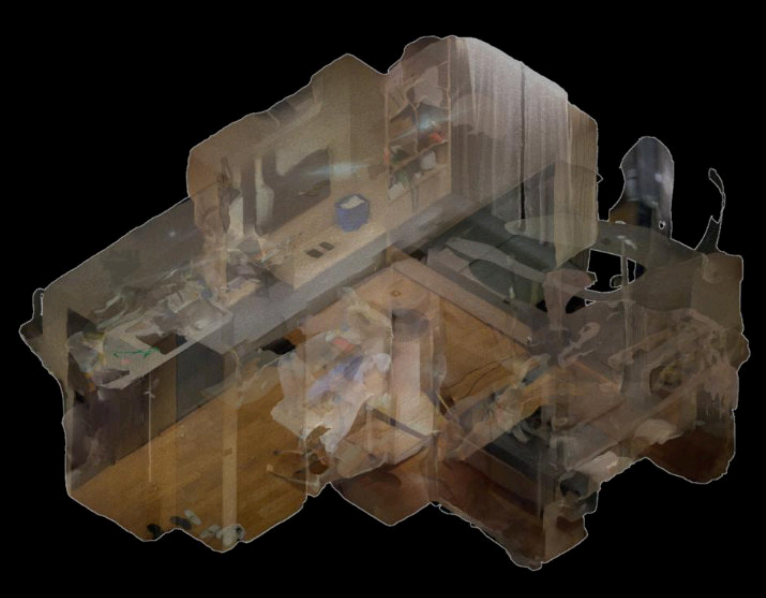


CREE LIGHT ON THE MANIFIER LENS

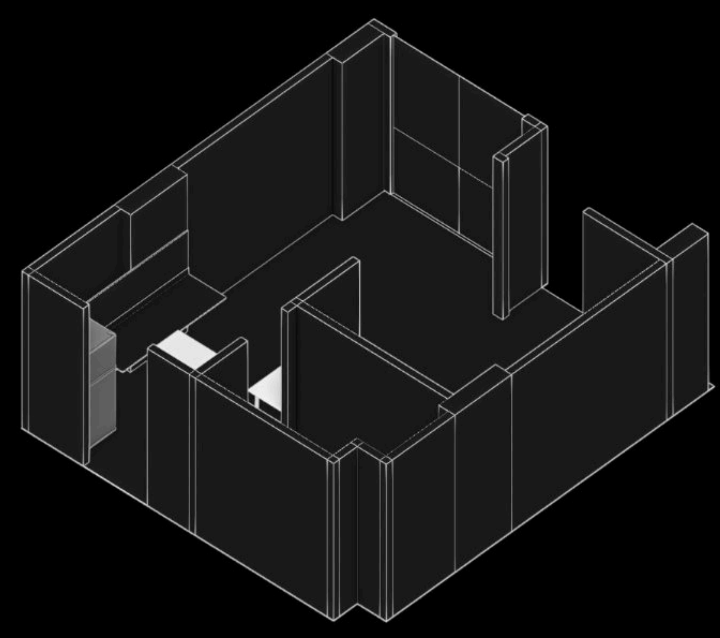
PATTERN PROJECTION



DIGITAL TWIN
3D PHOTOGRAMMATRY



3D photogrammetry

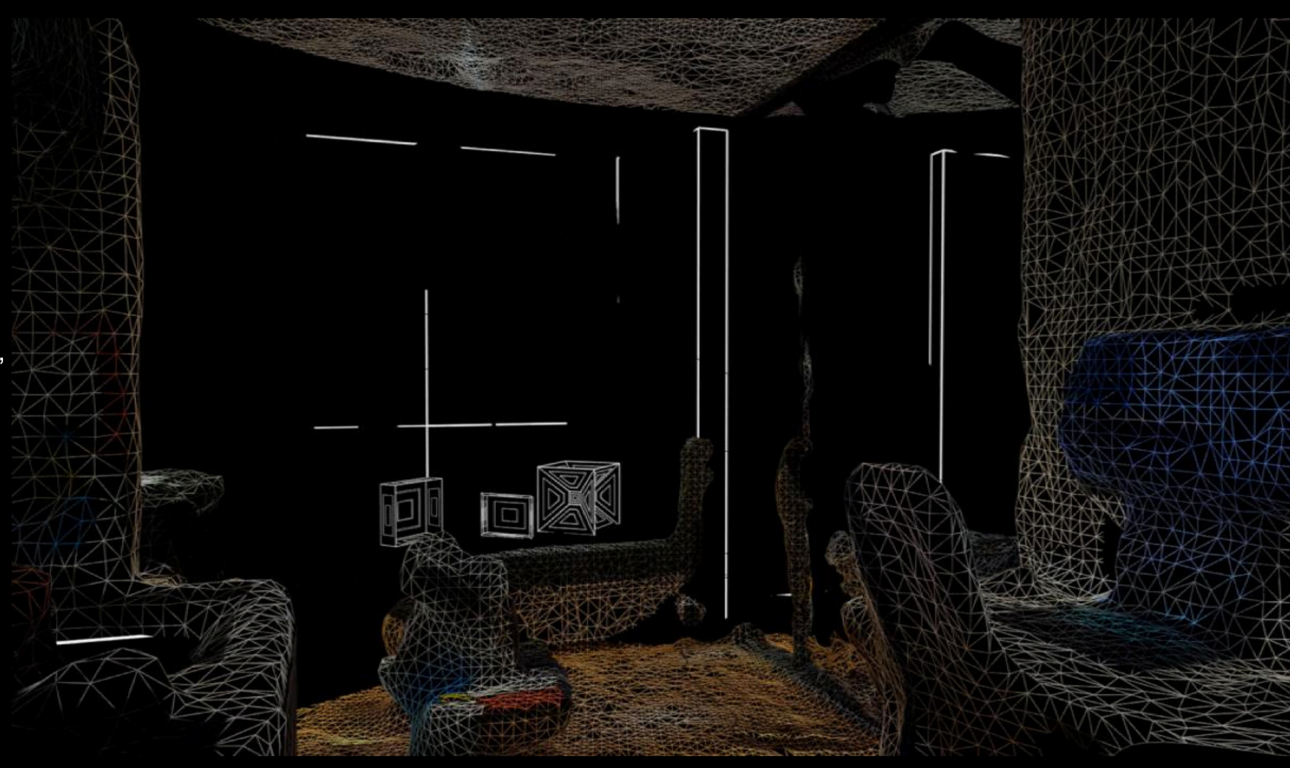


DIMENSIONAL ACCURATE

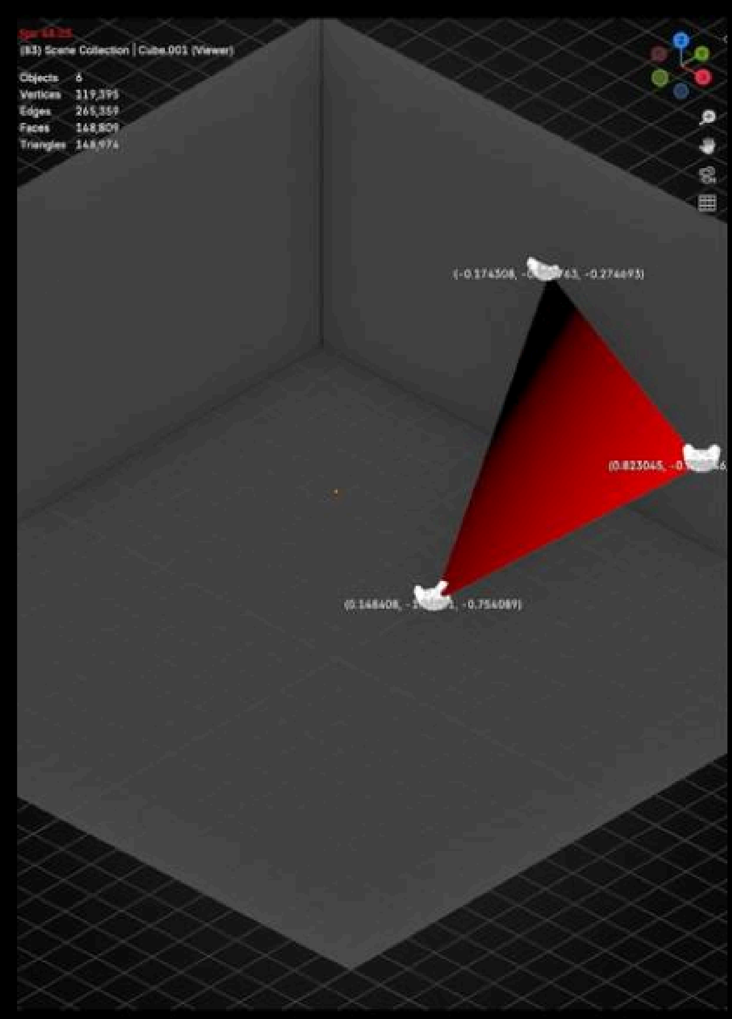
Using photogrammetry and accurate room measurements, a digital twin of the physical environment is created. This includes both a highly detailed 3D scan and a simplified dimensionally accurate model for performance and control.

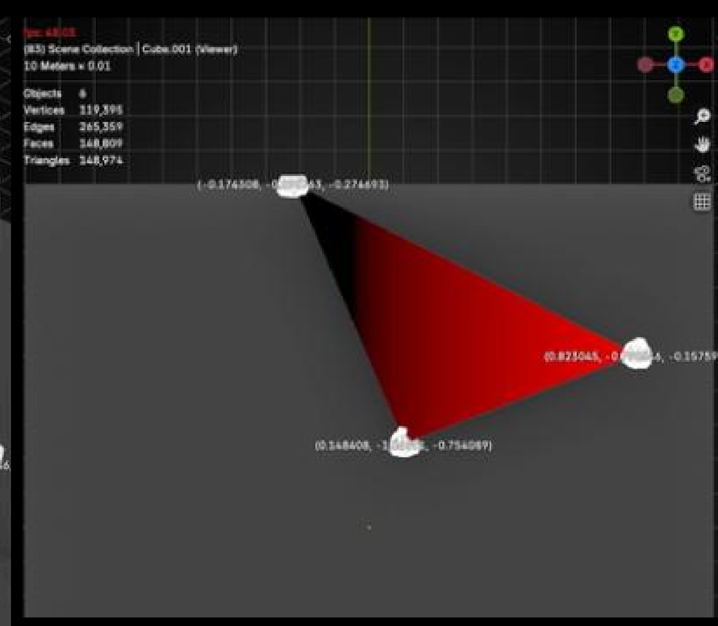
The digital twin becomes the canvas for projection and lighting simulation. By aligning digital and physical geometries, this foundational step allows for seamless virtual-physical integration, essential for projection mapping, lighting analysis, and dynamic spatial experiments.

The twin also serves as a calibration reference and simulation environment inside Blender, ensuring all subsequent layers of the system are grounded in real-world scale and spatial relationships.



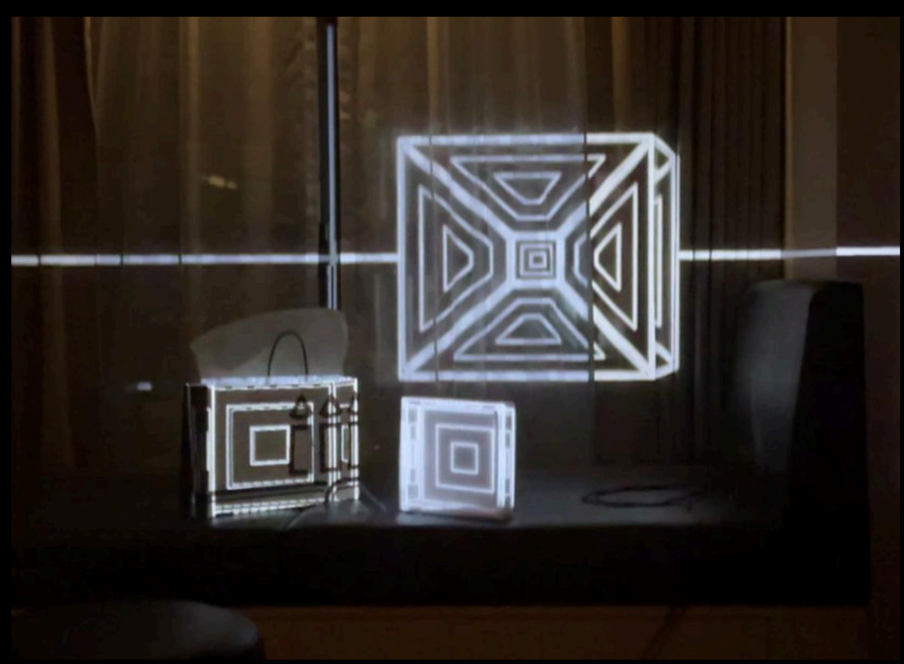
REALTIME
OBJECT TRACKING

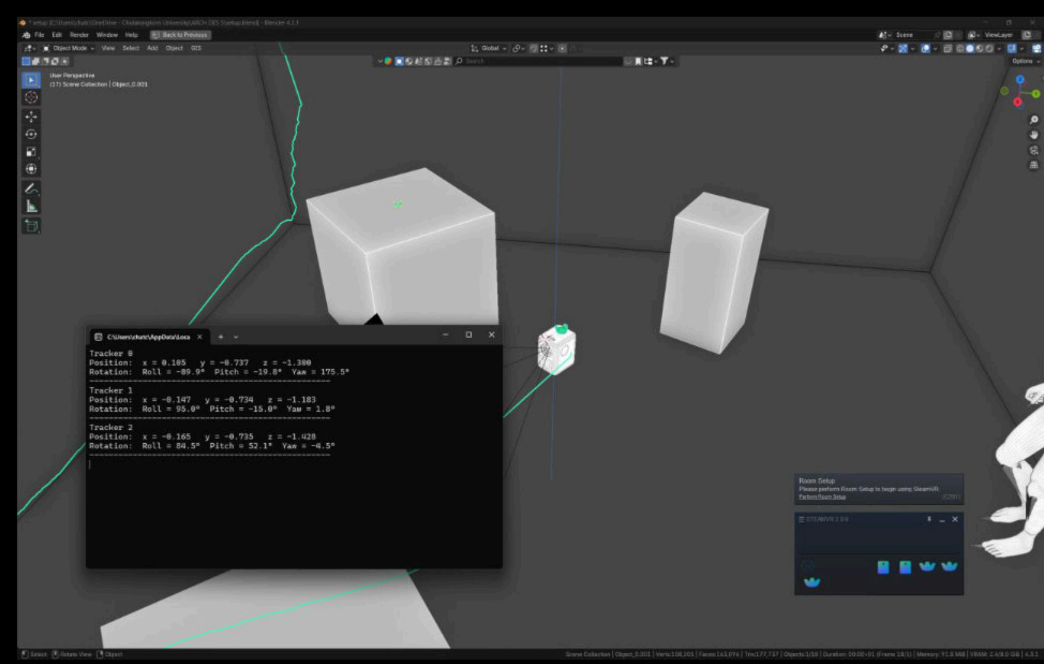




Using HTC Vive trackers and base stations, real-time object tracking is achieved through Blender integration via OpenVR and Python OSC. The tracked object (in this case, a stool or user's hand) updates its position and orientation live inside Blender, allowing digital elements to follow or react to movement in physical space. This enables dynamic projection mapping that can follow a person or object as it moves, allowing for interaction-driven installations. The real-time tracking system bridges the motion between the physical and virtual world, offering a responsive, reactive framework for immersive environments.

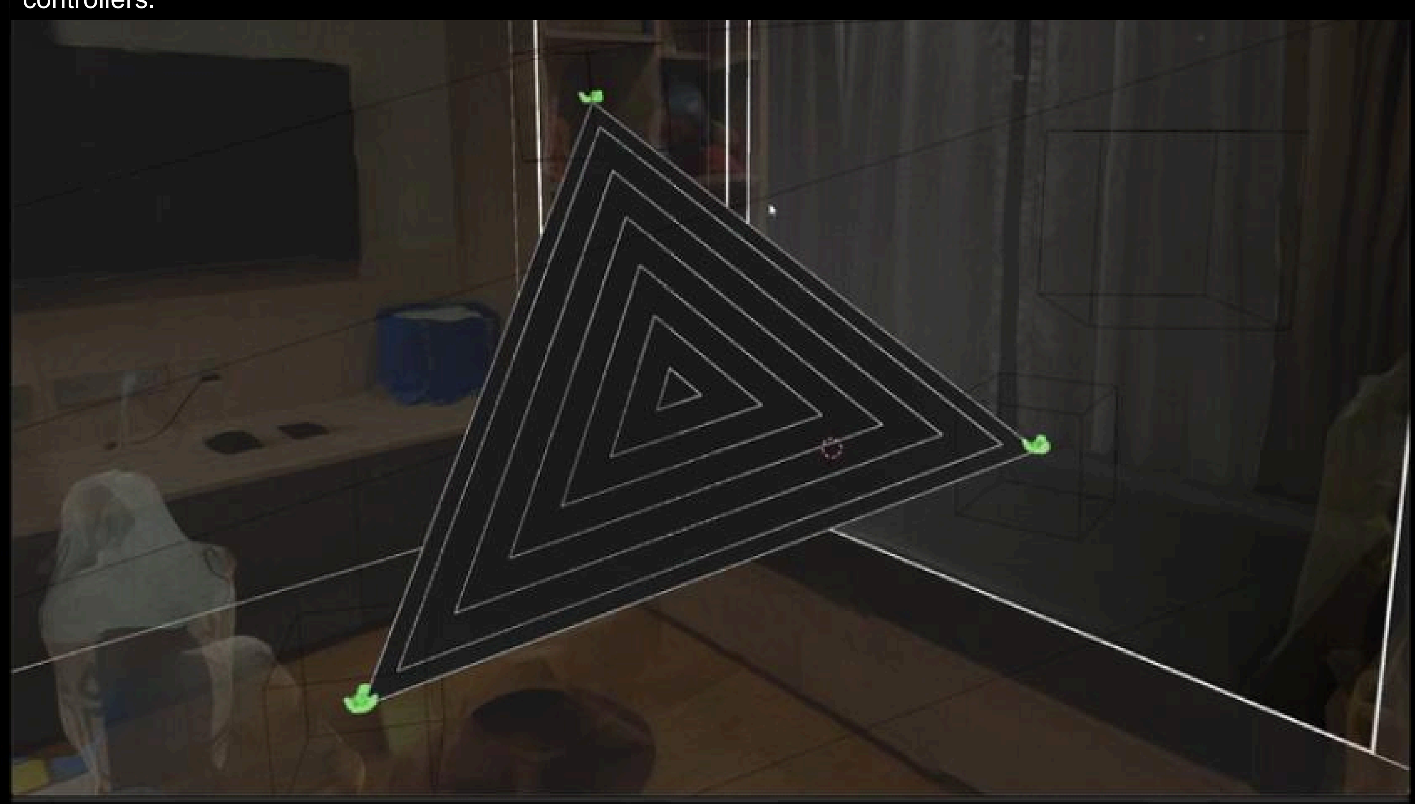
PROJECTION
CALIBRATION



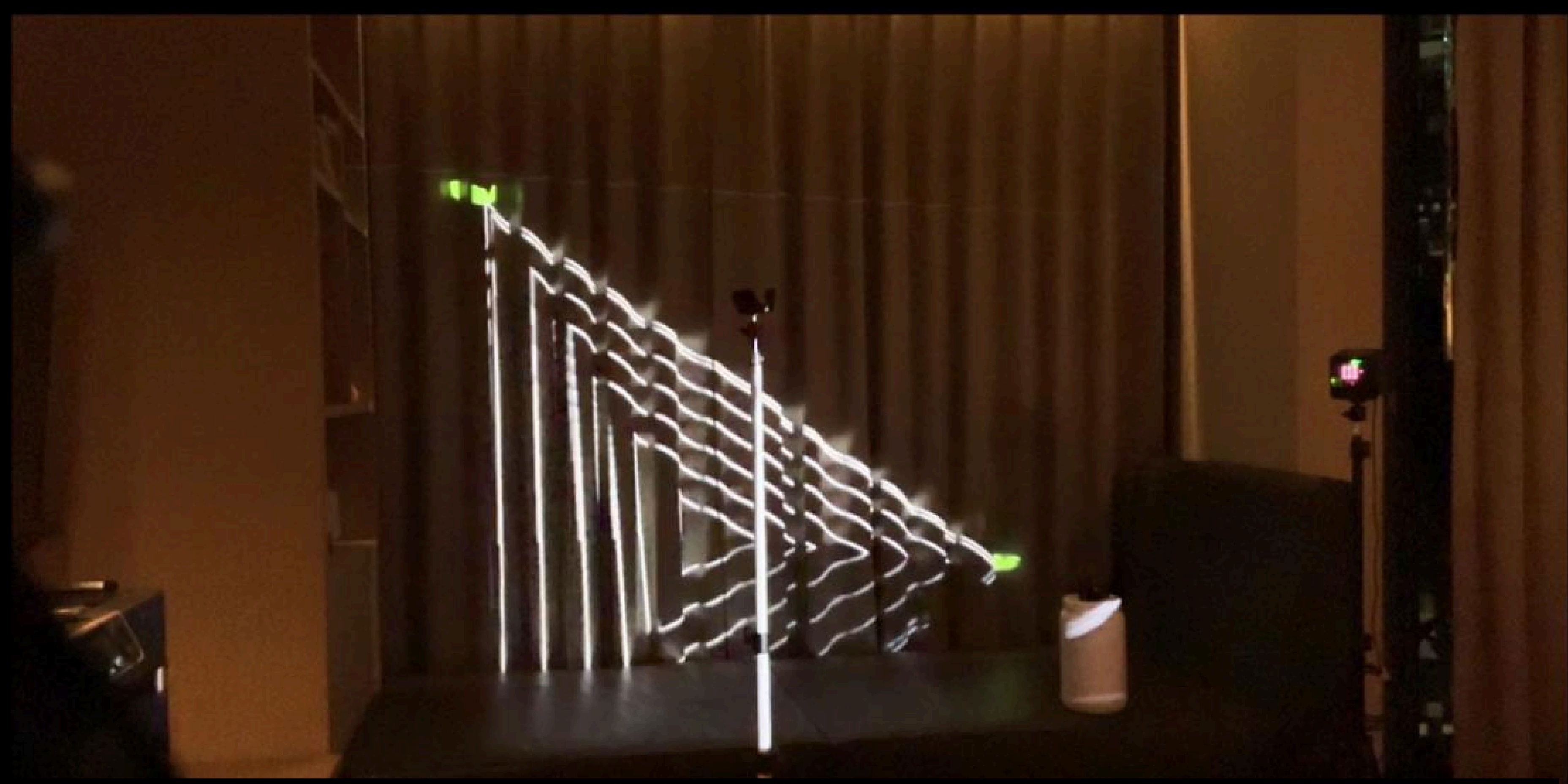


To ensure accurate projection alignment, the projector is modeled as a camera in the 3D scene. A calibration routine uses projected geometric guides to match the virtual projection cone with the real-world output. By aligning projection coordinates through visual feedback and Blender camera matching, virtual content can be tightly mapped onto physical surfaces. This process transforms the projector into a "light printer" that can embed digital forms precisely onto real architecture, even with angled or curved surfaces. The calibration also lays the groundwork for more advanced effects like interactive shadows, light simulation, or occlusion-aware rendering.

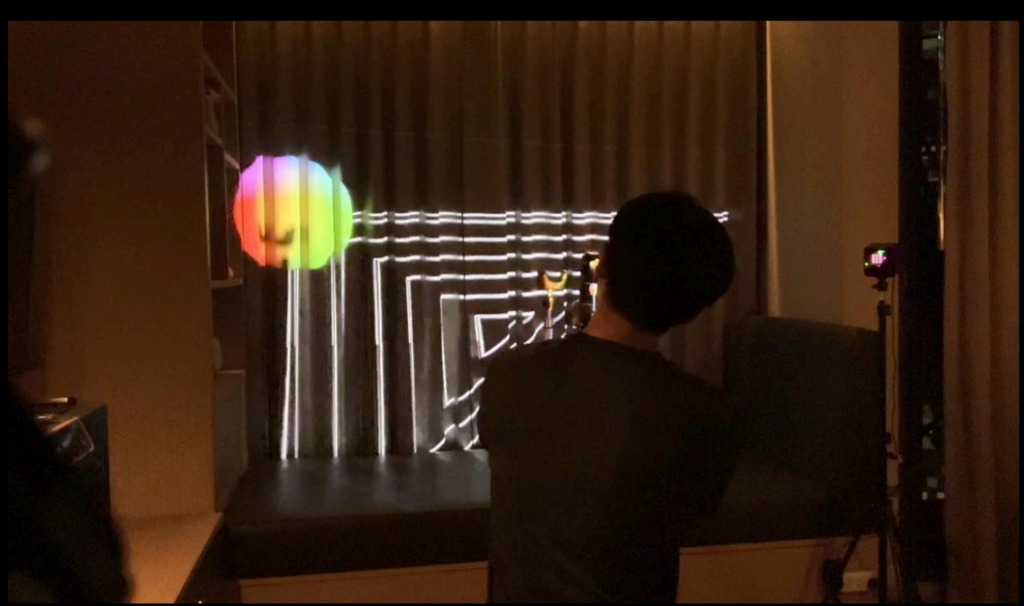
With three independent Vive trackers in the space, spatial triangulation can be used to define dynamic coordinate systems. This enables not only object tracking but plane orientation and spatial reference. When three trackers are placed on a rigid object or known positions (e.g., corners of a table or stage), their positions form a triangle in 3D space. From this, a custom origin, local axes, and orientation matrix can be calculated in Blender. This allows projection or lighting to align with mobile objects or dynamically define stage zones. By mapping the triangle to a virtual control plane, the installation becomes capable of multi-perspective tracking, augmented stability, and even shape deformation recognition. This approach elevates the role of trackers from mere sensors to spatial anchors and modular architecture controllers.

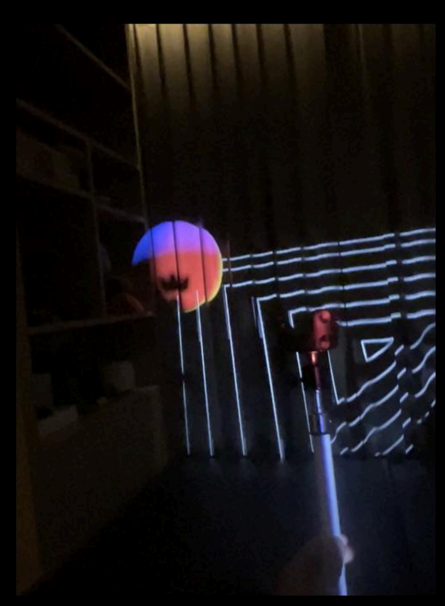


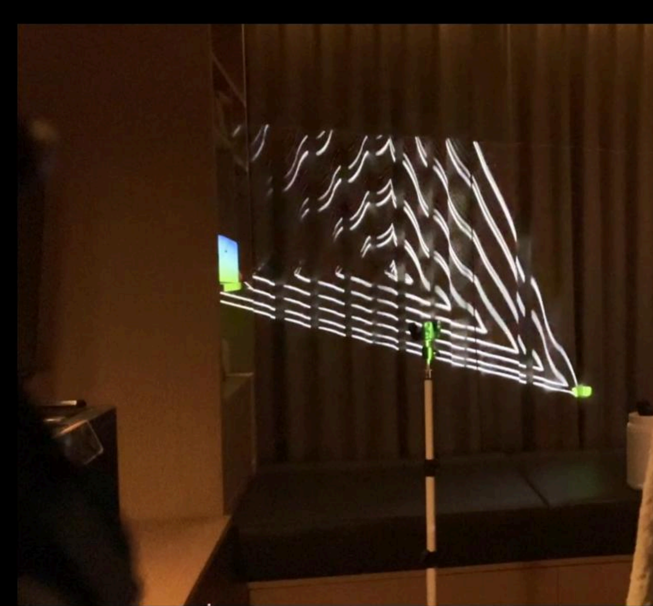
OBJECT CALIBRATION
LOCATION SCALE ROTATION



Physical props or objects in the space are tracked or manually calibrated in Blender by adjusting their location, scale, and rotation to match their real-world counterparts. This step is crucial when integrating 3D elements into the projection system, as it ensures accurate spatial relationships. With this setup, content can be projected "onto" or "around" physical items in the room. Once calibrated, these objects can act as projection surfaces, motion triggers, or spatial anchors for effects. Combined with the tracking system, this creates a flexible stage where light adapts to changing configurations.

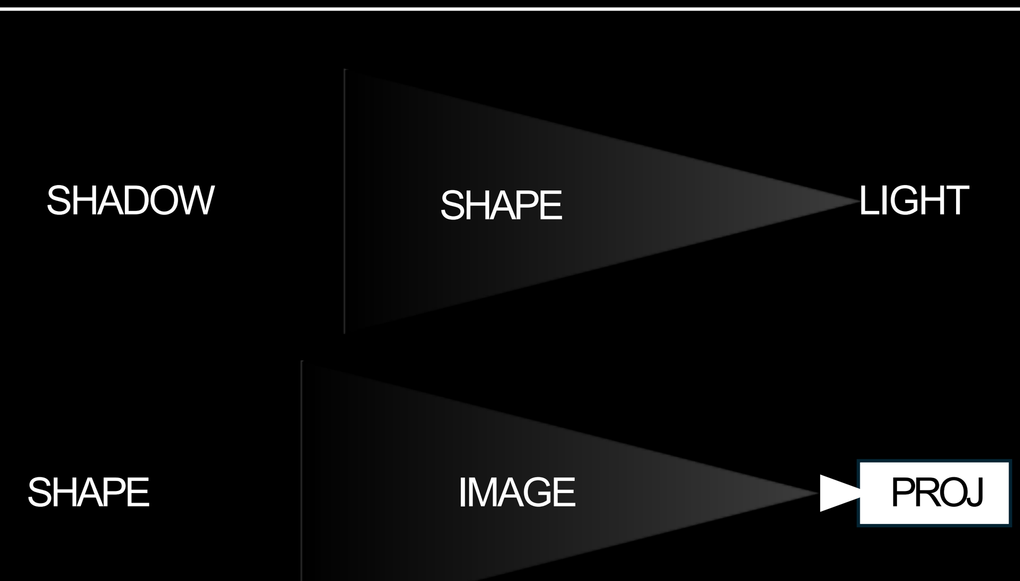


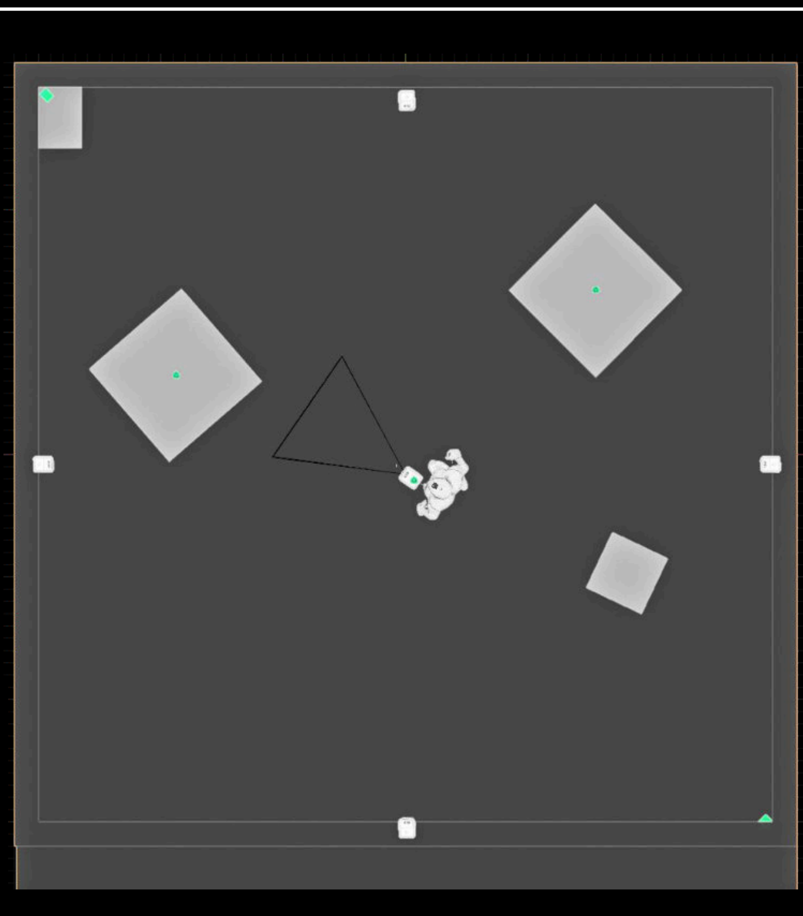


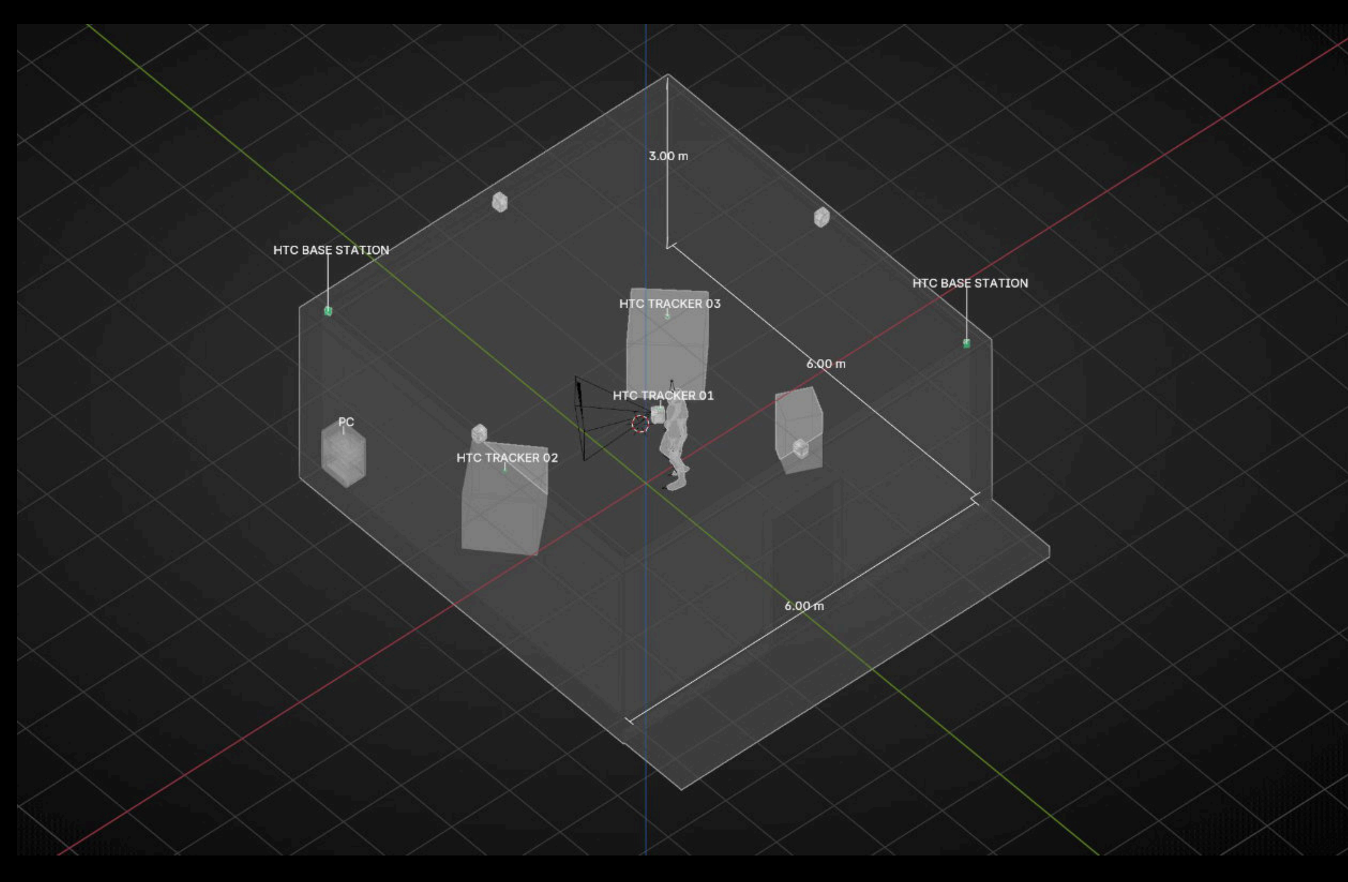


Jittering is caused by small fluctuations in tracker data due to sensor noise or IR interference. To reduce this, a smoothing algorithm is used in Blender that averages position over several frames, creating more stable motion without noticeable delay. Ensuring clear line-of-sight between the tracker and both base stations also significantly improves accuracy. Together, these methods enhance the precision of projection mapping and real-time interaction.

SETUP AND
EQUIPMENT







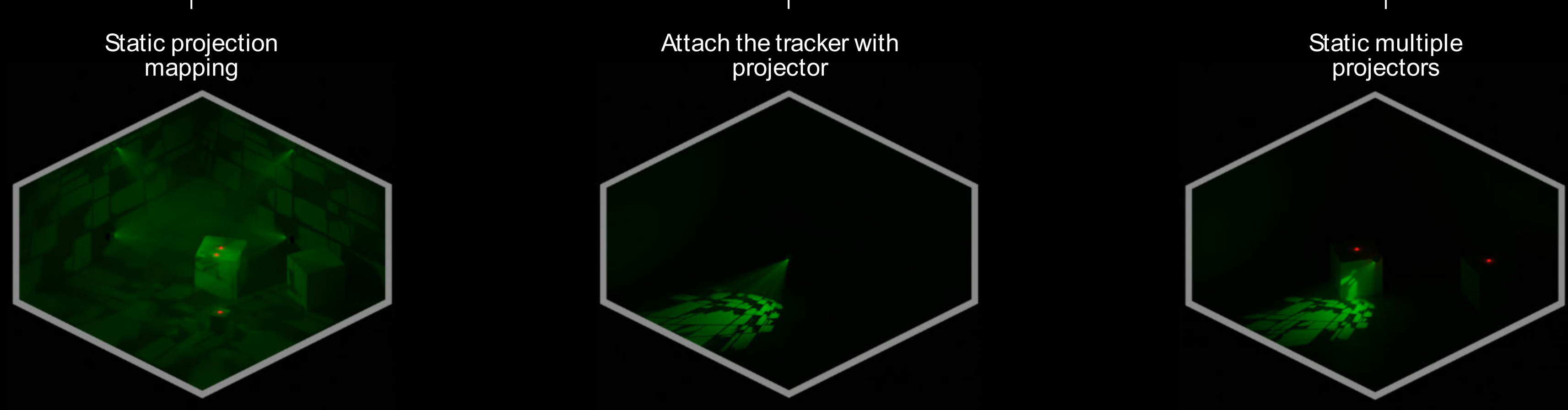
This installation uses two **HTC Vive Base Stations (3.0)** for spatial tracking and three **Vive Trackers** to track physical objects in real time. A **gaming laptop with RTX4070 GPU** runs Blender for 3D visualization, object calibration, and projection control. A **projector** is positioned and calibrated as a virtual camera in the Blender scene, allowing for precise projection mapping onto real-world surfaces. Additional tools for the photogrammetry like ios reality capture for capturing a digital twin of the space and custom Python scripts for integrating live tracker data into Blender via **OpenVR** and **OSC**. The setup allows seamless synchronization between digital and physical environments.

HARDWARE LIMITATION

To maintain responsive interactivity in the projection-mapped environment, system latency across tracking, computation, and output must be carefully analyzed. The tracker, operating at low-latency (5ms), communicates position data to Blender in under 4ms via a real-time API. Once received, the data is processed through a custom visualization routine with an average render time of 20ms. However, the primary delay emerges from the projector itself–introducing a latency of approximately 120ms, even under "low latency" mode. This cumulative latency (~149ms) results in a perceptible offset between physical movement and visual response. Recognizing this bottleneck enables strategies like pre-motion prediction, hardware optimization, and perceptual alignment, essential for maintaining immersion in dynamic, interactive installations.

5ms (tracker)
4ms (input)
20ms (render)
120ms (projector)
≈ **149ms** (or ~0.15 seconds)

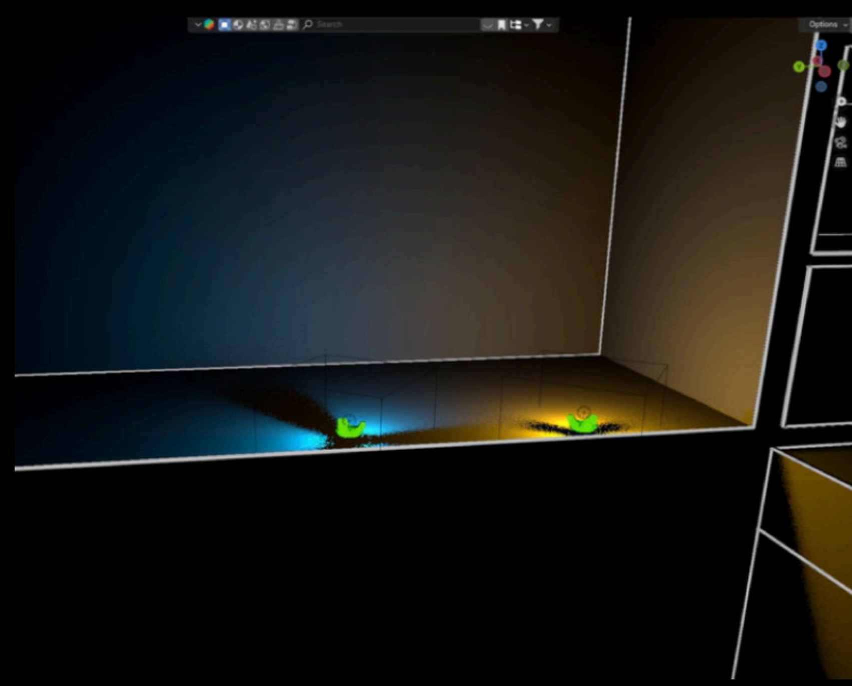
MAKING THE INTERACTIVE DIMENSIONAL EXHIBITIONS



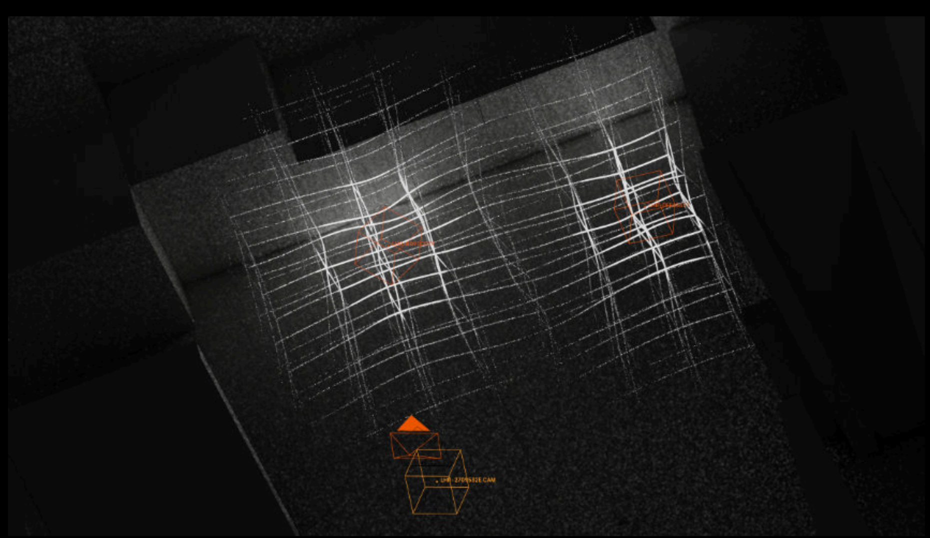
Tracking the objects static projection

Tracking the rotation and location of the projector

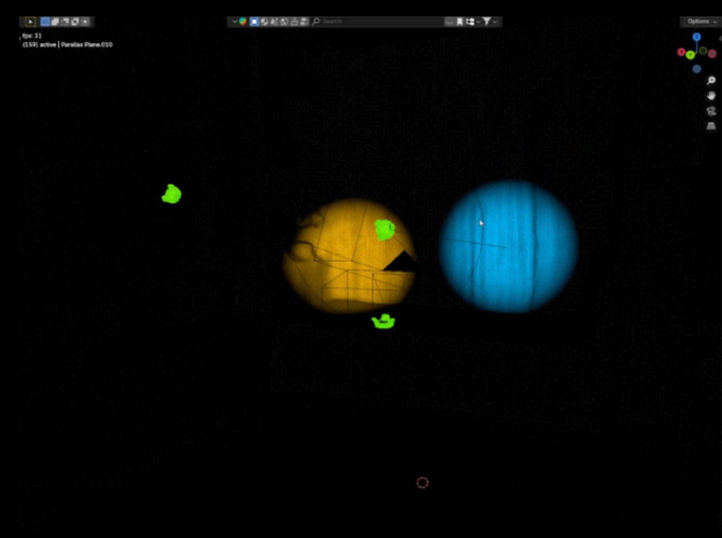
Tracking the projector and objects



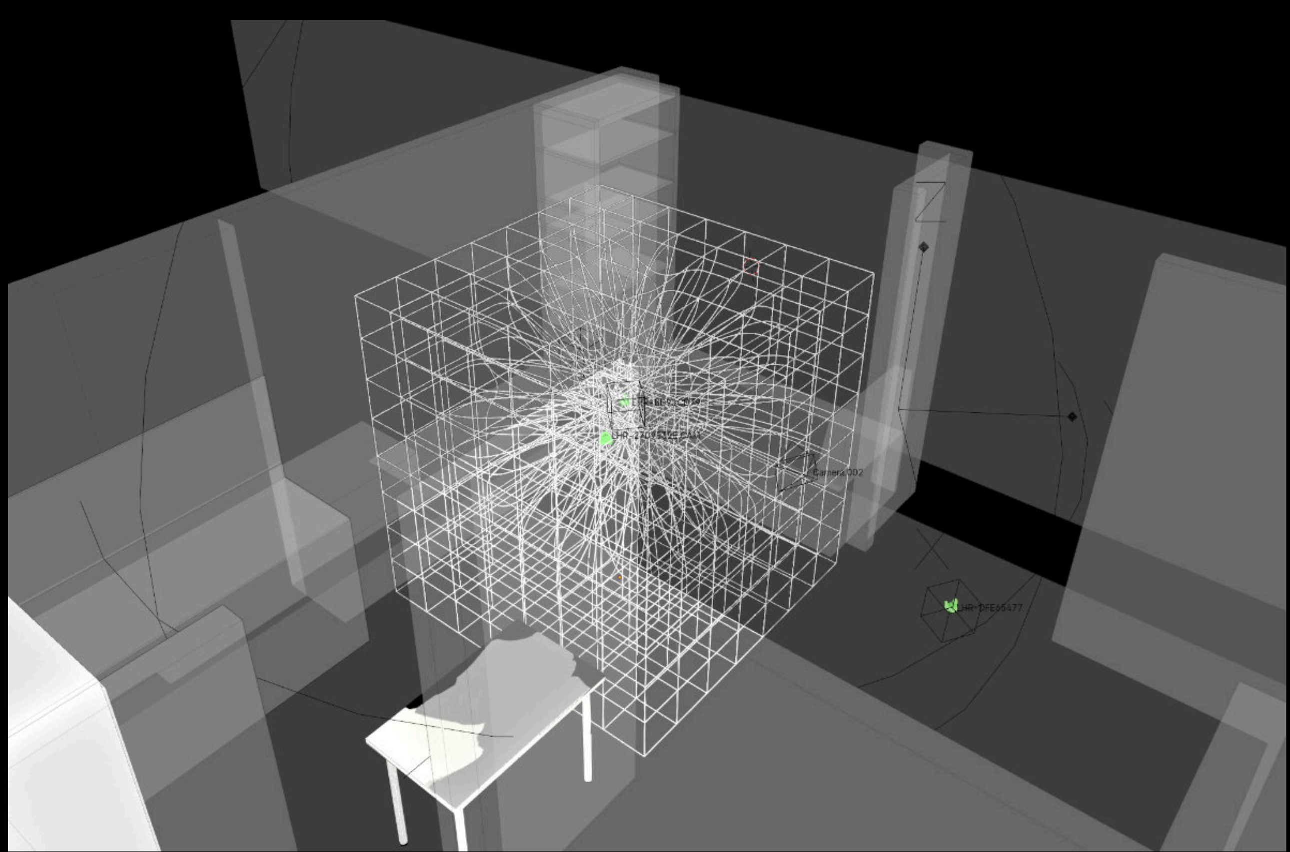
TRACKING AN AMBIENT LIGHT AND THE PROXIMITY

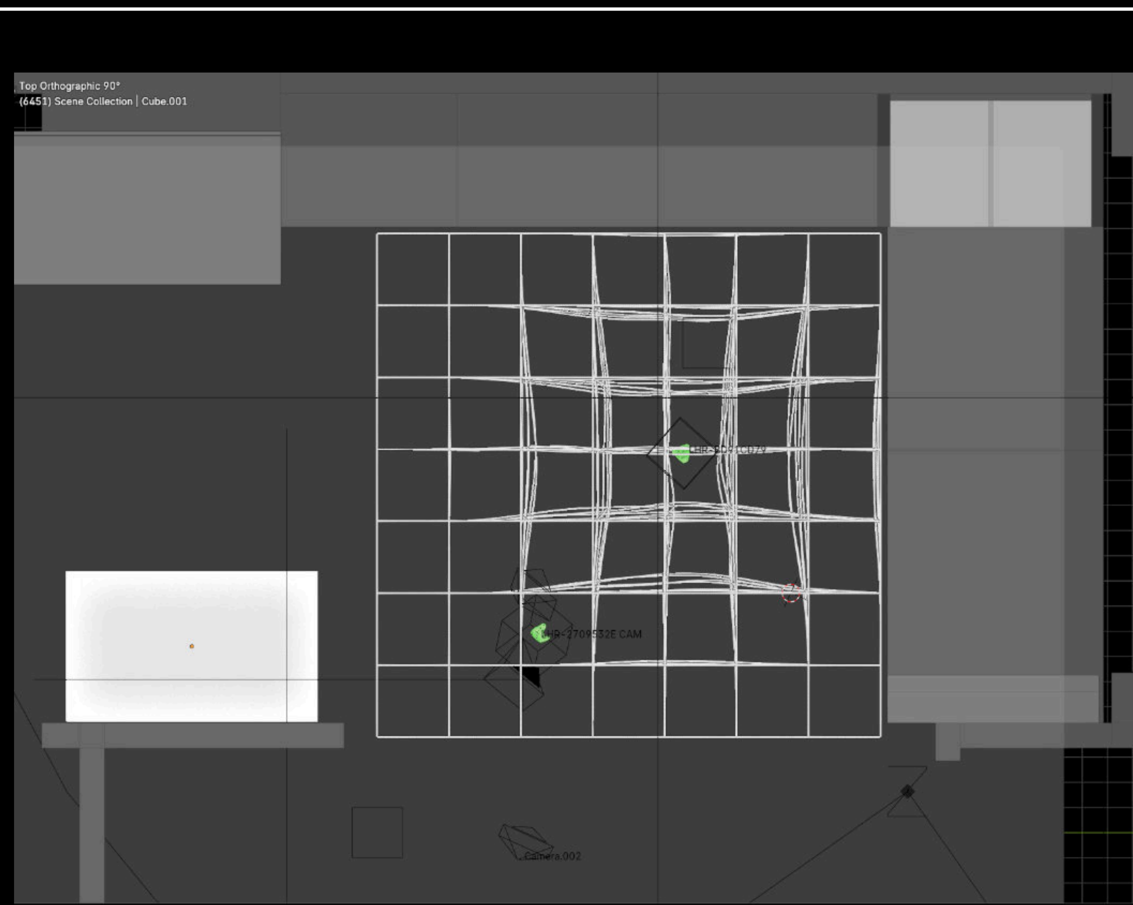


There approaches to creating interactive dimensional exhibitions, each offering unique possibilities for spatial engagement. In the first setup–static projection mapping with object tracking–projectors remain fixed while tracked objects move, allowing projections to respond dynamically to their position. This is effective for installations with moving elements but a stable projection source. The second method–attaching a tracker to the projector–keeps objects static while the projector's movement and orientation are tracked, enabling handheld or movable projections that adapt in real-time to viewer interaction. The third and most advanced option–tracking both projector and objects using multiple static projectors–allows for comprehensive spatial synchronization, where both the environment and projections respond to each other. This unlocks the highest level of interactivity, suitable for immersive environments where architecture, object, and light continuously influence one another. Each method presents a different degree of adaptability, with increasing complexity and experiential depth from the first to the third.



TRACKER AS FLASHLIGHTS





SPATIAL IMPRINT PROJECT.

In the exploration of the architectural potential of real-time human interaction within a dynamically projected environment. Using a volumetric grid system as both spatial language and responsive canvas, the installation invites viewers to become active agents in the transformation of space. As the user moves through the grid, their position–tracked via Vive Tracker–distorts the virtual structure, warping its geometry around them in real-time.

This spatial deformation is not merely a visual response; it becomes a conceptual reversal of traditional architectural relationships.

"Instead of architecture shaping the body, the body imprints itself onto space."

The installation is a "living blueprint" where physical presence redraws the environment, proposing a new understanding of built form as fluid, participatory, and contingent on human agency.

Projection mapping is used to integrate the virtual grid directly onto the surrounding surfaces of the room. The projector is calibrated as a virtual camera within Blender, allowing the 3D scene to align precisely with physical coordinates. Despite inherent latency–such as the 120ms delay of the projector and minor delays from tracker-to-visualization–the illusion of immediate spatial responsiveness is preserved through optimization and visual smoothing.

Set within a dim, enclosed space, the installation creates an atmosphere of spatial intimacy and technological immersion. It draws on architectural principles of section, volume, and structure but transforms them into dynamic systems responsive to occupation. The result is a poetic exploration of presence, data, and architecture as a reciprocal dialogue–where space no longer contains the body, but is continuously rewritten by it.

THREE DIMENSIONAL GRID MANIPULATION