

Living Shadows

for Living Architecture Environments

PHILIP BEESLEY, KEVAN CRESS, MATT GORBET & TRACEY EVE WINTON
LIVING ARCHITECTURE SYSTEMS GROUP

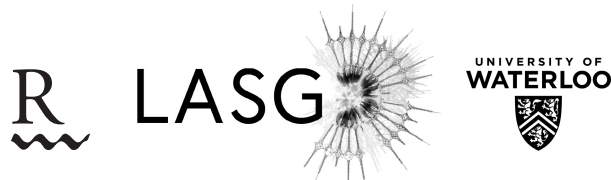


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Third Edition



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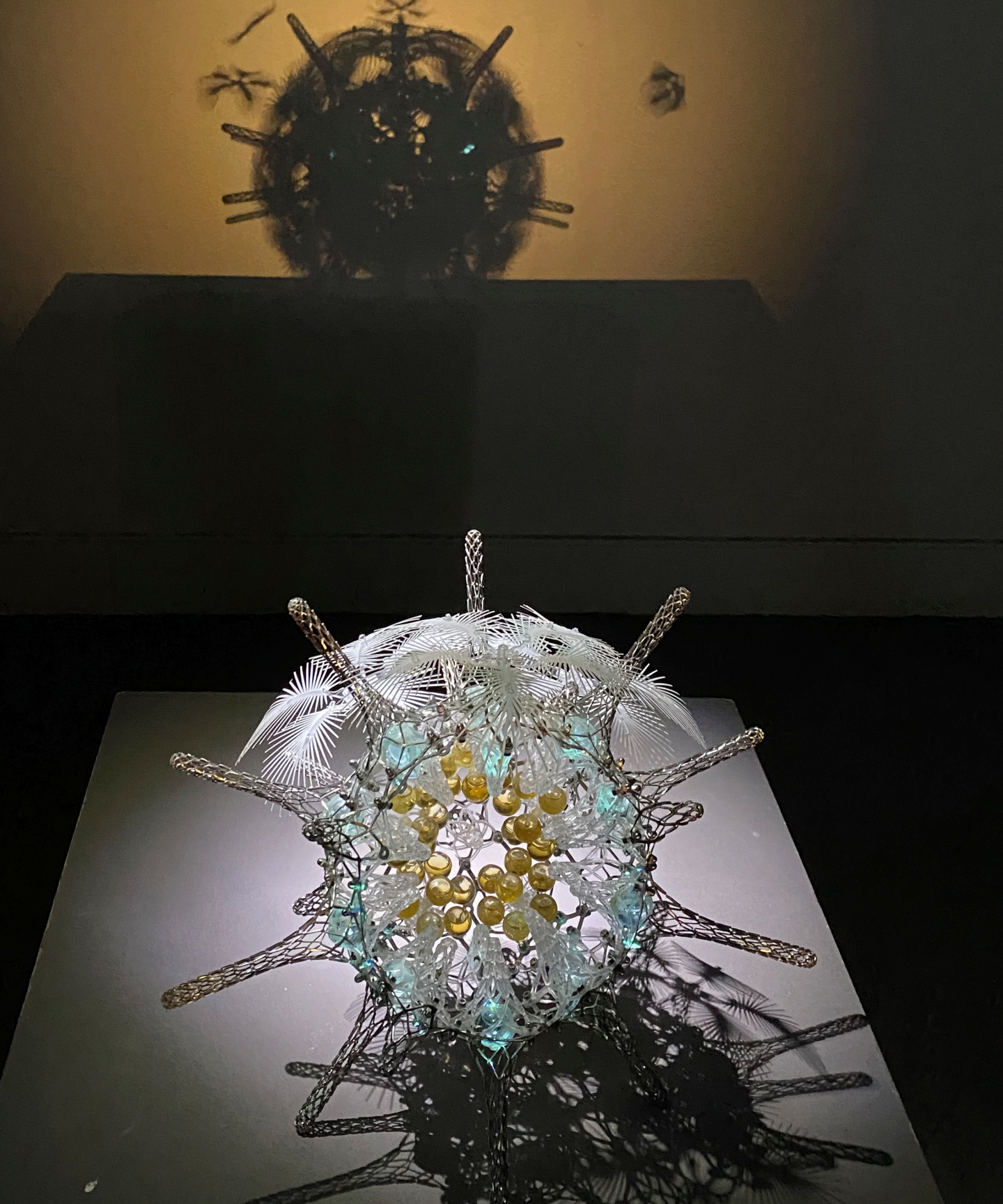


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Introduction

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Living Shadows demonstration:
stellated truncated icosahedron
sculpture with accompanying
digital twin projection

The Living Shadows project is an augmented reality experience that explores the intersection of physical and virtual worlds through the medium of shadowplay. It investigates how the shadows of a physical object might be augmented with the shadows of animated creatures and field conditions that exist within a virtual world. The aim of the Living Shadows project is to create a virtual world that is closely linked to its physical counterpart. In this virtual world, a digital twin takes on a life of its own, with actions and influences that are projected back out into the physical world and made visible through the interplay of light and shadow on objects and their surroundings.

Overlaid on a physical work, this virtual world of living architecture evokes new dimensions for exploring the lives of virtual beings immersed within environments. The creatures that inhabit this virtual world help develop the identity of a sculpture's static physical components. Action composed within the virtual environment is related to the particular components and organizations of physical fabrications within LASG sculptures. The Living Shadows project explores behaviours that these assemblies might manifest if they were given autonomy and set free within a virtual environment.

This project represents an early step in the Living Architecture Systems Group's exploration of augmented reality environments.



Umbracula Futurorum: Living Shadows as Architectural Drawings

Tracey Eve Winton

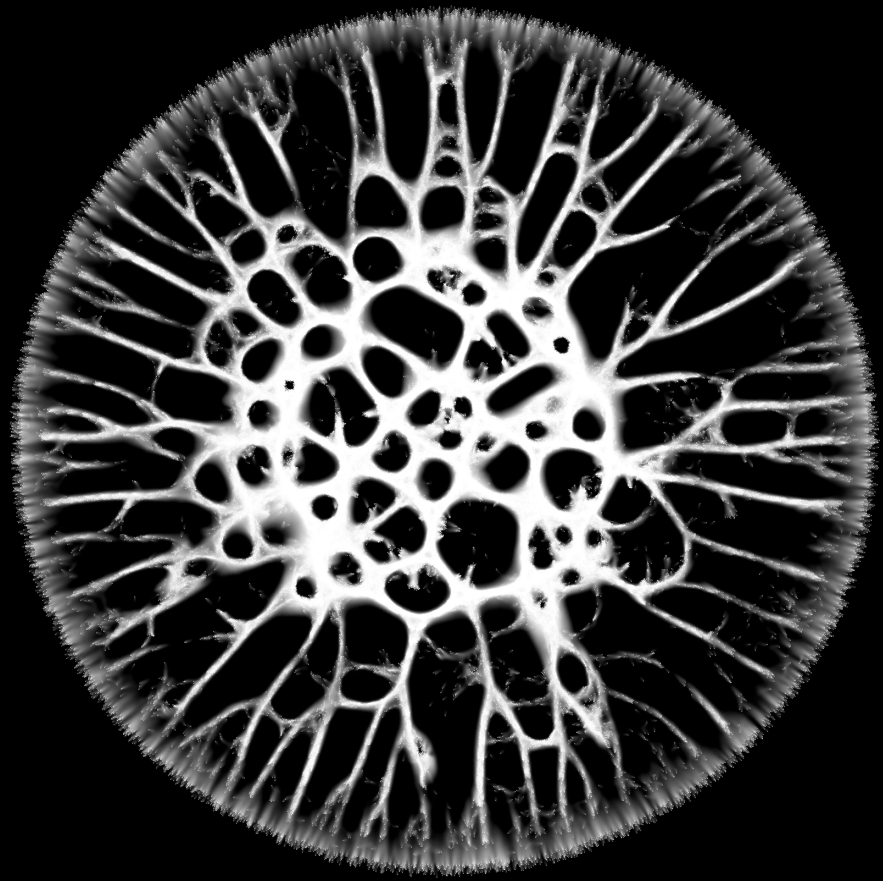
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Lucid Dream digital twin
projection with Poietic Veil Tilburg
by Philip Beesley Studio Inc./
Living Architecture Systems
Group, and Lucid Dress by
Iris van Herpen, "Is it alive?",
TextielMuseum, Tilburg, 2023

"Reality only reveals itself when illuminated by a ray of poetry. All around us is asleep." — Georges Braque [1892-1963]

Imagine: a lithe tentacle buds forth ornamentally from the Medusa's snaky head. It stretches into the upper airs and unfurls, recoils. Serpentine ripples spread around you. Yet you perceive it with a sense other than your eyes. There is no object, natural or cultural, but a form sculpted into the space of your imagination by radiant light: a living shadow in the ethereal atmosphere.

Living Shadows, a series of digital projection works by Philip Beesley and Living Architecture Systems, mobilizes cutting-edge digital technology to introduce phantom shadows within dynamic luminous fields that surround and envelop the visitor. The immersive field of the Museum's hall is staged with digital light sources that play over dresses designed by the global couture designer Iris van Herpen. These are the finely articulated objects of *Sculpting the Senses*, whose movements cast real, shifting shadows on the architecture behind them. Living Shadows is spatial poetry. Its meaning inheres in the extraordinary experience of patterns and gestures coming to light from a perpetual fluxion as drawings in a volume of space as well as across the wall's planar surface. Grounded in the continuity of the Musée



des Arts Décoratifs building's geometrical and material matrix that stabilizes and harmonizes your sense of space and self, shadows evolve from the planar space of the far wall, to conjure metamorphic creatures circling the air around you. Projected alongside fictive light intrusions like spirit fireflies circling an unseen orb of gravitation, the actual lights and imaginary shadows interfere with self-awareness as we subliminally cross-reference conscious vision, bodily experience, and peripheral movement

Starting with the digital media installations that were launched in his 1995-6 Prix de Rome residency, Philip Beesley's earlier works have thematized the emergence of life and explored the mimicry of lifelike processes in artificial material substrates. These biophilic networks channel the long history of architects making automata from Daedalus onward, and physically react and respond to the visitor's presence. From this comes the collaborative group that now shares authorship of these works: Living Architecture Systems.

Above

Physarum Living Shadows, "Iris van Herpen: Sculpting the Senses", Musée des Arts Décoratifs, Paris

Above

Voltage Living Shadows, "Iris van Herpen: Sculpting the Senses", Musée des Arts Décoratifs, Paris

The 2023 Sculpting the Senses project includes three new projections by Beesley in collaboration with Kevan Cress, members of Living Architecture Systems group and Atelier van Herpen: Physarum, Voltage Shadow, and Medusa Shadow. Physarum takes its name from a slime mould, a fungus that exhibits intelligent behaviours similar to those seen in complex animals with brains. Physarum contains half a million microscopic cell-like digital 'beings', each moving independently, each adapting its path as it is drawn towards its neighbours and their traces in the medium, generating dynamic patterns that are magnetic and biomorphic. The resulting open web describes a lacy filigree with diverse density and strength in each of its filamentary channels.

Voltage Shadow gathers a dream space around the Voltage Dress, with its serrated fronds and reticulated petals, in which the material patterns come alive and spread into the surrounding area. Traces guiding the design of each frond expand into crystalline fragments and thickenings within the surrounding space, like electrical sparks tracing out vectors of thunderbolts in the aether.



In the Medusa Shadow gallery's dynamic glow, the mannequin wearing the van Herpen's now-iconic Snake Dress becomes a statue of the Medusa whose hair was transformed into living serpents, and whose gaze turned living things to stone. Here, your own gaze reverses the sorcery, as her serpentine tresses swirl around you. Medusa's live movements in close proximity prompt an uncanny sensation that some vast energy is awakening in your own flesh, with the corresponding feeling that the artworks alongside the architecture are passing into your body and you into them, as qualities interpenetrate and limits dissolve, abolishing the spatial isolation and illusory separateness of our everyday lifeworld.

Behind the scenes, the team makes magic by creating a digital twin of the gallery's system of lighting, including its artifacts and their corresponding modulations of light, alternately eclipsing and reflecting the brightness. These digital projections illuminate the animated dresses and foreground their contours in a halo of shimmering movement and cast shadows. However, this doublure of projection introduces elements that don't

Above

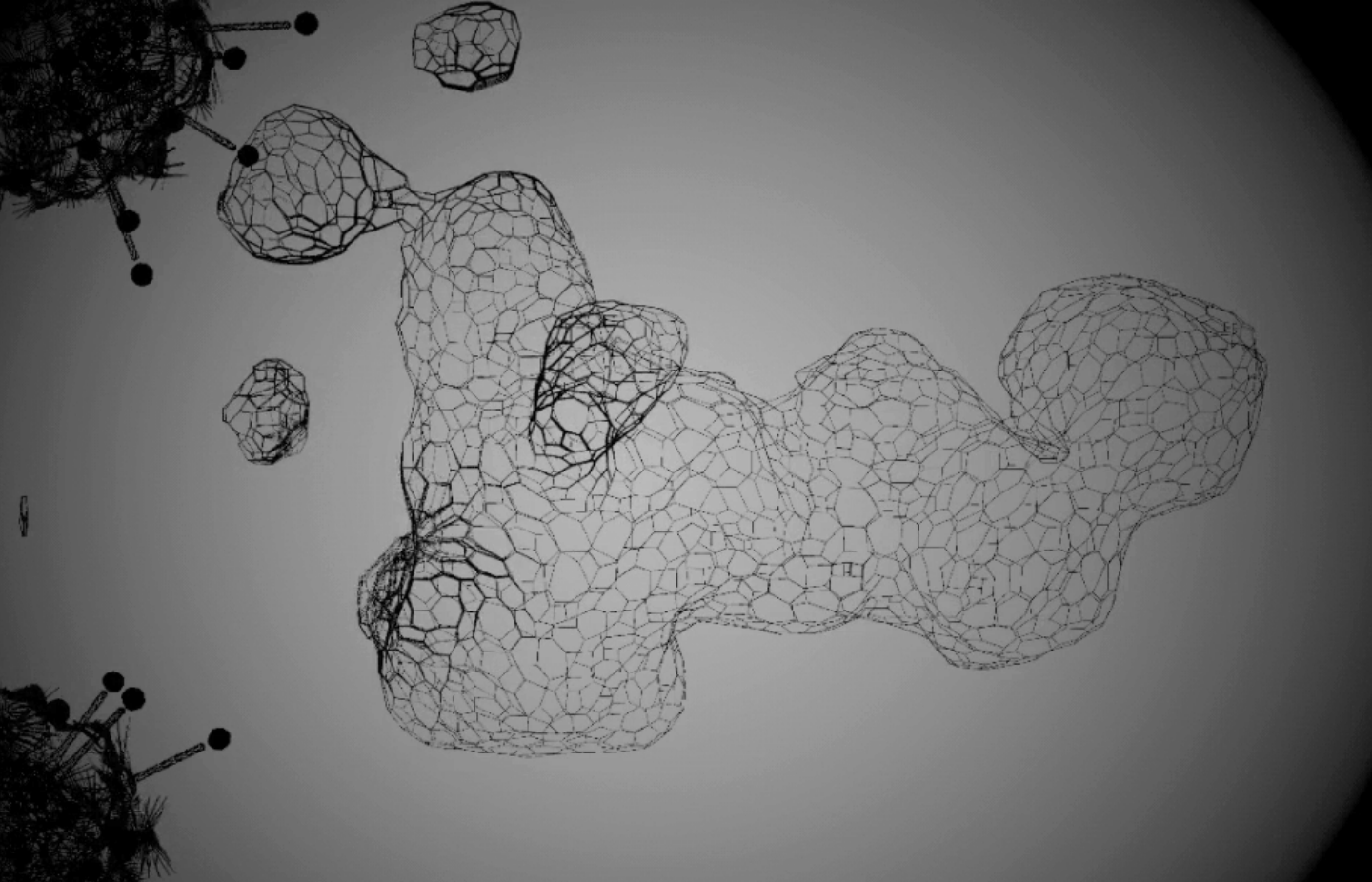
Medusa Shadow, "Iris van Herpen: Sculpting the Senses", Musée des Arts Décoratifs, Paris

exist in the natural space of the room. Foreign bodies made of emergent clusters of dark matter spontaneously grow from the mass's protrusions, split and detach themselves from the centre of gravity within the churning and convulsive dress. These liberated shadows conjure cells growing and dividing, becoming specialized in the process of growth and then migrating between centre and periphery of a space defined by light, colonizing and being reabsorbed into the ground of existence. The doubling creates a subtle perceptual disparity between the physical dress in the plastic space before you and a shadow play that merges them into a field that also absorbs the visitor, cued by disembodied shadows floating free from their corporeal sources. From a neuroscience perspective this environment acts on us in a cognitive cascade of affect, opening a fissure of dissonance between conscious and unconscious functions. Just like in binocular vision in which sensory inputs from our offset eyes generates an intuitive grasp of spatial depth, the complex environment heightens your corporeal awareness by collocating real objects with imaginary objects sharing the area around you.

Shadow is an absence that indicates a presence. As an artwork, Living Shadows plays on our native ability to relate a shadow back to the object that casts it, and locate that thing in space. The beguiling physicality of Iris Van Herpen's dresses establish that a tangible embodiment is at play. The human forms of the mannequins activate the visitor's mirror neurons, while the projections, the inflected double of reality called a digital twin, contribute to the articulation of our world, in which artificial shadows become kinesthetic emanations linked via a corporeal schema to our own bodies.

Neuroscience tells us that the brain's right hemisphere, key to emotional processing, produces awareness of the overall spatial environment and layout and detects changes or anomalies. It processes information holistically, assembling and integrating intelligence more globally and spatially than the left which discriminates fine details, and deals in logic.

As you witness Living Shadows, specialized neurons in your primary visual cortex, detecting contrast and movement in each uncanny shadow, respond to the presence of stimuli. The thalamus receives this information and relays the sensation to other regions of the brain, including the amygdala, a critical structure that evaluates sensory information for threats. The shadow signals the presence of an unknown object, so the amygdala may activate the sympathetic nervous system, flooding your body with hormones and



increasing adrenaline, muscular strength, and alertness. At the same time, the prefrontal cortex helps process the scene comprehensively, assessing the context, gradually elevating the fainting shadows to responsive awareness and subjecting them to higher cognitive processes. These percepts are in our consciousness but also beyond it, out of the corner of your eye as one senses a moth in a large room before detecting it. In this way the art stimulates visitors to re-conceive the relationship of their body and its environment, making sense of our impressions in an emergent ordering of experience of the surrounding space and its interconnectedness.

Similitude of form crosses categories. Transformed by these projected shadows, the gallery's dusky space seems a correlate of the fertile, spongy earth, a glimpse into the world's subconscious prefiguring a superabundance of forms and realities. Seen in their simplest most elemental particles and in their capacity to form complex living systems, the organisms of Living Shadows become medusas and coralline anemones,

Above

Lucid Dream digital twin projection with Poietic Veil Tilburg by Philip Beesley Studio Inc./ Living Architecture Systems Group, and Lucid Dress by Iris van Herpen, "Is it alive?", TextielMuseum, Tilburg, 2023

mudskippers on the primeval shore of our perceptual fields, simultaneously zoomorphic and mythological in convergent evolution. You pause to attend to the life cycle of a polyps that begins as a swell on the penumbral boundaries. In aquatic motions, by contractions and releases of imaginary muscles, fringed by ossicles, it flexes to fold and reopen like a starfish, radiating outward into the sphere of brightness. Its flapping through space evokes the webbed flight of a bat, the buoyancy of a jellyfish. The weird creatures flit from sea to sky and back again, centre to periphery, unconsciously demonstrating the core principles of Neoplatonic philosophy. What are these mysterious hybrid creatures? How do we recognize them? They seem to afford us access to deeper dimensions of memory, a vibrating in our bodies of atomic particles more than 13 billion years old.

This kind of inhabited environment engages us in a kind of ancestral remembering. Blood memory, even atavistic, transfers to us an awareness of mycological creatures that recede from and re-integrate into us, in great and little cycles, a biological space of continuous rebirth, development, and adaptation. The constructed situation with otherworldly presences and movements of light and pods of darkness developing from abstraction into figuration transports us in deep time. It makes us eyewitnesses to the microscopic origins of life and to Jupiter and beyond, remote galaxies and stellar flares, if not the Big Bang and the universe's enduring mystery.

The dramatized increase in complexity and emergence of dynamic responsive patterns from the stardust refuses all linear thinking, time's directionality and the law of entropy, the breakdown of pattern and increase in disorder, and argues for optimism.

Foreshadowing metaphorically references our capacity to see the shadow before the substance, and to perceive a shadow as a harbinger of a reality in the process of emergence, through the space of time. The unseen and incorporeal, part of our world since before its beginning, the spiritual purveyors of higher meaning, faded with Enlightenment reason and Modernism's grip of functionalism and logic, and with them a critical dimension of human experience.

Living Shadows was inspired by noticing how detailed artifacts being assembled in the studio threw crisp silhouettes on the walls. Since the dawn of man, the celestial regions have offered us a sphere of numinous

lights with their regular motions, cycles, and auspices, while shadows have been the province of the Earth. Illumination and light speak of knowledge, articulation, and shared understanding, while the secrecy of darkness and obfuscation of sight suggests a mystical immersion in an opaque matrix beneath the horizon of vision, Light's counterpart is gravitation. The gallery's dark figures summon ancient cults of darkness and the night, a revelry of formlessness, of hyle, of unstructured prima materia, the non-dual experience that Freud called the oceanic feeling. In the cavernous matrix of the Magna Mater, humanity's archaic connections with the divine took shape through the prehistoric underworld goddess, Cybele, who materialized in the form of a sunless, aniconic stone, and whose beloved lay shrouded in sleep and obscurity. Traverser of boundaries, she mediated the realms of the known and the unknown. Hers is the chthonic realm of olbios, the privileged treasure of dreaming adepts who have witnessed the sacred rites and consequently enjoy a special destiny in this life and the next. In ancient Greece, figurative drawing was called skiagraphia, literally a shadow-drawing. When a body obstructs a beam of light, an image forms on a receptive surface. So in Roman times, for Pliny the Elder, the profile of a human face on a wall was the forerunner of the artistic image.

In the middle ages, optics was an important branch of theology. For medieval philosopher Robert Grosseteste, invisible light was a force to engender and propagate the continuum of corporeality, spreading in rays and multiplying itself to form the cosmos. Light structured all of reality, an active power that formed the world from the inside. As Dante knew, a shadow also could be a guide to the form of the cosmos. In his Divine Comedy, the poet's word ombra describes both the shades the pilgrim encounters in the afterlife, and his own cast shadow, meaning that his human body blocks light from passing through it, signalling him as belonging to the world of the living. His companion, the poet Statius, describes how the intertwined meanings of shade and shadow express a fundamental relationship between life and the afterlife, the power and limits of resemblances. When the soul leaves its body, it impresses a spectral form on the surrounding air, like a rainbow, and like flame to fire, this phantom form shadows the spirit.

The doubling of perception by overlaying rays of light reminds us how in 1415 Filippo Brunelleschi's experimental perspective used a mirrored surface to reveal the coincidence of natural and pictorial worlds in the play of drifting

clouds animating the skies. The persistence of shadows prefigures both John Locke's model of the memory as a camera obscura, transposing the infinite outer world into the mind's own room, and the modern invention of photography.

Changes in representation at the turn of the modern age sidelined iconic images and symbols, the mimetic resemblances of traditional knowledge creation, to explore the trace or indice, the clue left in matter by an event, action, or process, to be known later only through fingerprints left behind, by impressions of the marks of time and metamorphosis. This paradigm shift moved visual artists away from their traditional focus on representing an object or landscape, real or imaginary, and toward understanding the art as inhering in making: in the process itself, with a secondary focus on the technical processes to produce the materials involved. The mystical source and meaning of our visible world in the winking stars and moving constellations of ancient astrology entered the modern era's visual-spatial arts one hundred years ago, through the kinetic sculpture of László Moholy-Nagy's Light-Space Modulator (1922–30). Within this sculpture's ever-changing patterns of projected shadows, the viewer sees the shapes of invisible mechanisms that appear to lie far beyond their literal visual field. Rotating elements with reflective and translucent geometrical surfaces activated and nuanced the light forms while the polymer material's subtle imperfections introduced subtle biomorphic traces into the choreography. The project activates imagination by overlaying the space of embodied experience with another space, delineated by gradations of light and darkness. The air around the viewer might seem heavy within a topographic continuum freighted with things, waves of matter and light, and local centres of gravity that attract other particles.

Similar to Lazlo Moholy-Nagy's projects, this new series employs media of beams of light, continuous with starlight traveling beyond the walls of the room, far past the Museum, Paris, and the Earth. In Living Shadows, mediating terrestrial and celestial orders, dynamic shadows dramatize light's capacity to spread distances and depths, forming networks through resonances and unknown laws of physics. Today, technological thinking and instrumental approaches to making continue to alienate us from our emplacement in the world and our relationship to nature. In remote antiquity, techne meant art: knowledge related to making, ultimately indivisible from poetics as techne-poesis — a revealing of something that was concealed. That creative knowhow emerged from direct encounters with

things and tasks embodied in a world resonant with meanings. Art was profoundly connected to the inner workings of nature, and mankind's limited understandings of those powers. Art also was not separated from life, and everything emerging from this process of making drew meaning and beauty from the ultimate order of the cosmos, offering glimpses of truth.

Living Shadows is eloquent not only in its phenomenological qualities, the thaumaturgy and the beauty, but also in its capacity to question and dismantle the autonomy and instrumentality of modern technology, with its sophisticated networks of tools and instruments. In this creative space, the alchemical transmutation of the mechanical and digital into the biological and celestial become present in the only way available to them, through their common origin in rays of light.

This vision in which space is never empty, and everything is pregnant with potential, is profoundly optimistic. It's a drawing-forth, and a foreshadowing of the future.

Facing Page

Medusa Shadow, "Iris van Herpen: Sculpting the Senses", Musée des Arts Décoratifs, Paris





Coupled Physical and Virtual Characters

Facing Page

Living Shadows demonstration:
stellated truncated icosahedron
sculpture with accompanying digital
twin projection

Imagine a scenario where the physical movement of individuals in the space in and around a Living Architecture testbed triggers reactions in a virtual world. In turn, events within that virtual world can affect the behaviour of mechanical actuators embedded throughout a sculpture. Subtle sounds permeate the environment, suggesting the presence of unseen beings. Shadow-play on the walls reveal not just the intricate structure of the physical environment, but also the occasional movement of otherwise invisible virtual creatures. Sudden movement by a human, picked up by sensors and fed into the parameters of the influence engines, might momentarily quiet the movement of components and/or virtual automata, signaling perception and sensitivity within the ecosystem. The buildup of emergent behaviours from dozens of simple virtual creatures might set off a cascade of sound and light within the physical sculpture synchronised with its virtual twin. Looking closer with an augmented-reality lens, participants could uncover whole communities of virtual creatures. They might also discover weather-like patterns containing shifting, flowing virtual elements, positioned around the physical parts of the environment.

Experiences such as this imagined scenario are proposed by the Living Shadows project. Creating this wealth of virtual biodiversity presents a design challenge: how can we design a host of virtual creatures that inhabit a virtual space coupled to physical environments?

The characters and behaviours generated within the virtual space of the Living Shadows project are linked to physical components in living architecture environments. The conception of the actions and behaviours within the Living Shadows project starts with the development of a conceptual identity that encompasses both a virtual creature and a corresponding physical component. This physical component represents one particular manifestation, or instance, of this conceptual identity.

The physical component expresses this identity in our physical reality. The related virtual creature is not a separately conceived entity that incidentally shares some formal similarities with its physical counterpart, but is rather another instance of that same conceptual identity – one that is manifested in a virtual reality.

This conceptual framework of identities and instances is a useful tool when conceiving of the types of expressive behaviours that might manifest in a virtual space for each of a sculpture's components. To illustrate how this conceptual framework (hereafter called the "identity-instance framework") might be applied, the development of the jellyfish-like "polyp" creatures seen within the Living Shadows Demonstration are described here.

The conception of a component's identity starts with a consideration of the experience it should offer to a human encountering it. The polyps, for example, are inspired by a visually rich mylar material light enough to shiver in response to nearby movement or even in resonance with a loud sound. In the physical world, these behaviours are a direct result of the components' form and materiality, carefully crafted over many iterations of prototyping, testing, and refinement. The identity-instance framework prompts designers to give the same care to a component's virtual behaviours, considering how a component's identity might manifest both in the physical form language and in virtual behaviours that might (currently) be physically impossible. Those behaviours are designed to resonate with the materiality of the physical object, closely coupled to its environment.

In many LASG physical sculptures, expressive mylar fronds are anchored to expanded metal skeletal components, called "spars". In the virtual world, these spars act not only as anchors, but also as birth points for the polyps. These virtual elements are designed to emulate the delicate mylar petals that can be found within their physical frond counterparts. Given the right conditions in the virtual world, each physical spar has the potential to generate virtual polyps. The spars' relationship to the mylar fronds, as physical anchor point and virtual spawn point, expresses an integral part of the spars' identity. Similarly, the two manifestations of the fronds, as virtual polyps and physical dressing, can be conceived as two instances of a core identity that is ultimately responsible for the viewer's experience. All physical components of testbeds could have similar virtual-world behaviours that manifest when the two worlds are brought together.



Above

Lucid Bubbles spawning from the augmented shadow of a truncated icosahedron triad chandelier

Considering each component's specific behaviours, both physical and virtual, as part of its identity in the early design phases of a sculpture or testbed helps facilitate the assembly of scalable, distributed active sculptures and environments with many different types of expressive components.

The behaviour in the scenario described at the start of this section can emerge, bottom-up, from the presence of intrinsic behaviours specific to the various physical components within the sculpture. These components may be organized to act in response to each other or in response to changing conditions in the environment. A designer can coordinate top-down effects such as shifting virtual currents or changes to the timing and sensitivity of virtual activity by setting and saving the desired states of parameters. Emerging smart materials and active matter have the potential to translate some of these behaviours into the physical world. Anticipating this future by adding virtual layers to living architecture can support discovery of future expression within existing forms and materials.



From Physical Sculpture to Extended Reality

Above

Grove installed at the Arsenale,
Venice Architecture Biennale,
2021

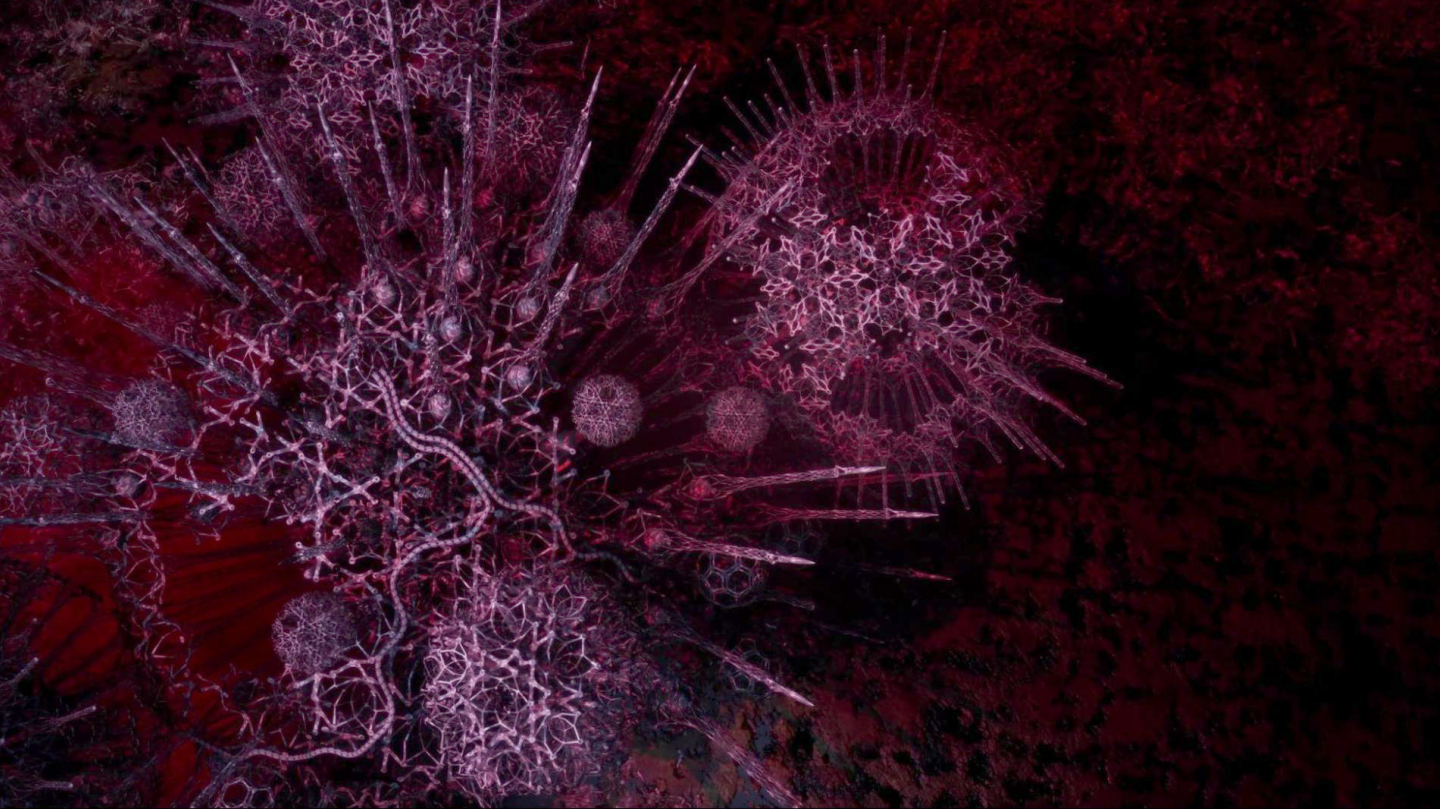
Facing Page

Static shadows of *Ar Frouf Reef*,
Ar Frouf Castle Carantec, France,
2021

Shadow has played important roles in the immersive environments created by the Living Architecture Systems Group's (LASG) testbeds. A testbed's shadow projects its sculptural shape outward onto its environment, flattening its forms and making them manifest as crisp compositions of light and darkness.

The Grove installation, created for the 2021 Venice Architecture Biennale, featured some explorations of animated virtual worlds and animated shadow play.

Surrounding Grove's largely static construction of undulating clouds, simple animated shadows provided an illusion of shifting, billowing forms, evoking dream-like worlds of activity just beyond the threshold of the physical. This shadow play was created by alternating the intensities of digitally controlled lighting distributed around the perimeter of the sculpture.

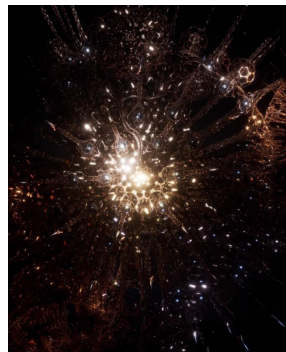


At Grove's core, the short film *Cradle* was projected onto a pool-like screen on the floor of the installation. Created by Philip Beesley in collaboration with London-based filmmakers Warren du Preez, and Nick Thornton Jones, with sound composition by the Amsterdam artist Salvador Breed, the film showed elements of the LASG's physical testbeds growing, shifting, and influencing one another. These behaviours, as of yet impossible to achieve in the physical world, imagined dynamic future identities for living architecture components. Within *Cradle's* computer animation these components were witnessed being born, living, and dying in cycles.

Within the physical installation of the Grove project, animated shadows and projected film that augment the physical sculpture remained largely separate. Physical projected shadows originated from the physical form of the sculpture. The locations of real-world lights determined their forms, behaviour, and location on the walls of the Arsénale. The projected film presented a window into a virtual world, bounded by the shimmering pool of projected light at Grove's centre. With the exception of *Cradle's* sound, which acted as a bridge between the physical and the imagined, movements in one realm remained separate from each other.

Above and Below

Stills from *Cradle*, by Philip Beesley, Warren du Preez & Nick Thornton Jones, showing the imagined life cycle of LASG components. Image depicts a Double Shell Noosphere form in alternating states of decay and vibrant life.



Above

Lucid Dream digital twin projection with Lucid Dress by Iris van Herpen, "Is it alive?", TextielMuseum, Tilburg, 2023

Lucid Dream

Poietic Veil Tilburg is an installation composed of an interactive, suspended veil, the Lucid dress authored by Iris van Herpen, and Lucid Dream, which couples the dress to the sculpture with light and shadow. Poietic Veil was conceived and fabricated with students at TU Delft, featuring a lace-like structure with responsive components that invite curiosity and visitor interaction. The installation is part of the immersive exhibition *Is it alive?*, staged at the TextielMuseum in Tilburg from October 14, 2023 to April 7, 2024.

Overleaf

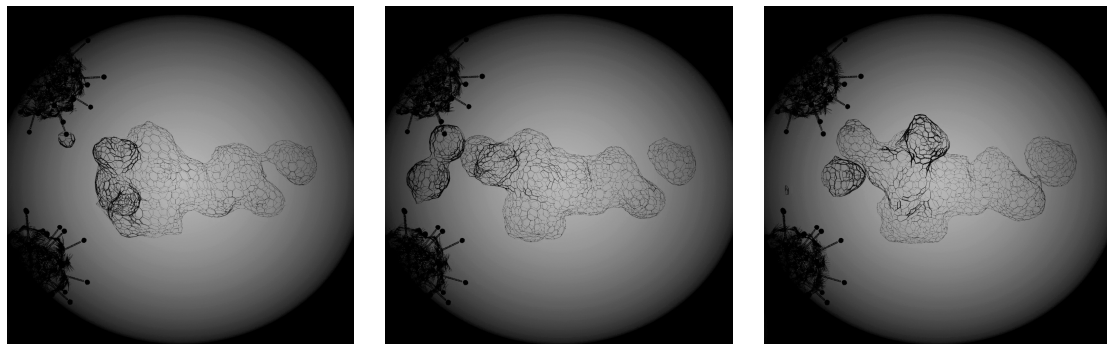
Lucid Dream digital twin projection with Poietic Veil Tilburg by Philip Beesley Studio Inc./ Living Architecture Systems Group, and Lucid Dress by Iris van Herpen, "Is it alive?", TextielMuseum, Tilburg, 2023

Voltage Shadow with Voltage Dress by Iris van Herpen, "Iris van Herpen: Sculpting the Senses", Musée des Arts Décoratifs, Paris

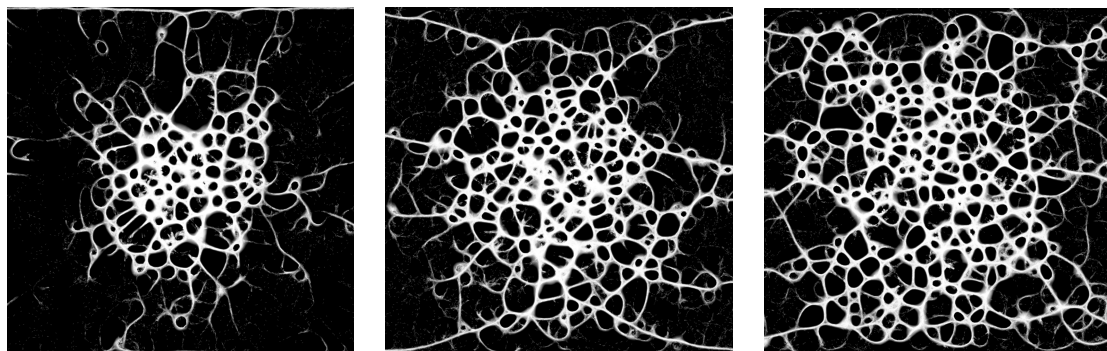
Physarum, Voltage Shadow, Medusa Shadow

Presented within the exhibition *Iris van Herpen: Sculpting the Senses* at the Musée des Arts Décoratifs, Paris from November 29, 2023 to April 28, 2024, the work of Philip Beesley and the Living Architecture Systems Group includes experimental fabrics, textiles and forms that have gone on to be incorporated into Van Herpen's dresses and Beesley's immersive installations, and a series of projections that inaugurate Living Shadows. Halo-like spaces radiating around each dress are filled with growing, multiplying, interacting forms, expanding the physical fabrics of the couture into animated worlds of possibility.

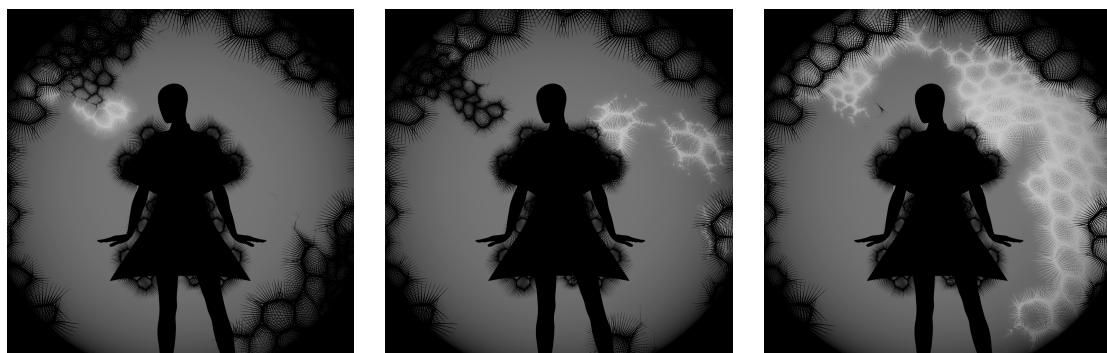




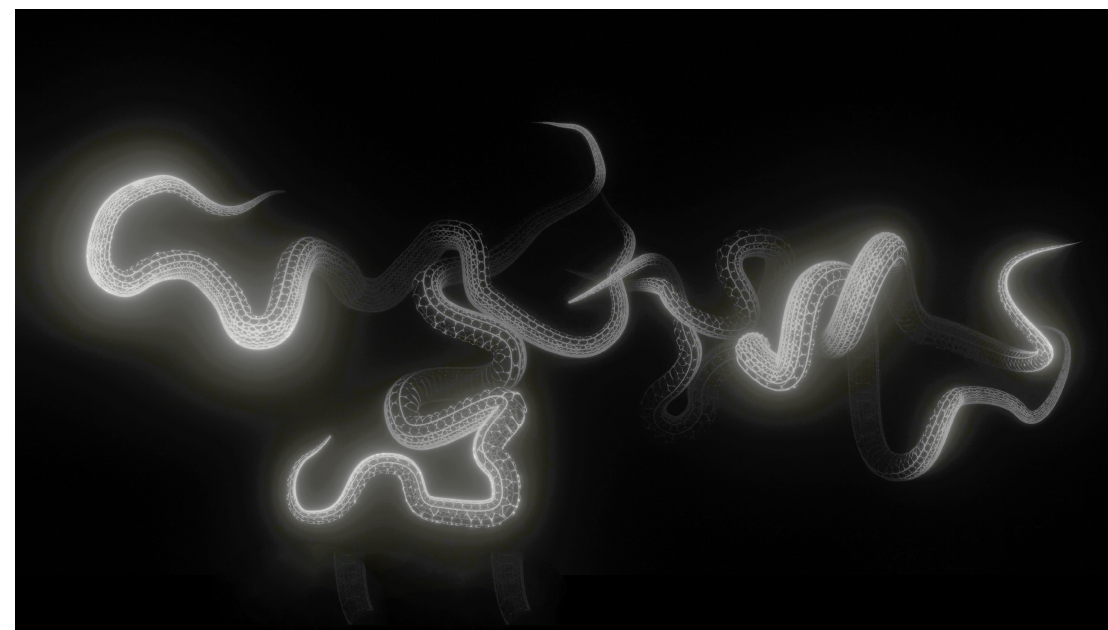
Sequence from Lucid Dream digital twin projection with Poietic Veil Tilburg by Philip Beesley Studio Inc./ Living Architecture Systems Group, and Lucid Dress by Iris van Herpen, "Is it alive?", TextielMuseum, Tilburg, 2023



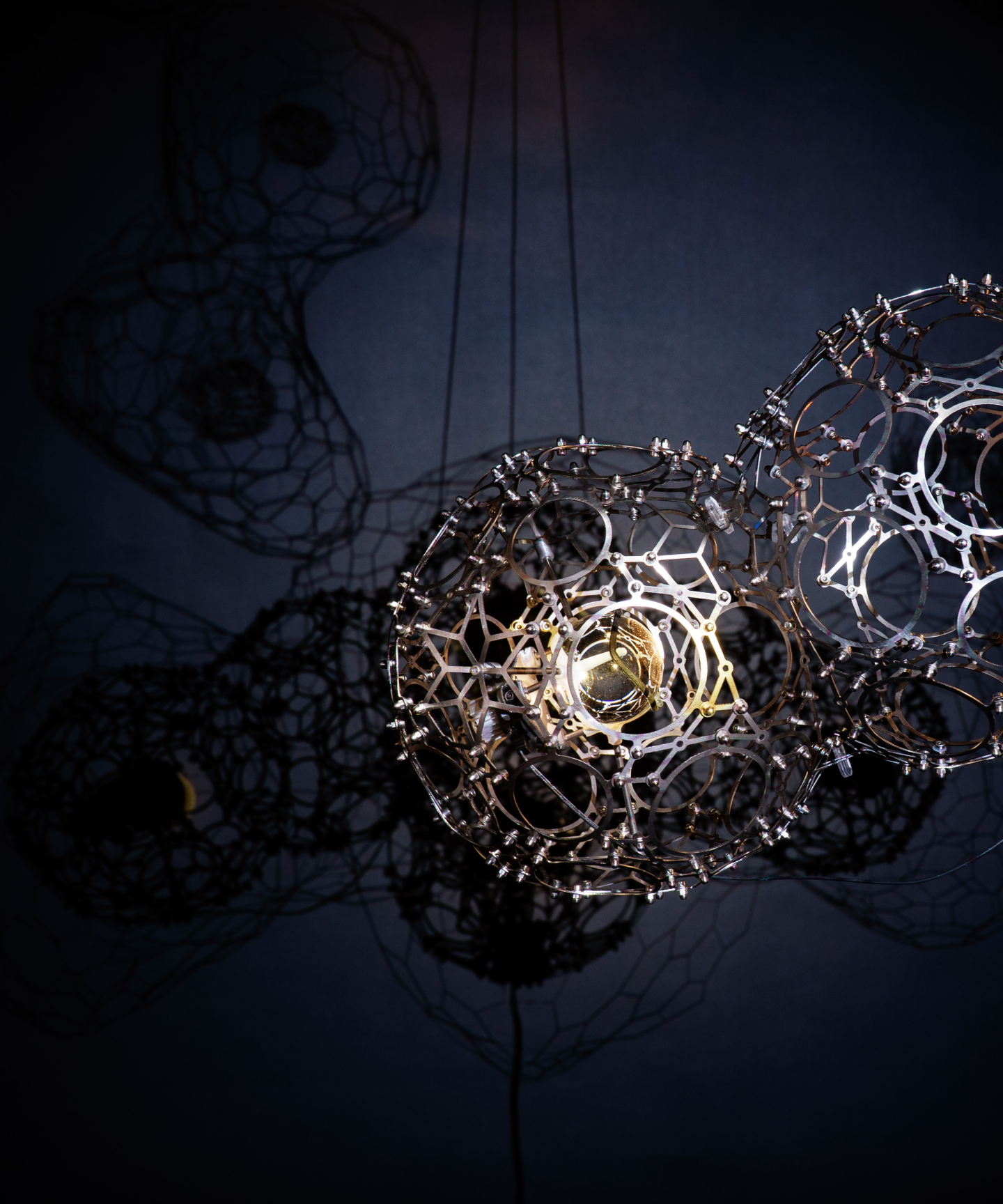
Sequence from Physarum Living Shadows, "Iris van Herpen: Sculpting the Senses", Musée des Arts Décoratifs, Paris



Sequence from Voltage Shadow, "Iris van Herpen: Sculpting the Senses", Musée des Arts Décoratifs, Paris



Sequence from Medusa Shadow, "Iris van Herpen: Sculpting the Senses", Musée des Arts Décoratifs, Paris



Living Shadows Demonstration

Facing Page

Living Shadows demonstration:
truncated icosahedron triad
chandelier with accompanying digital
twin projection

The Living Shadows demonstration features first implementations of the systems required to augment a work of Living Architecture through projection. The demonstration illustrated here features a single sphere and single data projector. The projection used for this demonstration employs a real-time simulated virtual environment created in the Godot Game Engine. Godot is a free open-source engine for creating 2D and 3D games.

The Living Shadows Demonstration is composed of the following systems:

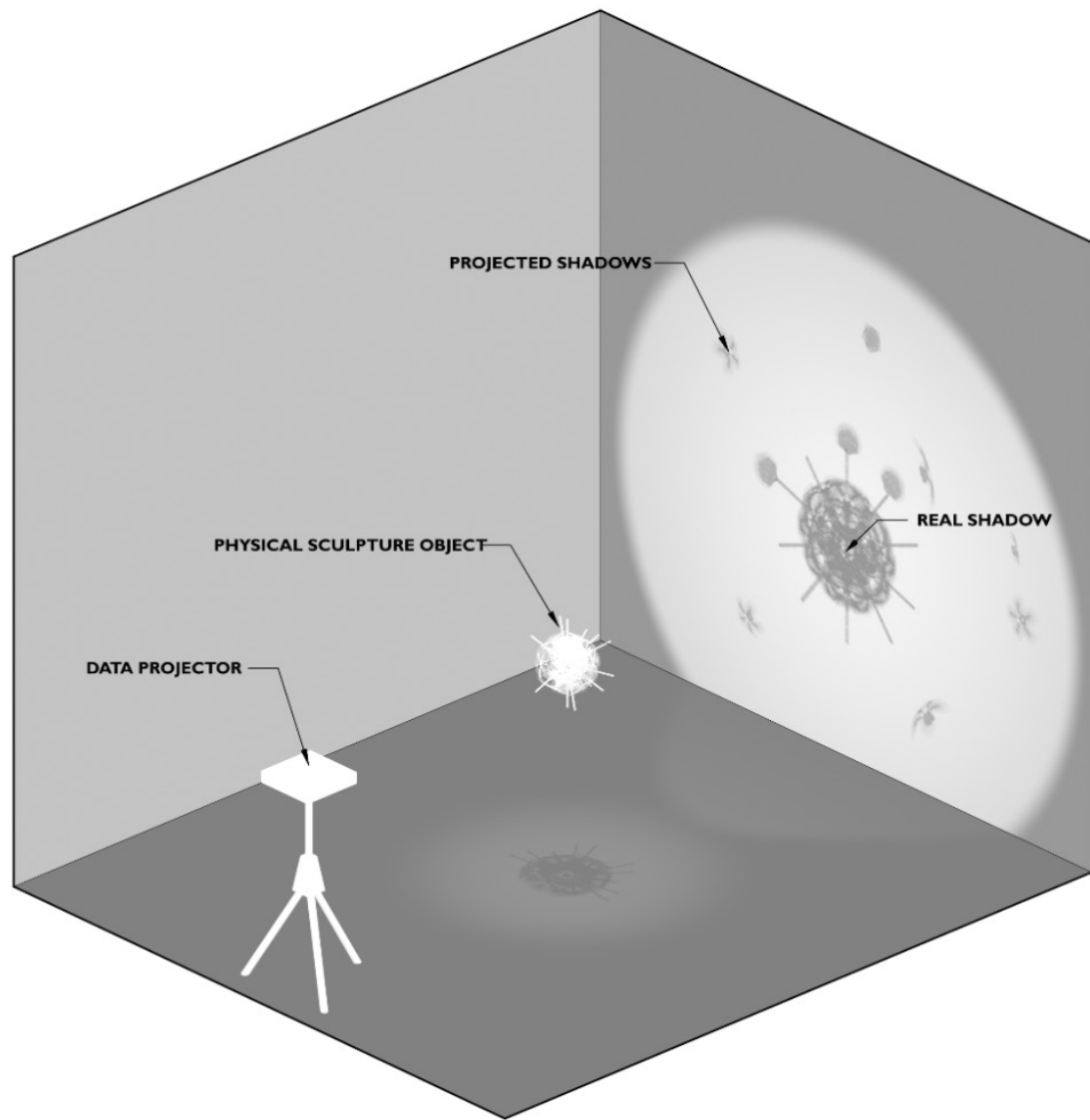
Physical Sculpture

The physical sculpture in the demonstration consists of a single, static sphere composed of expanded metal and thermally formed laser-cut acrylic skeleton components. Miniature glass vessels are integrated within these forms, filled with aqueous solutions of copper sulphate and potassium ferricyanide. These chemical solutions give distinctive teal and orange transparent colourings. Delicate mylar fronds dress the outer ends of the expanded skeleton forms.

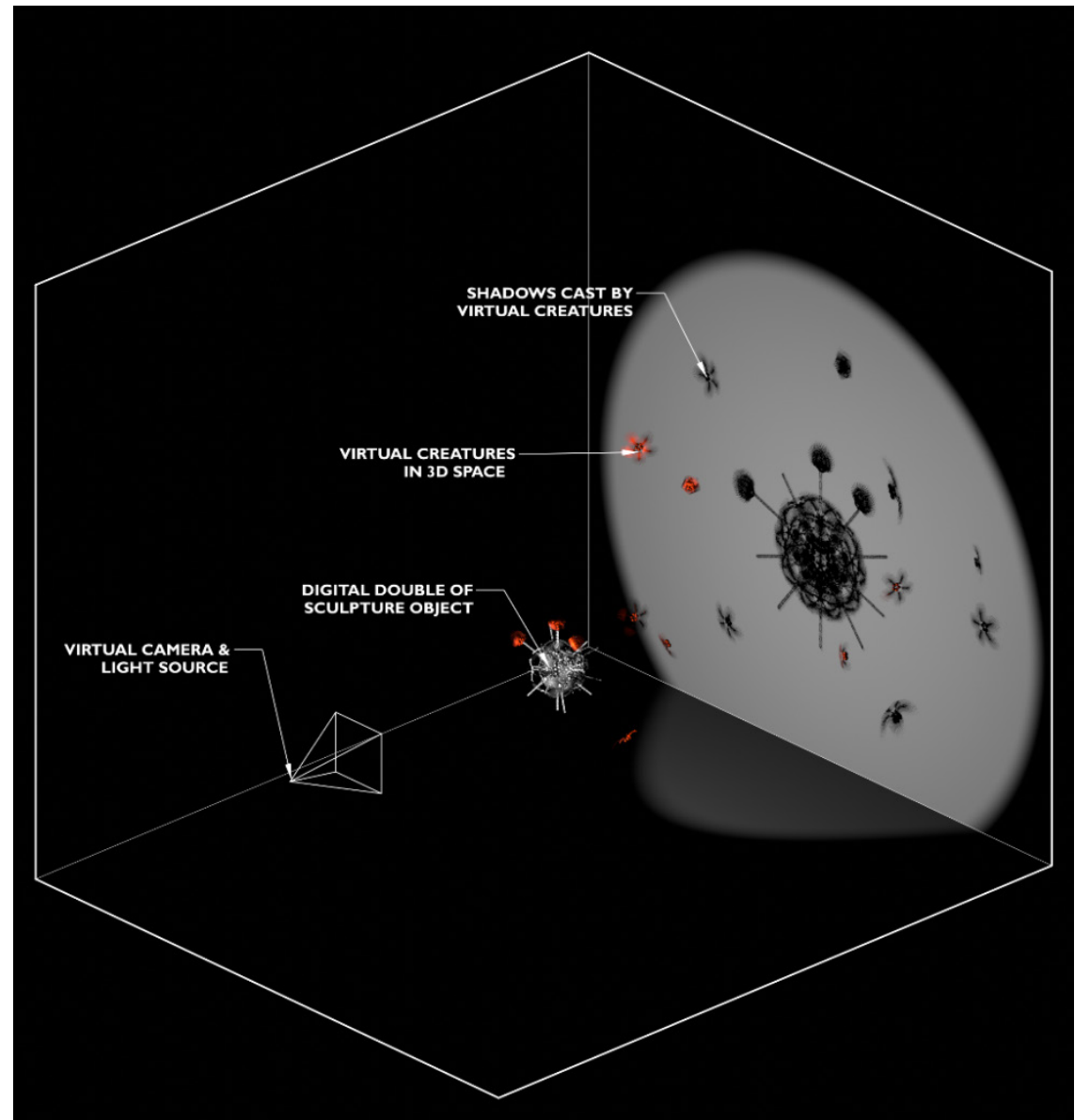


Link

View a video of the Living Shadows
smart projection by visiting [http://
media.lasg.ca/livingshadows/video](http://media.lasg.ca/livingshadows/video)



Physical World, Living Shadows Demonstration



Digital Twin, Living Shadows Demonstration



Virtual Model

A digital double of the physical sculpture is imported into the Godot Game Engine. This digital twin is based on physical assemblies that were created by the LASG studio. These schematic design models are transferred into the game engine using the Living Architecture Systems Description (LASD) file format and a custom import script written for the Godot engine.¹ This importer automatically configures game-engine suitable materials and attaches behaviour scripts to sculpture elements based on the metadata defined in the LASD file.

Digital & Physical Alignment

Within the digital twin, a virtual camera captures creature and component behaviours within a set field of view. In the physical world, a projector mirrors the camera's position and viewpoint in relation to the sculpture. The focal length of the virtual camera is calibrated to match the optical characteristics of the real-world projector. Aligned across the virtual and

Above

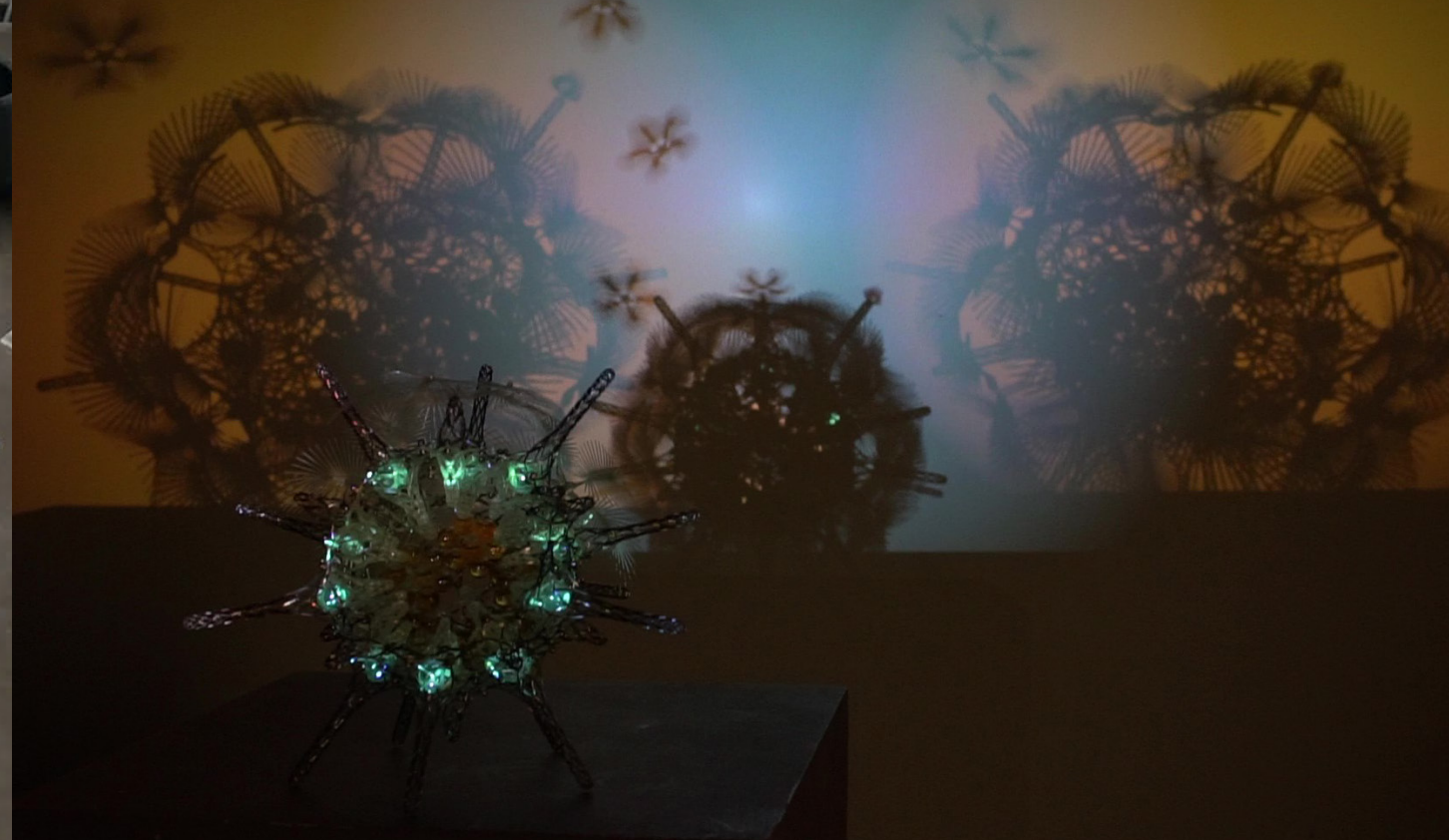
The physical sculpture and its digital twin. Presented next to each other in an augmented reality viewport.

- 1 The use and development of the LASD file format is described in the folio *Living Architecture Systems Description: Extensible Spatial Data System for Responsive Architectural Environments* by the LASG, available at <https://livingarchitecturesystems.com/publications/>



Link

View digital twin through mobile phone camera augmented reality interface by visiting <http://media.lasg.ca/livingshadows/digitaltwin>



Above

A Living Shadows setup with three virtual lights.

Center light, (Blue) aligns with the Virtual Camera and Physical Projector.

Second and third lights (orange) exist to either side of the virtual camera, and have no discernable source in physical world.

physical realms, the physical projector and virtual camera form a coordinated pair that allows the virtual world to be projected back out into the physical world. The virtual camera is paired with a virtual light that casts shadows in the virtual world. These shadows are rendered by the virtual camera and projected into the physical world via the projector. The viewer sees a composite of physical-world shadows cast by the light coming from the projector and the projected image of virtual shadows on the wall or screen behind the sculpture.

The effect is most convincing when the virtual light and virtual camera are aligned, creating an illusion of one single integrated set of shadows. However, the virtual light can also move, creating illusory lights that cast shadows in the physical space but have no discernable source. Carefully balancing the intensity of physical lights (both spotlights and ambient lighting) and the virtual light sources being projected creates a compelling merging of the physical and virtual worlds. The illusion is further enhanced when viewers place body parts such as an arm or hand within the beam of the projector, creating their own shadows alongside the shadows of virtual creatures.

Virtual Creatures

Virtual creatures birthed from the digital twin model inhabit the virtual world. Spawn points for virtual creatures can be automatically created (attached to user tagged sculpture components) on import or manually placed in the 3D scene.

Currently only one species of virtual creature is active in the Living Shadows demo. The “polyp” creature is a jellyfish-like manifestation of the delicate mylar fronds that dress the ends of the metal spars in the sphere at the heart of the physical sculpture. The polyps grow curled and bulbous from the spar tips until they reach maturity and are ejected into the fluid-like field of the virtual world. Once ejected, polyps are autonomous, navigating the virtual space and interacting with others of their kind before eventually withering and dying. Upon their death, each of a polyp’s froned arms, now tattered and spindly, breaks free of its body’s core, drifting off in the currents of the virtual field.

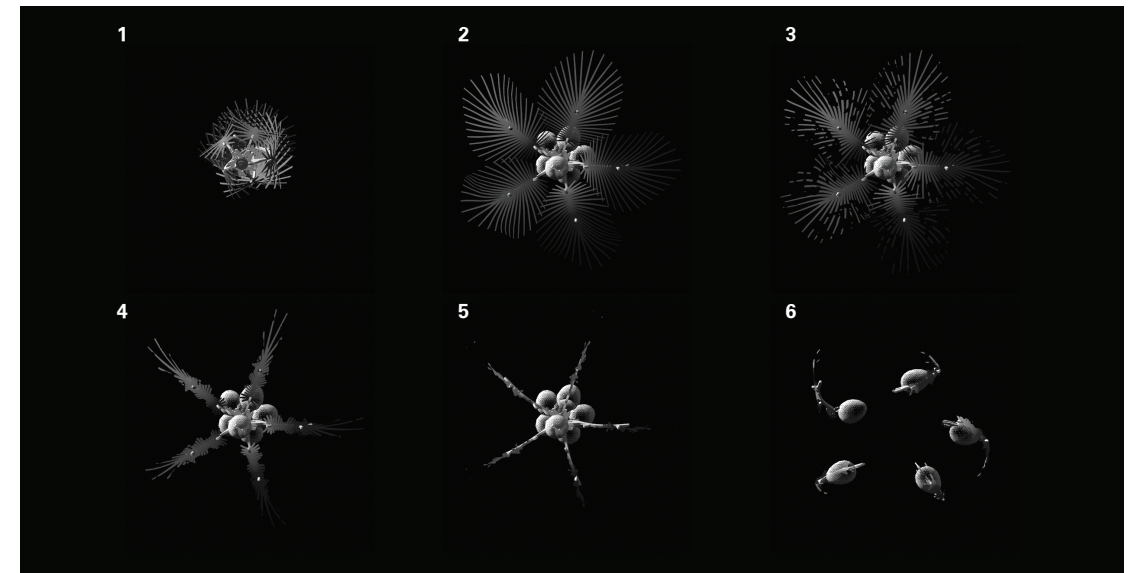


Left
Shadows of a Virtual Polyp Spawning

- 2 Warren McCulloch and Walter Pitts, “A Logical Calculus Immanent in Nervous Activity,” *Bulletin of Mathematical Biophysics* 5 (1943): 115–133.
- 3 Edward F. Moore, “Gedanken-experiments on Sequential Machines,” *Automata Studies, Annals of Mathematical Studies* 34 (1956): 129–153.
- 4 See, for example, John H. Conway, *Regular Algebra and Finite Machines* (London: Chapman and Hall, 1971).

The polyps are finite state automata. Originally presented by Warren McCulloch and Walter Pitts in their 1943 paper “A Logical Calculus Immanent in Nervous Activity,”² popularized by the American computer scientist Edward F. Moore in 1956,³ and refined and revised by many others in the decades since,⁴ a finite state automaton is a simple model of artificial intelligence in which the automaton’s behaviour corresponds to a particular state of being, with defined conditions that control the transition from one state to the next. For the polyps, each phase of their life cycle corresponds to a particular state, and a preset timer governs the transition from one state to the next.

Once a polyp has been ejected and is free to wander the virtual world, an additional behaviour model is used to guide its movement. The wandering and coordination of the polyps is driven by a “boids” model. Developed by



Polyp Life Cycle

Legend: 1. Birth 2. Prime Life 3. Aging 4. Decaying 5. Near Death 6. Broken & Drifting

Craig Reynolds in his 1986 paper "Flocks, Herds, and Schools: A Distributed Behavioral Model," the boids model results in emergent life-like flocking behaviour for groups of creatures, driven by simple rule sets.⁵ Each polyp determines its travel direction based on a weighted average of its goal position and its fear of, or desire to be near, others of its species, a variable that is set when it is released by its spawn point.⁶ By altering the weight of these three parameters for each polyp, individual behaviour can be created within the flock.

5 Craig W. Reynolds, "Flocks, Herds, and Schools: A Distributed Behavioral Model," *Computer Graphics* 2, no. 14 (1987): 25–34. The rules in a boids model dictate steering behaviours, governing separation (how close one individual will get to another before moving away), alignment (individuals steer in the average direction of the flock), and cohesion (individuals steer towards the average position of their flockmates, bringing the flock together).

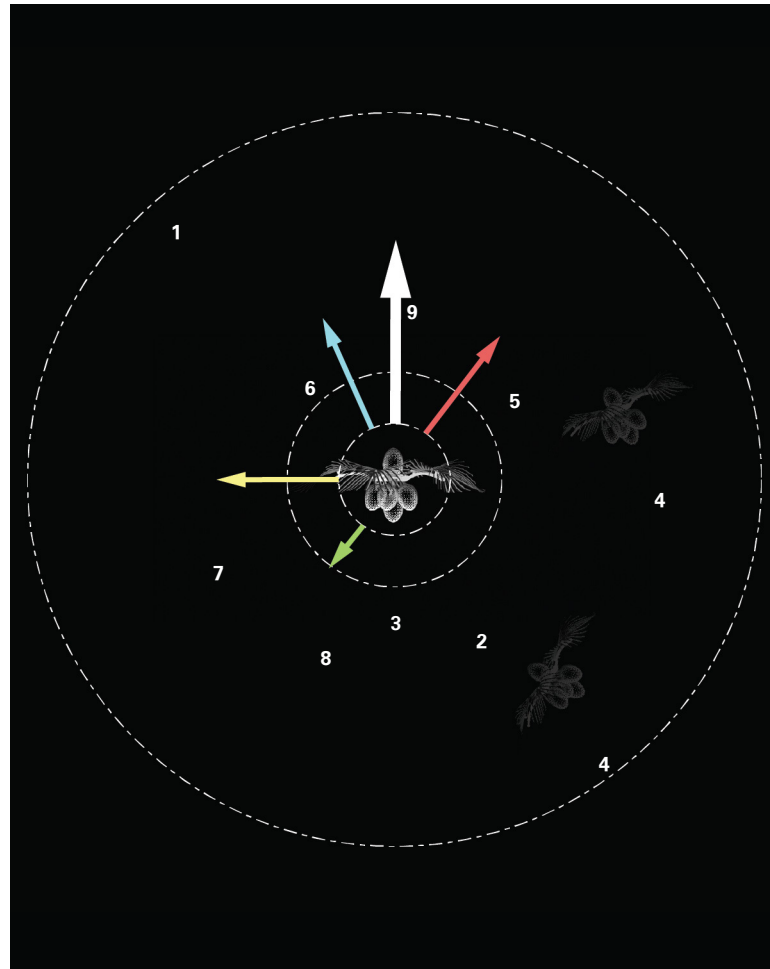
6 A polyp's "fear" level determines how close it must get to other polyps before moving away; a polyp that gets quite close to its fellows before changing direction will join the flock and appear to demonstrate less fear than a polyp that changes direction at distances that prevent them from joining flocks.

Each cell component that spawns a polyp in the digital twin has a set fear range, and each polyp is assigned a specific fear level within the range of its spawning component when it is released. Component fear ranges may be more or less wide and inclined towards lower or higher degrees of fear, allowing for a broad range of fear levels in the individual polyps.

Left

Polyp Flocking Behaviour:

- 1) Neighbour detection radius
- 2) Direct Interaction radius
- 3) Collision radius
- 4) Neighbouring Polyps
- 5) Target Vector
- 6) Conformity Vector: The average path of travel of Neighbouring Polyps.
- 7) Fear Vector: The path of travel that maximizes distance to neighbours
- 8) Field Vector: The influence of the Curl Noise vector field that permeates the virtual space. This has minimal influence on living Polyps.
- 9) Resulting Travel Vector: the weighted sum of the 5,6,7 with weights based on the Polyp's age and behaviour characteristics.



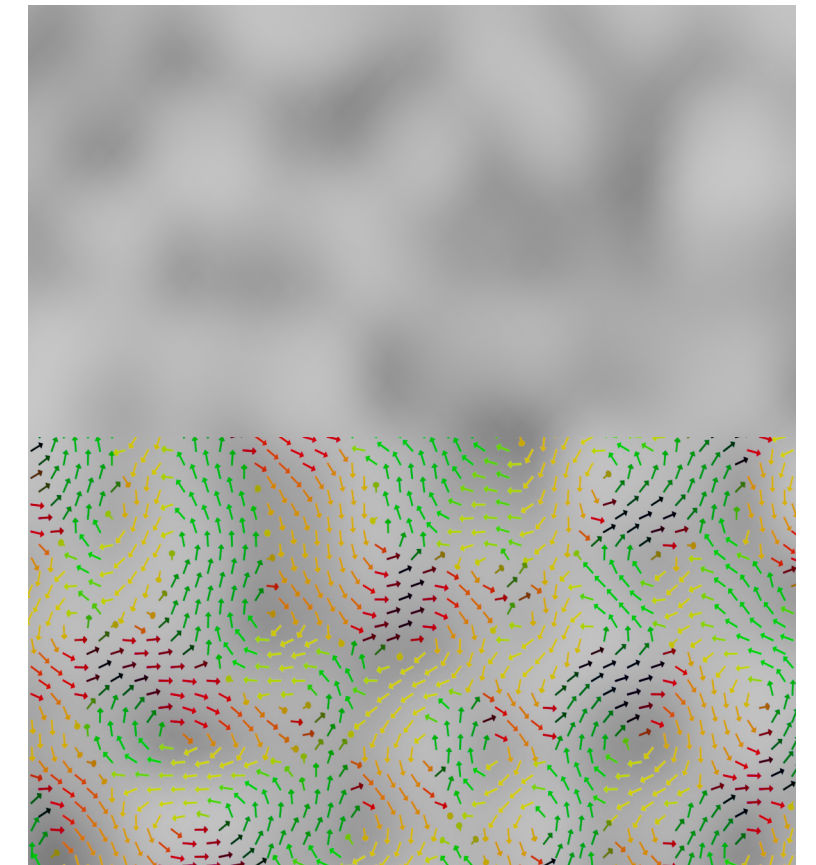
7 Robert Bridson, Jim Houriham, and Marcus Nordenstam, "Curl-Noise for Procedural Fluid Flow," *ACM Trans. Graph.* 26, no. 3 (July 2007): 46–es. <https://doi.org/10.1145/1276377.1276435>

Field conditions

In order to create the illusion of a viscous, fluid-like environment, the virtual field is configured to exert forces on the active polyps and polyp-debris that exist within it. While early Living Shadows explorations attempted to use real-time fluid simulation techniques, requirements for performance and simple art-directable control of fluid flow characteristics led us to settle on the use of curl noise to drive the fluid forces present in the virtual field.⁷ Curl noise produces a motion vector that is tangent to the derivative of a 3D simplex noise field, producing motion that appears similar to the vortices and eddy currents that emerge in turbulent fluid flow.

Right

2D Simplex Noise Field, and its associated Curl Noise Vectors.



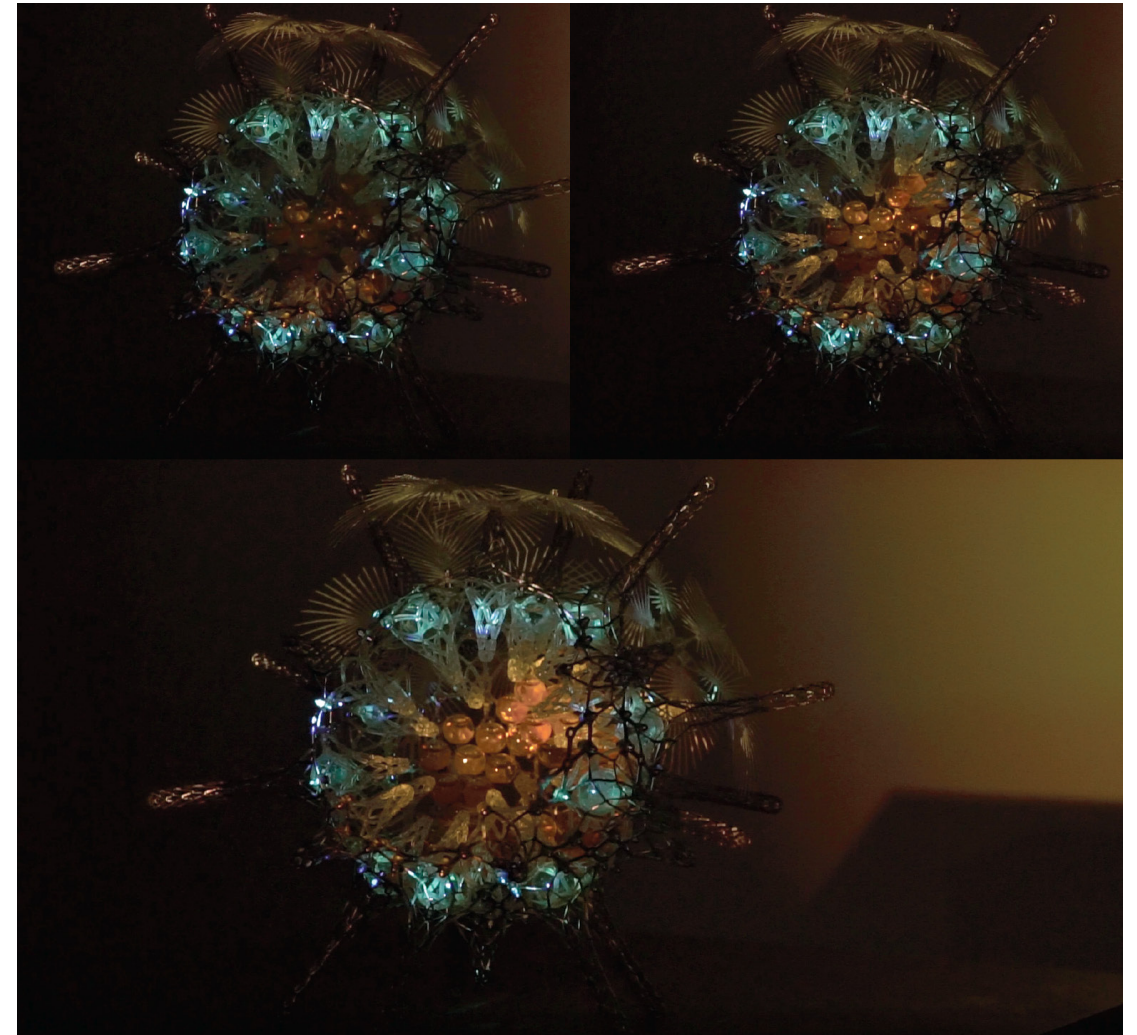
Virtual Actuation

In physical testbeds, devices are distributed throughout the sculpture, forming a networked topology of sensors and actuators that exchange influences and exhibit behaviour through illumination, mechanical movement, and sound. The arrangement of these sensors and actuators is documented in a three-dimensional digital model whose components are classified and organized using Living Architecture Systems Description (LASD). The LASD classification provides a systematic organization that permits efficient configuration of components, compatible with kinetic animation and behaviour scripting. The LASD framework is described within a 2023 publication within the same series as the current Living Shadows publication. In the physical testbeds, control software is configured to use this data in order to manage and simulate communication between devices. Open Sound Control (OSC) messaging protocol is used for this communication.

By using this data organization, device data can be read and emulated by the Living Shadows system. The configuration allows objects to be tagged as virtual actuators. These actuators can be given behaviours inherent to the virtual world, or alternately may be triggered externally from outside the Godot game engine by using externally generated OSC messages. The current Living Shadows demonstration has two types of virtual actuators. These elements are titled virtual lit vessels and virtual moths. Descriptions of these elements follow here.

Virtual Lit Vessels

In physical testbeds LED lights illuminate glass vessels embedded within the sculpture. Virtual lit vessels allow for these embedded glass vessels to be illuminated through projection instead of embedded LEDs. Virtual lit vessels are imported into the game engine with a virtual emissive material that emits light across its surface. When activated (via OSC or through interaction with a virtual creature), virtual lit vessels create bright spots in the virtual camera's view, which are projected back out onto physical glass vessels, causing them to glow.



Above

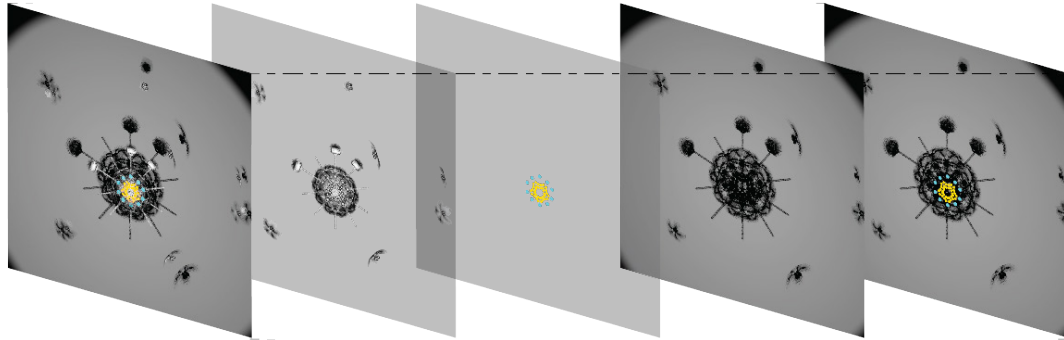
A wave of virtually actuated light passes through the core of the sculpture.

Virtual Moths

Virtual moths are the digital doubles of the static mylar dressing found at the ends of sphere spars. When triggered, virtual moths undulate with a shifting movement driven by a vertex displacement shader. The movement of the digital twin fronds creates a shifting shadow in the physical world that gives the illusion of subtle movement on the mylar fronds and their projected shadow.

Render Workflow

Render layers are automatically configured on import to ensure that the virtual camera only renders shadows cast and light emitted by virtual objects. The virtual objects themselves are omitted from the virtual camera's rendering.



Scalability and Distribution

The Living Shadows demonstration is currently composed of a single projector and sculpture object. Full-scale installation will involve several distributed projectors, rendering multiple coordinated views in real time from a central simulated virtual environment.

To support a distributed set of projectors, a system for real-time streaming of multiple virtual cameras was developed in Godot Engine. Godot Engine's render pipeline is designed to render from a single camera to a single root viewport for display on a single screen. However, Godot also supports the creation of sub viewports which can each render from a unique camera with unique render settings. These sub viewports are typically displayed as a user interface element on the same screen. Alternately they may be used for split-screen multiplayer games. The Living Shadows project extends Godot's native Viewport class to create a StreamViewport that can be configured with its own render settings, as well as a real time messaging protocol ('RTMP' stream address.

Above

Render layers used in the Living Shadows Demonstration.

Left to Right:

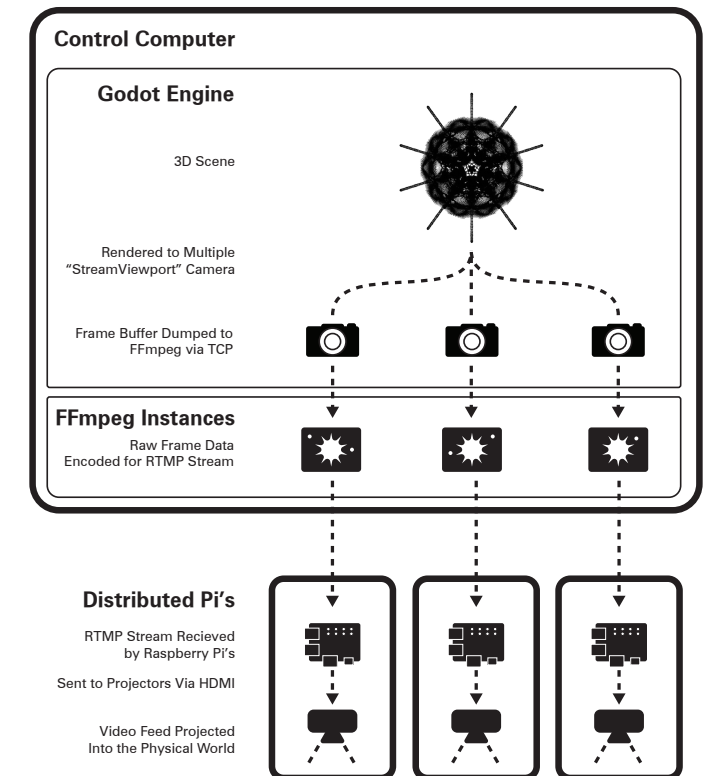
- 1) A typical render of the full 3D Scene.
- 2) The Virtual Objects in the 3D scene, used only by the virtual lights for shadow casting.
- 3) Emissive material used for Virtually-Lit Vessels.
- 4) Shadows cast on the environment.
- 5) The composite render used for projection. A combination of Layers 3 & 4.

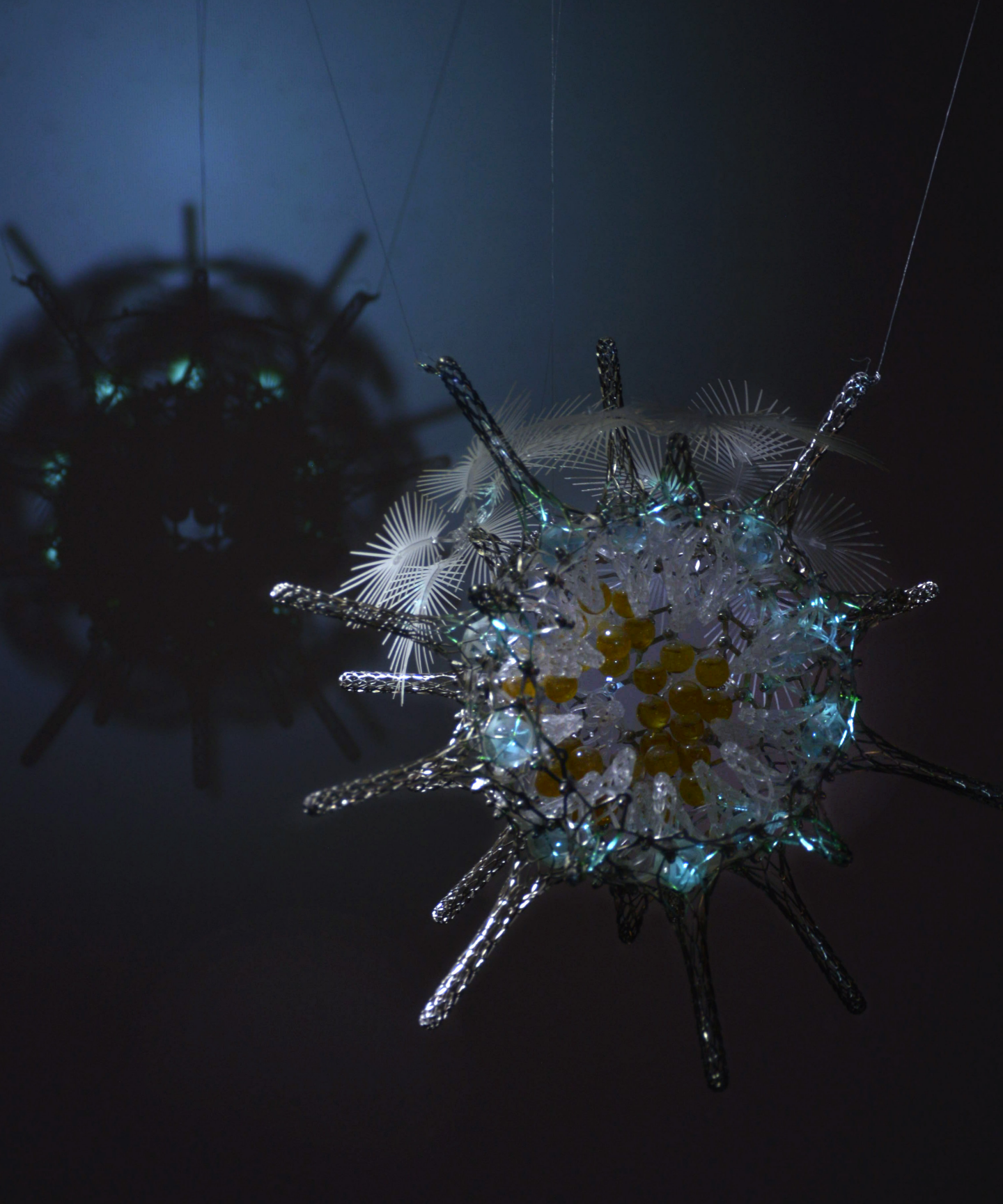
Right

Stream Configuration Diagram

When the virtual scene is run, each stream viewport creates an instance of the open-source audio and video encoding platform FFmpeg, configured with the user-defined RTMP stream address. Rather than rendering its camera view to the screen, each StreamViewport instead renders to its frame buffer, which is dumped directly to the FFmpeg instance over Transmission Control Protocol ("TCP"). The FFmpeg instance then encodes and broadcasts the frame data as a real-time video stream to the address specified.

A Raspberry Pi single-board computer, connected to a projector and configured to receive the same stream address, can then pick up and display the rendered StreamViewport over the local WiFi network. This allows for multiple distributed projectors to receive rendered video feeds from a central simulated virtual environment.





Next Steps for the Living Shadows Project

The Living Shadows project provides a new path for exploration within the realm of living architecture. The lights and shadows of its virtual world create a new realm where the lives of virtual beings and their influence on physical space can be investigated. The example of polyps described within this publication provide an example of dynamic cycles and life-like emergent behaviours that can arise from simple systems of artificial intelligence. The identity-instance model described here provides a framework to guide the creation of new creatures and new behaviours, drawn from a wide library of components used in testbeds created by the Living Architecture Systems Group. This demonstration of the concept of Living Shadows briefly describes the creation of tools and workflows that can support the creation of large, complex distributed Living Shadows installations.

Future versions of the Living Shadows project can increase the integration of virtual and physical worlds. By incorporating real-world sensor data as a driver for virtual actuation and creature behaviour, this project series can create cycles of interaction across the virtual and physical realms, allowing each to influence the other.

As the Living Shadows project continues to develop in tandem with the development of the LASG's physical testbeds it will grow into a diverse virtual world. An ecosystem of virtual creatures interacting with their physical counterparts can emerge. The digital realm of this project evokes vibrant emergent behaviour that enlivens the physical world with light, shadow, and sound, dissolving boundaries between natural and artificial life.

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About the Living Architecture Systems Group

This publication forms part of a series of work-in-progress reports and publications by Living Architecture researchers and contributors. The Living Architecture Systems Group is an international partnership of researchers, artists, and industrial collaborators studying how we can build living architectural systems— sustainable, adaptive environments that can move, respond, and learn, and that are inclusive and empathic toward their inhabitants. "Smart" responsive architecture is rapidly transforming our built environments, but it is fraught with problems including sustainability, data privacy, and privatized infrastructure. These concerns need conceptual and technical analysis so that designers, urban developers and architects can work positively within this deeply influential new field. The Living Architecture Systems Group is developing tools and conceptual frameworks for examining materials, forms, and topologies, seeking sustainable, flexible, and durable working models of living architecture.

Living Architecture Systems Group research is anchored by a series of prototype testbeds: accessible, immersive architectural sites containing experiments and proof-of-concept models that support living architecture as a practical model for our future built environment. These testbeds act as boundary objects⁶ that help researchers answer ethical, philosophical and practical questions about what living architecture means and who it is for within our societies and environments, creating sites of collaborative exchange that act both as research ventures and as public cultural expressions.

A series of far-reaching critical questions can be explored by using the tools and frameworks that are described within this specialized publication series: can the buildings that we live in come alive? Could living buildings create a sustainable future with adaptive structures while empathizing and inspiring us? These questions can help redefine architecture with new, lightweight physical structures, embedded sentient and responsive systems, and mutual relationships for occupant that provide tools and frameworks to support the emerging field of living architecture. The objective of this integrated work envisions embodied environments that can provide tangible examples in order to shift architecture away from static and inflexible forms towards spaces that can move, respond, learn, and exchange, becoming adaptive and empathic toward their inhabitants.

Living Shadows for Living Architecture Environments

Philip Beesley, Kevan Cress, Matt Gorbet & Tracey Eve Winton
Living Architecture Systems Group

This folio describes a new Living Shadows initiative within the Living Architecture Systems Group's (LASG's) exploration of augmented reality environments. Living Shadows uses real-time projections to create a virtual world that augments the physical shadows of an LASG testbed. Creatures based on the sculpture's physical components inhabit this virtual world. Set free as "living shadows," they are a way of exploring how these normally static components might behave if they were given the autonomy to move through and interact with the sculpture's environment. The publication forms part of a series of work-in-progress reports and publications by LASG researchers and contributors.

This expanded second edition includes 2023 collaborative Living Shadows projects integrated within "Is it alive?", TextielMuseum, Tilburg and "Iris van Herpen: Sculpting the Senses", Musée des Arts Décoratifs, Paris. Includes download links to virtual reality models and additional video media.



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