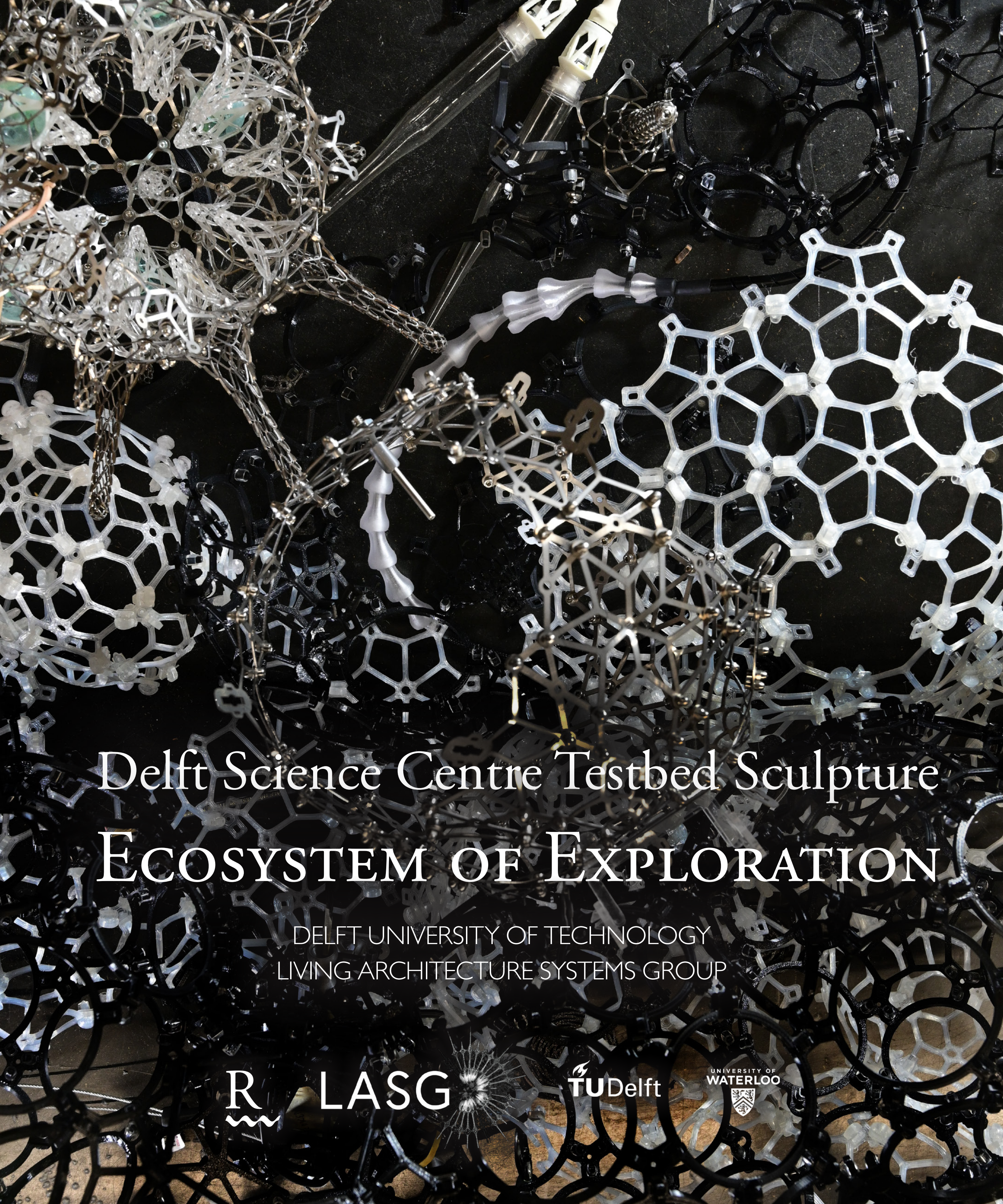


Delft Science Centre Testbed Sculpture

Ecosystem of Exploration

DELFT UNIVERSITY OF TECHNOLOGY
LIVING ARCHITECTURE SYSTEMS GROUP

Delft Science Centre Testbed
Ecosystem of Exploration

Living Architecture Systems Group

R LASG
UNIVERSITY OF WATERLOO

Publisher: Riverside Architectural Press | www.riversidearchitecturalpress.ca

Title: Delft Science Centre Testbed Sculpture | Ecosystem of Exploration
Names: Beesley, Philip, 1956-editor. | Chîu, Adrian, 1997-editor. | Cress, Kevan, 1995-editor | Living Architecture Systems Group, issuing body.

Description: Documentation of current research and discovery kits relating to the new testbed environment of the Delft Science Centre.

Identifiers: ISBN 978-1-988366-71-5

Design and Production by Living Architecture Systems Group

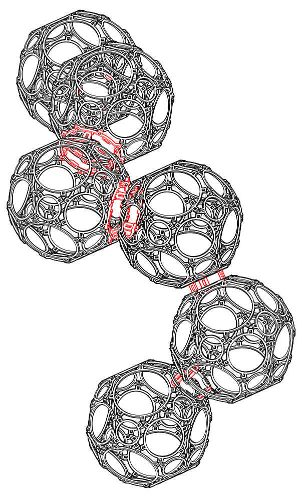
Publication: March 2024
Riverside Architectural Press
7 Melville Street
Cambridge, Ontario, N1S 2H4, Canada

Errors or omissions would be corrected in subsequent editions.
This book is set in Garamond and Zurich BT.

TU Delft
Canada Council for the Arts | Conseil des arts du Canada
University of Waterloo
Social Sciences and Humanities Research Council of Canada | Conseil de recherches en sciences humaines du Canada

Contents

Introduction



Above

A cluster of assembled spheres constructd with the Living Cell System kit

Facing Page

Robotic Explorations Workshop at TU Delft with Amsterdam Airport Schiphol staff and Interactive Environments Minor students, 2023

This folio describes a new series of exploration kits that have been developed by the Living Architecture Systems Group (LASG). Accompanying volumes are entitled Living Architecture Exploration Kit: Component Catalogue, and Living Architecture Exploration Kits: Introductory Assemblies. The set of folios provides a review of integrated open construction and exploration systems created by the LASG.

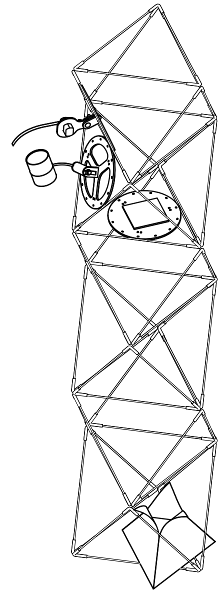
The Living Architecture Systems Group has developed a series of flexible discovery and creation kits that combine interactive electronics, geometric constructions, modular software, and expressive patterns of sound, light, and motion. These kits can help enrich the experience of visiting an immersive Living Architecture testbed sculpture. The kits are designed for a range of viewers and users including members of the public, artists, performers and composers, students and teachers, and advanced researchers. The material is designed to engage a wide range of users interested in exploring next-generation living architecture in imaginative world-making workshops, expressive performances involving sound, light, and motion, modeling of complex geometric structures, and development of interactive electronic systems. Advanced users can employ dashboards for editing and exploring the interactive behavior of these systems. 'STEAM' (Science, Technology, Engineering, Arts, and Mathematics) concepts oriented to elementary and secondary school students are integrated within this material.

LASG exploration kits include skeletal lightweight architectural scaffolds, devices, mounts, and control electronics. They are also accompanied by behaviour software and virtual interfaces, described in accompanying folio volumes. Diverse experiences can be created with these kits, including expressive performances, experimental architecture and design, STEAM (Science, Technology, Engineering, Arts & Mathematics) learning, and scientific research.

These interactive systems include low-cost components compatible with simple digital fabrication, simple mechanisms and sensors, geometric mounting scaffolds, pegboards that support easy assembly and combinations, and user-configurable software for controlling and composing behavior. The web-based software and the physical kit components that have been included within this set are part of an evolving collection of tools and component designs that have been developed by the Living Architecture Systems Group under Creative Commons licensing. These kits have been developed in order to provide combinations of devices containing actuators and sensors with diverse kinds of "intelligence".

The exploration kits encourage experimentation with interactive architectural constructions. The kits are designed to support the construction of combinations of individual components within multiple distributed arrays. The distributed organization of many inexpensive, small components can result in textile-like fabric surfaces that can be used in the creation of responsive architectural envelopes and canopy structures. The most recent of these kits is based on simple polygon tiles that can be attached together in order to create cells. Individual cells made from combinations of polygonal skeletal units can be combined in a variety of ways, creating garland-like chains, lattices, membranes, complex shells and other expressive, functional structures. This versatile scaffold system is designed to support the attachment of many kinds of devices.

Encapsulated cabling and microcontrollers are included, providing a comprehensive interactive system. Materials used for making kits range from rudimentary materials such as corrugated cardboard and bamboo skewers, to engineered high-performance materials including acrylic and stainless steel.



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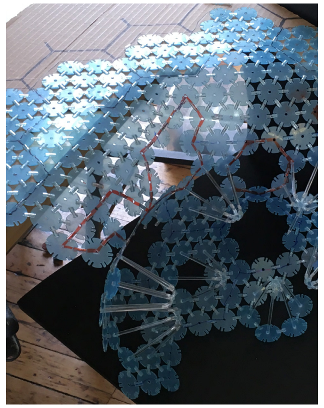
Endless Connections Domaine de Boisbuchet Kit, LASG/PBSI

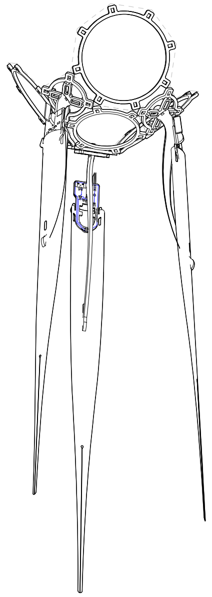


Above

LASG Disc Hub Exploration Kit used for design development of Meander in Tapestry Hall, Cambridge

Below

Vibrating Lashes mounted in rings of Living Cell System kit.



Physical scaffold structures support the exploration devices, mounts, and electronics. These scaffolds can be constructed from lightweight efficient materials such as bamboo skewers and wood skewers, and connected using acrylic, flexible tubing, or 3D printed components. Mounts are attached to scaffolds to carry electronic parts. The mounts are the intermediary links that enable the scaffolds' interactive functions. These mounts include three-dimensional printed parts, laser-cut plates, and disks of thin wood and cardboard sheet materials. Electronic hardware is included within these kits, supporting the exploration of motion, light, and sound. Mounted devices include light light-emitting diode (LED) actuators, direct current motor actuators, light-dependent resistor sensors, and passive infrared sensors.

The physical components are coupled to behavior software, interface, and simulations which provide opportunities for programming and engineering. "Smart Cell" interfaces support the flexible development of distributed systems that can be easily multiplied and prototyped. Smart Cells take the forms of both physical electronic hardware and virtual software simulations and control modules. In parallel with individual physical devices, digital models can be constructed in order to create digital twins of designs. In turn, these virtual forms can be integrated with simulations of dynamic mechanisms and sensor networks, creating a wide range of interactive architectural constructions.

Living Architecture Exploration kits have been distributed and used at many locations including the University of Waterloo, University of Indiana, Domaine de Boisbuchet, Poitiers, France; LAUNCH Waterloo, Canada; and TU Delft. Users have ranged from grade school students to adult workshop participants. The exploration kits are continuously evolving to accommodate new design objectives and user groups.

Engagement Scenarios with Visitors & Users

Facing Page

Futurium Noosphere testbed, Berlin, 2021

The Delft Science Center testbed and its accompanying kit programming is being designed for a series of different kinds of visitors and users. These range from informal, unscheduled public visits, scheduled performances and guided educational visits, to student connections through workshops and coursework, and advanced research and collaborative development by artists, designers, scientists and engineers.

The LASG testbed provides an engaging entry point to discuss a variety of topics in Biology, Mathematics, Programming, Art, Architecture, Design, and Engineering that are engaged in the testbed's conception, creation and operation.

The following provides a brief outline of how these topics can be engaged with different audiences through interaction with the testbed, supported by kits and programming.

Young Students

Introductory Demonstrations

Target Audience: *Elementary Students (7-14)*

Above

Grade 7 and 8 LASG STEAM curriculum explorations, Palestine, Texas, 2016

Facing Page

Sibyl, Sydney Biennale of Art, 2012

Scheduled groups of students, led by a knowledgeable expert, are introduced to the testbed and invited to explore it in specific ways through a variety of interactive demonstrations, and through tactile play with geometry kits. Activities and discussion are facilitated according to a designed curriculum, at a level appropriate for the visitors. Introductory demonstrations might include the following:

- *A Guided Demonstration of the Testbed*
- *Identifying and discussing the properties of primary geometric shapes (Hexagon, Pentagons, Squares etc.)*
- *Exploring Geometric concepts like pattern making and tiling using geometry kit components.*
- *Exploring how 2D geometric patterns (nets) can be folded up to make 3D shapes.*
- *Discussing how geometric shapes can be applied in Art, Architecture and Engineering to create complex systems*
- *Exploring the application of artistic principles (color, shape, texture, light, composition) and their use in creating mood and atmosphere*

Teens

Intermediate Explorations & Worldmaking

Target Audience: *Highschool Students 14-18*

Scheduled groups of students, led by an expert, are invited to explore the ecosystem of the testbed through guided activities and simple interfaces. These demonstrations and activities would highlight how knowledge from the fields of Science, Technology, Engineering, Art, and Mathematics combine to create works of Living Architecture. Groups could begin to develop a deeper understanding of the physical and digital systems that make up the testbed through the following kinds of activities:

- *Exploring the testbeds Influence Engine parameters using a desktop actuator field and simple user interface on a phone or tablet.*
- *Engaging in the creation and assembly of medium size scaffolds and assemblies (like the archimedean polyhedra) with the geometry kit components.*
- *Explore how electrical systems are used in the testbed by engaging simple desktop circuits with switches and actuators.*
- *Participate in transformative fabrication processes (like thermoforming) that demonstrate how an understanding of material properties can be used to create evocative forms*

Facing Page

Endless Beginnings, Endless Connections workshop installation using LASG exploration kits, Domaine de Boisbuchet, 2021

University Students
Focused Engagement & Advanced Skills

Target Audience: *18+ Undergraduate Students*

Advanced students, collaborating with faculty, are prompted to engage with the sculpture on a deeper technical level as part of targeted workshops, or coursework in related classes. Longer-term and more in-depth than a guided educational visit, this would be a faculty-supervised and collaboratively-developed curriculum offering opportunities for students to create material related to the piece at a level appropriate for their expertise, from form-making to the integration of experimental electronics, or scripting of behaviour states. Such an engagement would be bounded in time and organized by the faculty. Similar in scope to prior Interactive Environments Minor engagements, these workshops might involve:

- *Enhancing the experience of the piece with augmented reality in the context of a data-visualization course.*
- *Augmenting the virtual world of the testbed's Living Shadows through the creation of new virtual entities deployed in a game engine. Done in the context of a game-design or animation course.*
- *Integrating experimental electronics from coursework with the testbed behaviour infrastructure to create new experiences.*
- *Developing integrated assemblies composed of a scaffold, actuators and tuned behaviours, using the ecosystem of exploration kit.*

Facing Page

Exploration of polyhedron kit forms by students of the Interactive Envirionments Minor workshop TU Delft 2023

Advanced Collaborations in Research & Creation

Target Audience: *Researchers & Artists*

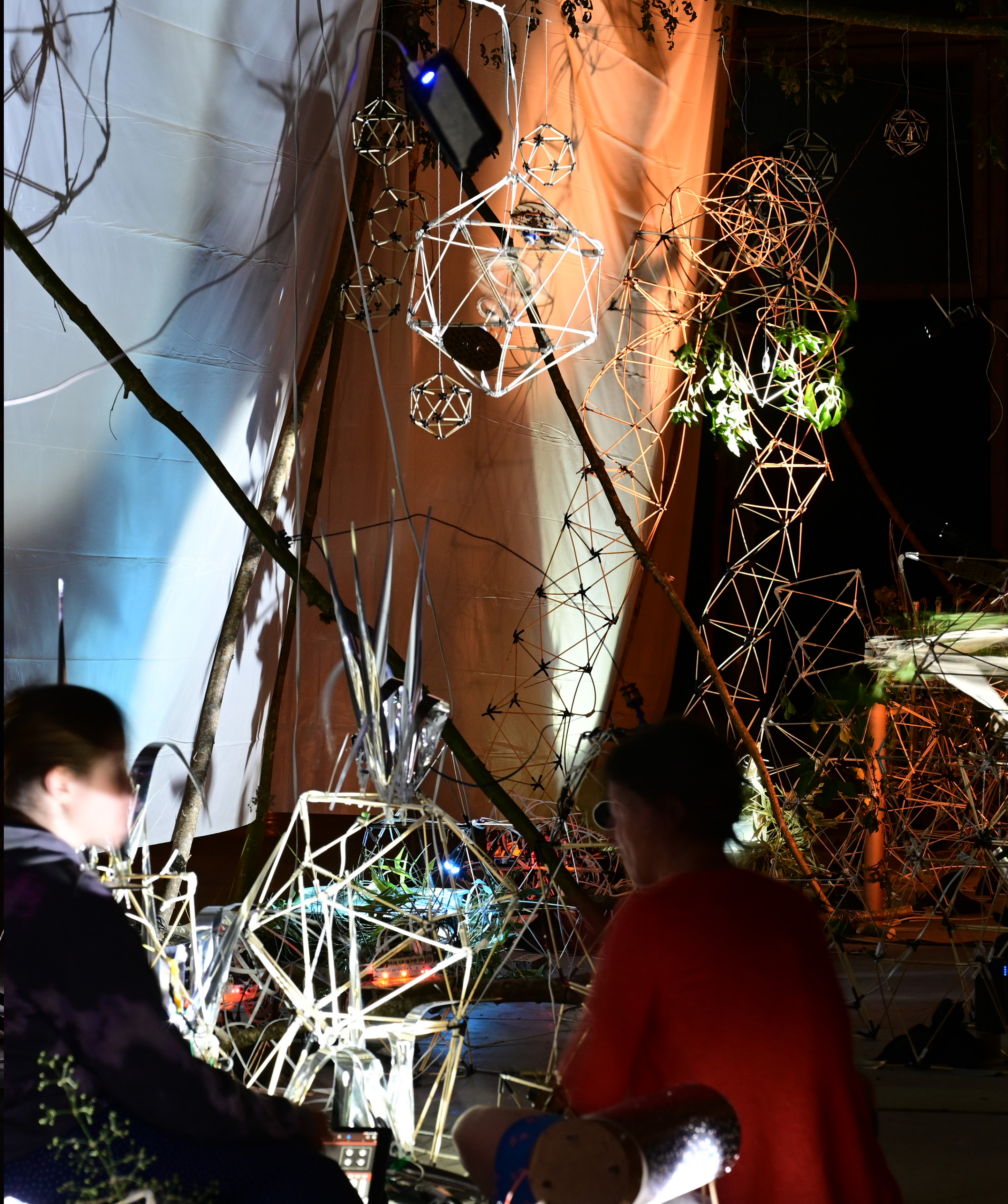
Facing Page

Examples of collaboration between researchers and artists at the TU Delft Interactive Environments Minor Workshop. Delft, Netherlands, 2022

Following Page
Left & Right

LASG exploration kits were used to produce sound and light performances, Shadows and Whispers workshop, Domaine de Boisbuchet, 2022

Professional researchers (professors, post-doctoral students, etc.) or artists (musicians, dancers, filmmakers) can explore integration of specialized research and art practice within the testbed and its environment. Researchers engage with the testbed's infrastructure, and accompanying kit materials to explore and make contributions to the digital and physical ecosystem of the Living Architecture Testbed. Artists can create compositions with the piece's performative capabilities. These deeply integrated collaborations are driven by the ongoing research or artistic interest of the collaborator, and occur in close consultation with the testbed creators to develop and enhance the expressive qualities and technical systems of the work. This may result in public performances, co-authored papers, or other academic dissemination.

Riverview High School STEAM Curriculum

2021-24 description by Ian Fogarty

The following descriptions were made with high school students creating a new series of interactive LASG systems at Riverview High School, New Brunswick.

Many biological systems,like schooling fish, act as independent individuals making their own decisions but appear to behave as one sentient organism. How might we code such a thing in our installation to give a perception of life and thought? We used some theatre and improv exercises for students to act out different emotions. They made some graphs on how we might codify different emotions. They used custom designed software to help design a light profile to control how and when lights might turn on and off. We can add different sensors to the installation to make it sense and perhaps seem intelligent. Do we want the light pattern to be one way if it is quiet and a different way if it is loud? Or perhaps a light pattern would be triggered if a person stands in one location.

The LASG built custom circuit boards that would read the sensors and trigger the light pattern. Students were required to develop an understanding of electrical engineering of the sensors and soldering parts to the actual board. At the present, we are becoming expert solderers as we build the customized microcontroller circuit boards, build customized LED resistor combinations and start to wire the inside of the art. Rather than hiding the electronics, students are having conversations about making the electronics part of the art that might resemble nerves and ganglion, and the flashing lights might mimic active nerves. Students first used cardboard to draft their initial ideas of the structure.

Facing Page

Students exploring lasercut interlinking chevron forms and pattern language as part of Riverview High School's STEAM Curriculum, Riverview, New Brunswick, 2023

Centre for Architectural Structures & Technology

LASG Workshop, 2020

The CAST-LASG Workshop was a week-long collaboration between the Living Architecture Systems Group and the Centre for Architectural Structures and Technology (CAST) at the University of Manitoba in Winnipeg, held February 17-22, 2020. The workshop focused on the terminology and form-language of polyhedral and related geometry, culminating in the design and installation of a lightweight architectural scaffold which integrated CAST's ongoing experiments concerning fabric as formwork for liquid-to-solid casting and shell structures. A new form-making method was advanced during the development of the scaffold installation, by which basic hexagon-to-pentagon geometries were scaled up to produce dramatic changes in surface curvature. The workshop was preceded by preparatory talks and instructional folios as well as an introductory lecture by Philip Beesley.

The Centre for Architectural Structures and Technology at the University of Manitoba is an interdisciplinary research laboratory embracing technical and poetic dimensions of making. CAST provides equipment and conditions for critical and creative experimentation with technologies contributing to the design, construction and performance of the built environment.

Facing Page

Archimedean Polyhedron kit explorations at CAST Workshop, School of Architecture, University of Manitoba, 2020

Shadows And Whispers: Emerging Forms At The Edges Of Nature

Domaine de Boisbuchet Lessac, FR 2022

Shadows and Whispers: Emerging Forms at the Edges of Nature was a workshop that produced an environment mounted in the natural landscape of the Domaine de Boisbuchet in Lessac, France. The workshop brief suggested that within whispering sounds, new voices might be heard, and within glimmering shadows, dream-like worlds might be seen. What can we learn from the patterns of nature and, in reverse, what can we offer nature? Could the subtle boundaries between artificial and natural worlds hold keys to new kinds of harmony in our expanded, turbulent world? Workshop participants created an interwoven new world operated with the support of technical and digital devices and installed within Boisbuchet's unique architecture and nature.

The final environment consisted of a projection screen, sound and lighting devices, and The kinetic installation contained microprocessors and devices from the LASG's customized electronics system. Four construction kits including introductory stations, scaffolds, geometry explorations, and electronics hardware and software were combined to support the exploration and creation of polyhedra, geotextiles, and truss systems, activated by electronics and sound. Patterns of movement, clapping, whispering, and singing led to phased overlapping systems. These collective exercises were accompanied by talks and explorations. Talks reflected on elemental patterns that move from mineral and inert states into sentient living matter. In the final installation, fields of new space were created by using artificially created sounds and tones, interwoven with lights and shadows.

Facing Page

Sound and light performance at the Shadows And Whispers workshop,

Robotic Speculations Workshop

TU Delft Interactive Environments Minor 2023

Robotic Speculations was a workshop presented by the Living Architecture Systems Group (LASG) with Delft Science Centre and the Interactive Environments Minor of TU Delft in 2023. Multiple components for fabrication, software and behaviour control systems developed by members of the Living Architecture Systems Group were tested and developed during intensive sessions involving multidisciplinary teams of students and interactive-systems researchers.

The workshop asked how can we use interactive environments to bring stakeholders from the international airport of Schiphol in Amsterdam on a speculative journey to reimagine robotic possibilities. A student-built immersive interactive environment was based on a system of structures invented by Philip Beesley and the Living Architecture Systems Group, programmed with behaviours inspired by conversations about baggage handling at Schiphol. An initial design was used to spark discussion, from which students created new behaviours to redesign the ecosystem based on shared imaginaries.

A manual accompanied the workshop describing the electronic components and software, describing recommended connections between "control" boards, motors, lights and sensors. By following the recommended connections, the electronic components can be flexibly arranged in a wide variety of different configurations. This mount system includes cable-tie attachments that support precisely angled locations within the skeletal scaffold. A slotted tray design accommodates a range, of component mounts. Descriptions of software include the "profile" configurations used to customize how the physical electronics behave. This software will allow you to plan out physical configurations and simulate larger systems on a virtual canvas.

Facing Page

Demonstration of student work at the culmination of the Interactive Environments Minor workshop, 2023

Learning to Engage: An Application of Deep Reinforcement Learning

Lingheng Meng PhD Dissertation, University of Waterloo, 2023

Physical agents that can autonomously generate engaging, life-like behavior will lead to more responsive and interesting robots and other autonomous systems. Although many advances have been made for one-to-one interactions in well controlled settings, future physical agents should be capable of interacting with humans in natural settings, including group interaction. In order to generate engaging behaviors, the autonomous system must first be able to estimate its human partners' engagement level, then take actions to maximize the estimated engagement. In this thesis, Living Architecture Systems (LAS), architecture scale interactive systems capable of group interaction through distributed embedded sensors and actuators as a testbed are studied by appluomg Deep Reinforcement Learning (DRL) treating the estimate of engagement as a reward signal in order to automatically generate engaging behavior. However, applying DRL to LAS is difficult, because of DRL's low data efficiency, overestimation problem, and issues with state observability, especially considering the large observation and action space of LAS. The study proposed an approach for estimating engagement during group interaction by simultaneously taking into account active and passive interaction, and used the measure as the reward signal within a reinforcement learning framework to learn engaging interactive behaviors. The proposed approach was implemented in a LAS in a museum setting. The study compares the performance of the learning system to that of a baseline design using pre-scripted interactive behavior and includes analysis based on sensory data and survey data.

Facing Page

Reinforcement learning doctoral study was undertaken by Lingheng Meng with user testing conducted at Meander, Tapestry Hall, Cambridge, Ontario, 2022-2023. The sculpture was configured with Machine Learning, seeking to optimise viewer interactions and interest.

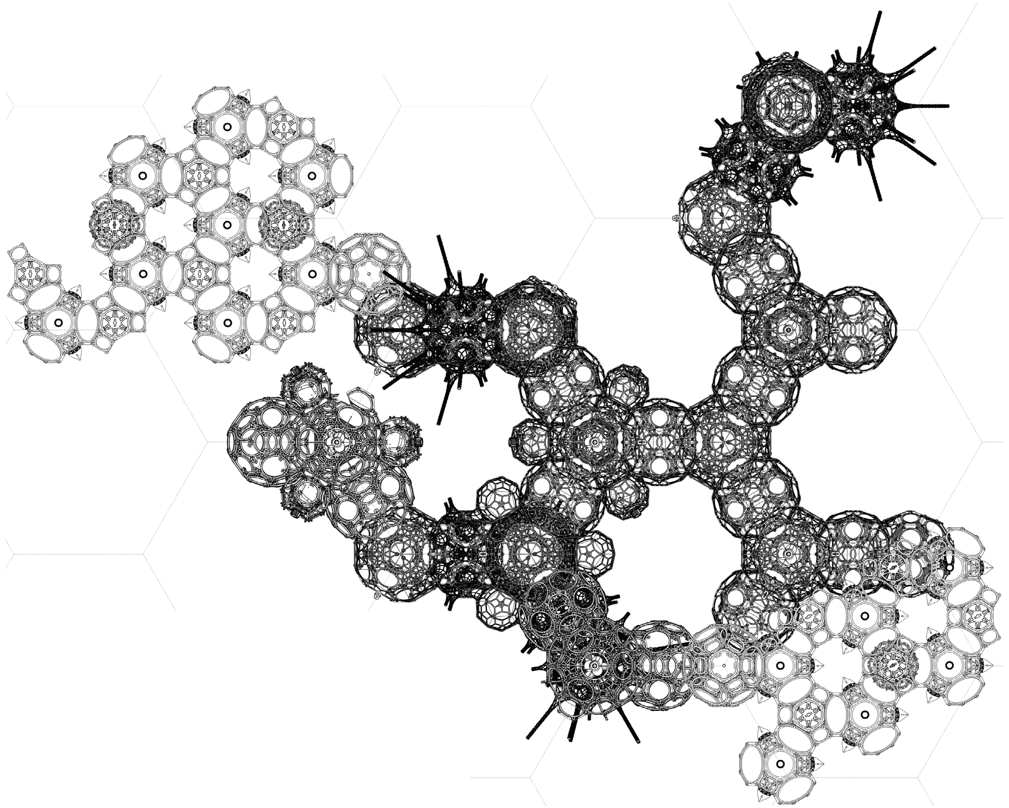
Living Cell Systems Exploration Kit

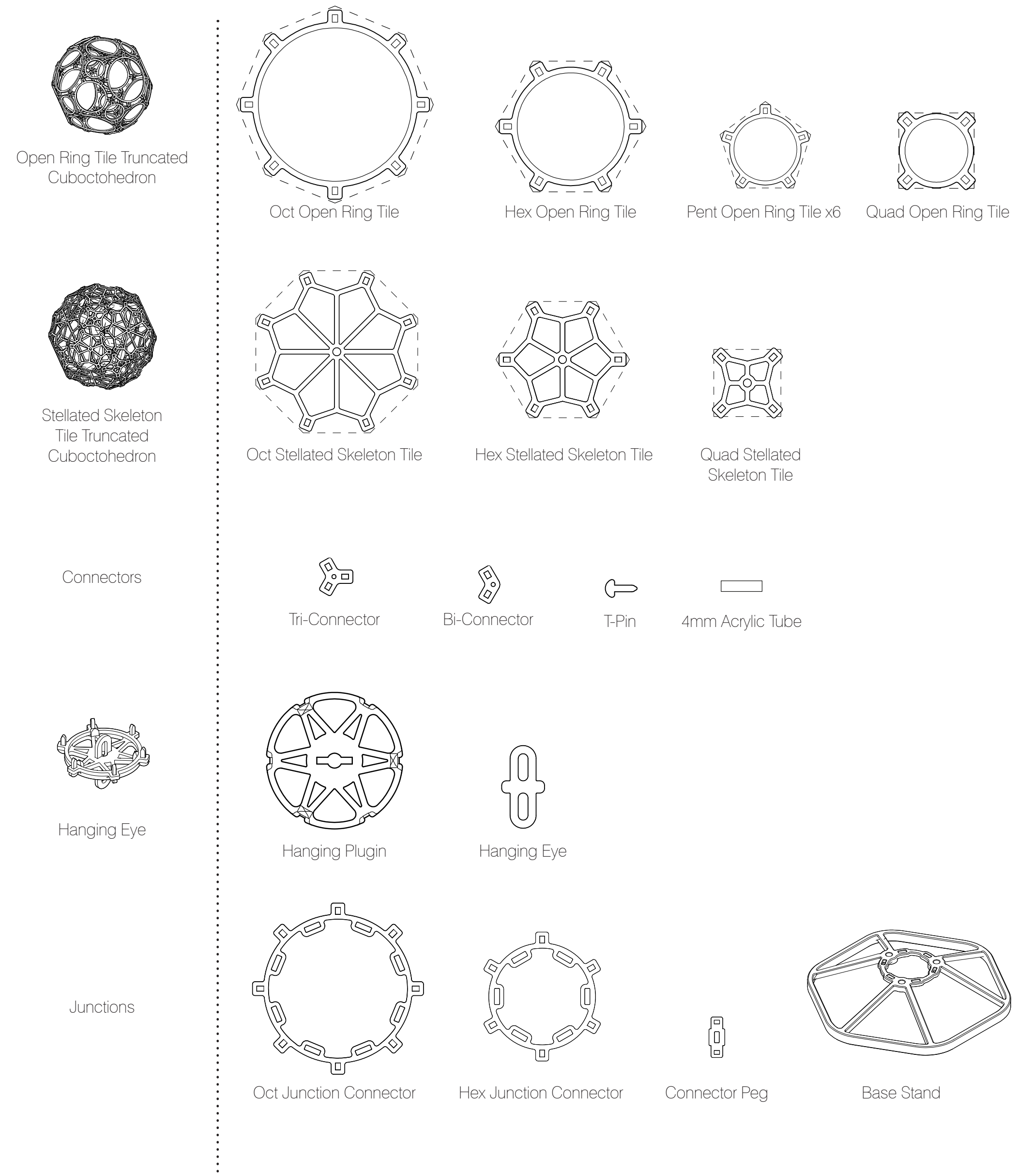
Living Cell Systems is the most recent series of LASG exploration kits. These systems can be used in the creation of responsive architectural envelopes and canopy structures. Living Cell Systems kits are based on simple printed and laser-cut skeleton polygon tiles that can be attached together in order to create cells. Assembled cells are made from combinations of polygonal skeletal units that can be combined in a variety of ways, creating garland-like chains, lattices, membranes, complex shells, and other expressive, functional structures. This versatile scaffold system is designed to support the attachment of many kinds of devices. Encapsulated cabling and microcontrollers are included, providing a comprehensive interactive system.

In the following pages, the Living Cell Systems kit is illustrated. The first section includes combinations of individual polygon skeleton units that make up physical scaffolds. The second section illustrates actuators and sensors. Sound, light, and motion devices can be plugged into the kit system, including lashes, vibrating fronds, and LEDs. Sensors include infrared motion detectors. Tray systems are provided permitting plug-in assembly of groups of actuators and sensors, supporting table-based exploration. In the following section of integrated assemblies complex assemblies are populated with actuators and sensors. In the final section, control systems are described including software, hardware, and interfaces. The software-based behavior controls within the Smart Cell system outlined here support crafting and tuning of expressive sequences of light, motion and sound.

Geometry & Scaffolds

The geometry & scaffolds portion of the Ecosystem of Exploration kit is composed of modular 3D printed components based on the set of regular polygons. Participants can use these components to explore patterns, tilings and form-making. They can be combined in free-form exploration, or used to create foundational geometric forms like the Platonic solids and Archimedean Polyhedra. Through the act of making, participants can develop a tactile understanding of how polygonal tilings can create varied curvatures and forms, and create scaffolds for further exploration.

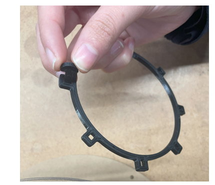


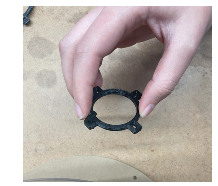


Scaffold Components

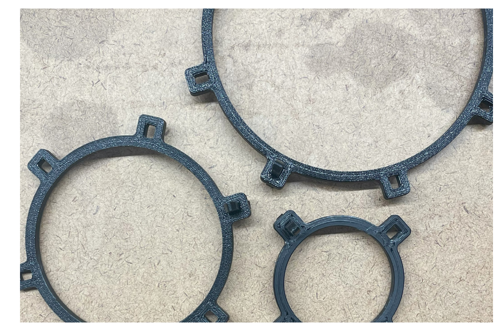
Ring Assembly Instructions

Step 1
Place T-pins into ring holes

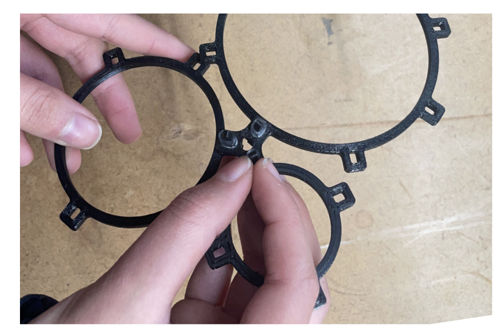


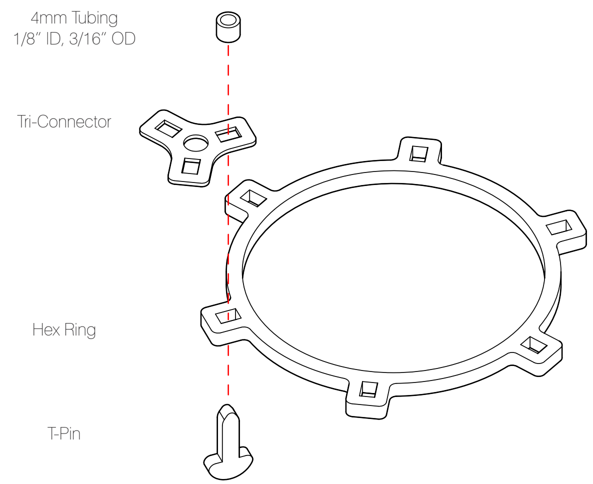


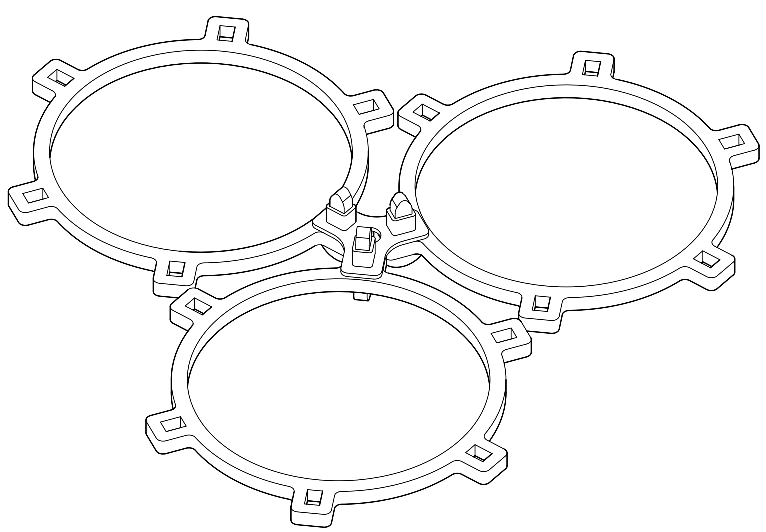

Step 2
Attach the rings together by placing a tri-connector over the t-pins



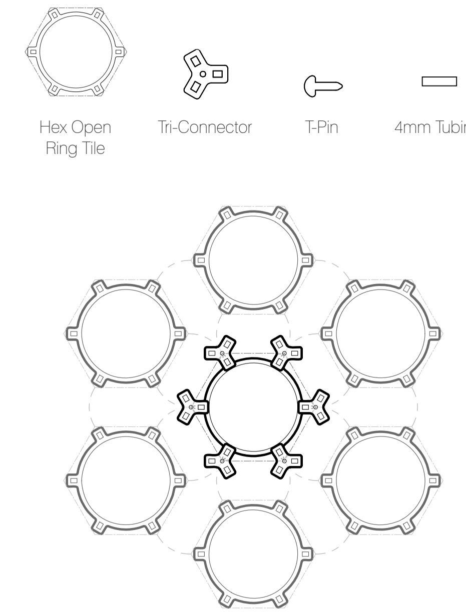

Step 3
Place a 4mm acrylic tube over the end of each T-pin to secure it in place

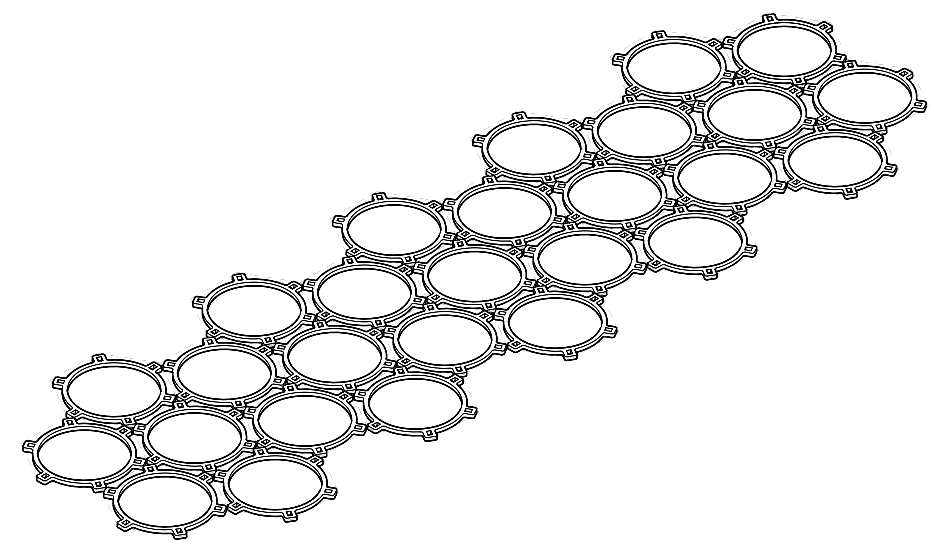


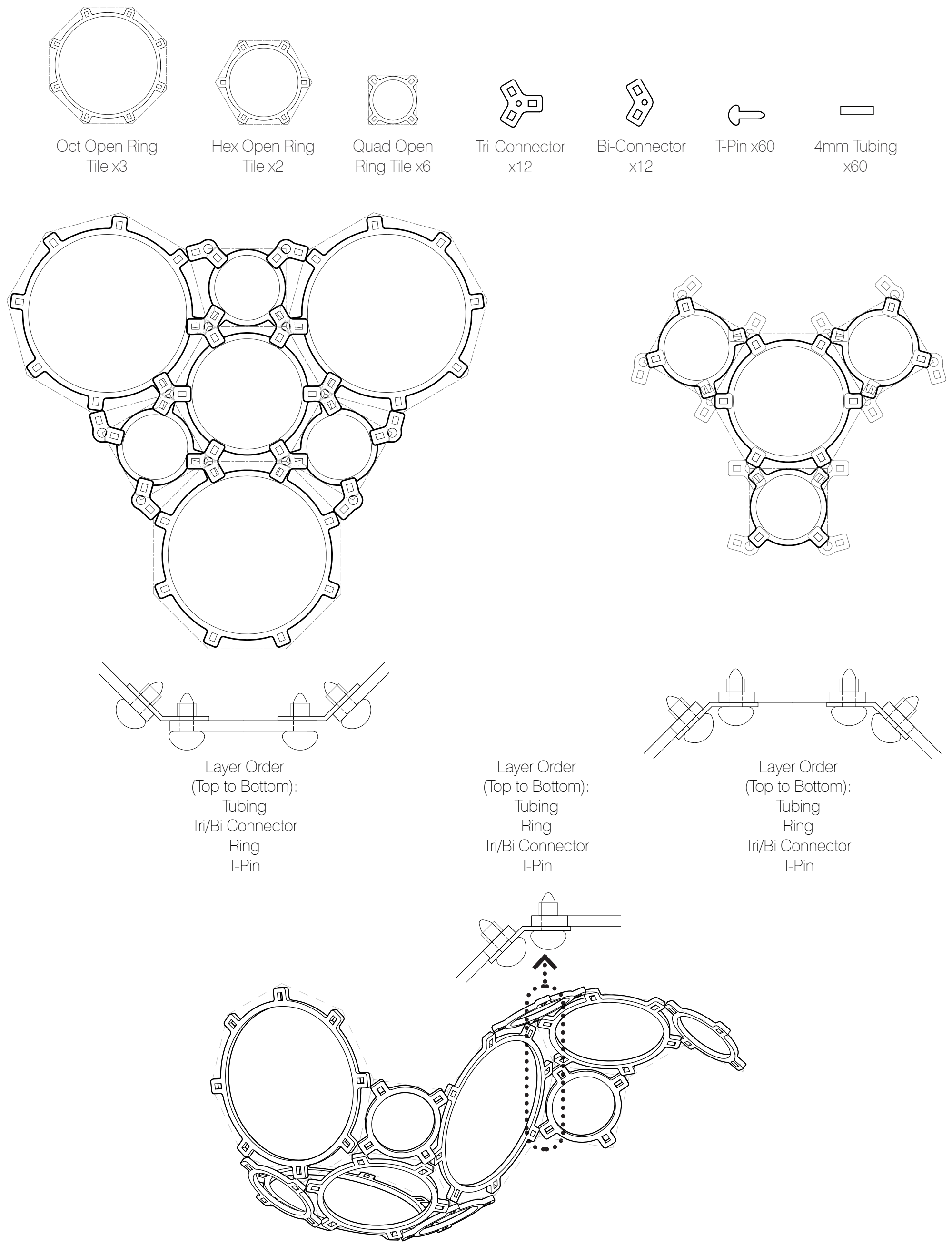


Connector Assembly

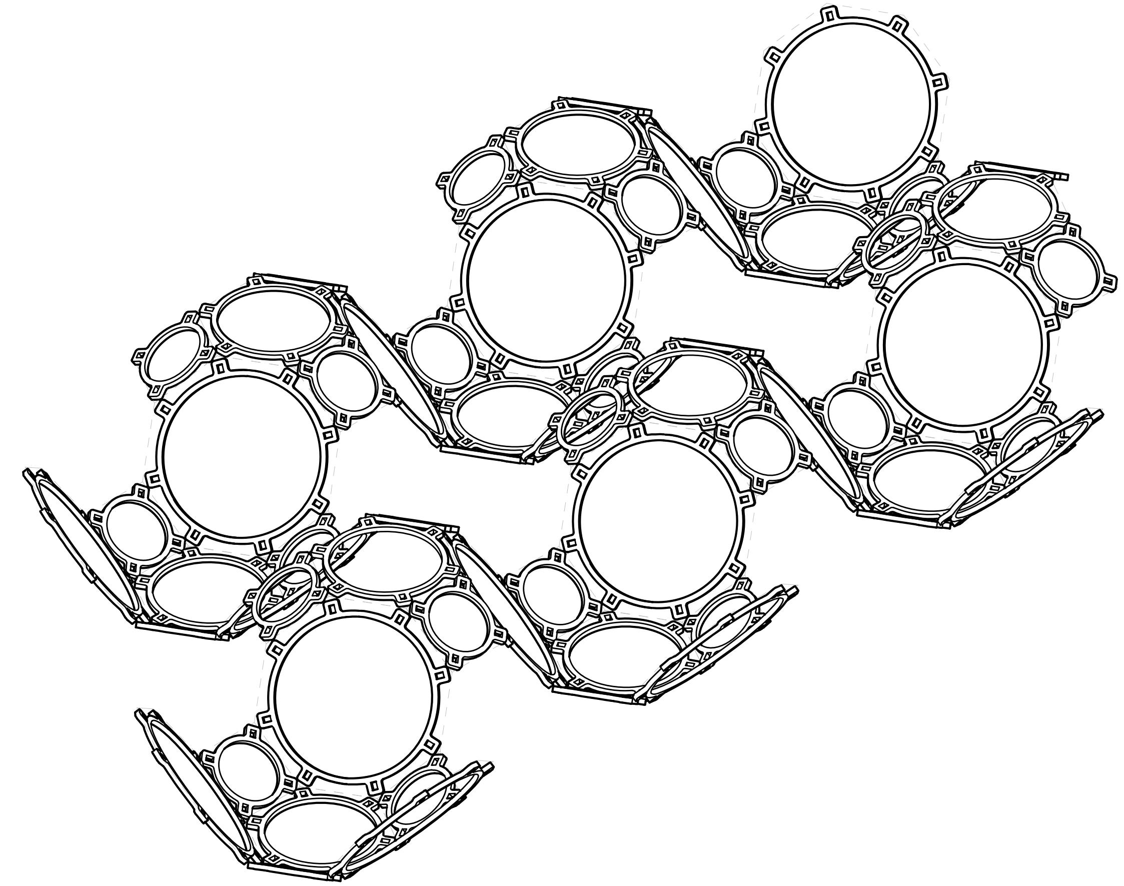




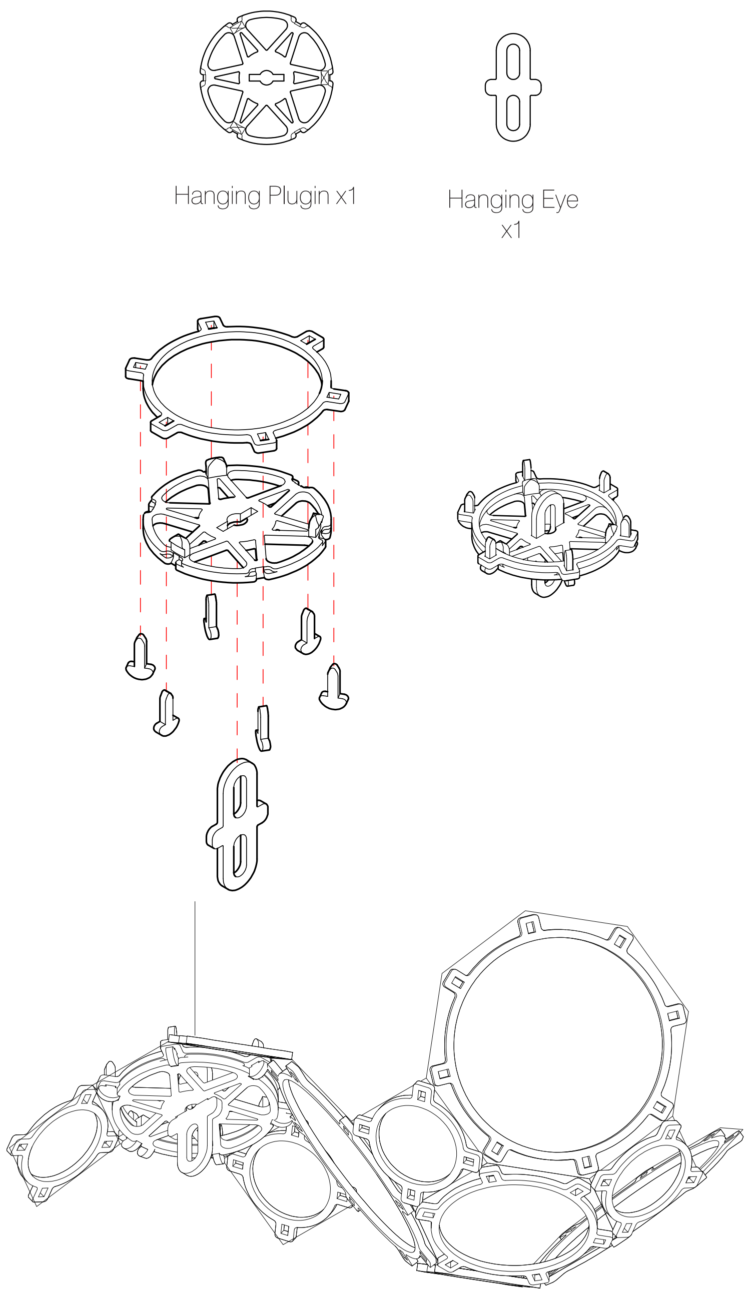
Hexagon Tiling



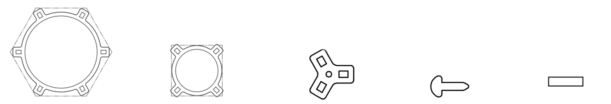
Truncated Cuboctohedron Waffle Unit

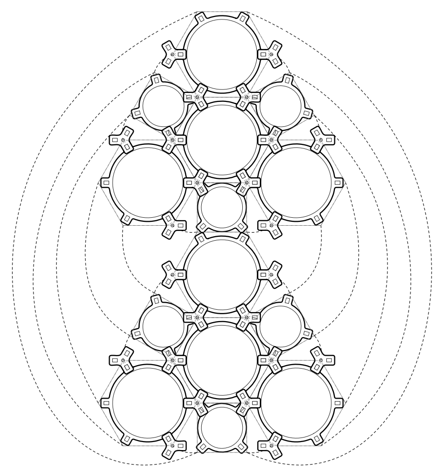


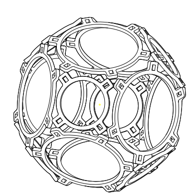
Truncated Cuboctohedron Waffle



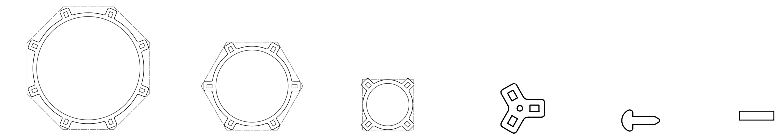
Hanging Point

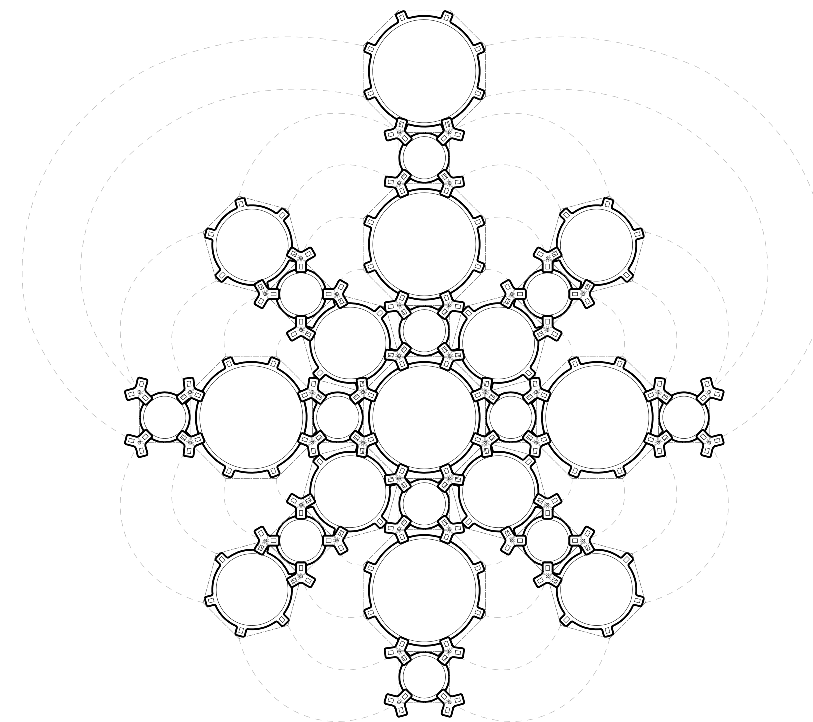


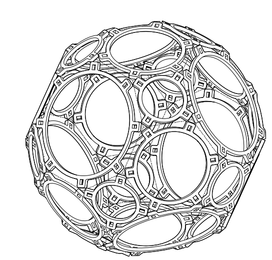




Truncated Octohedron







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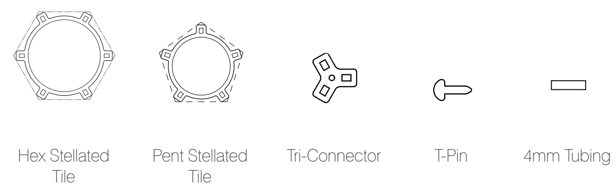
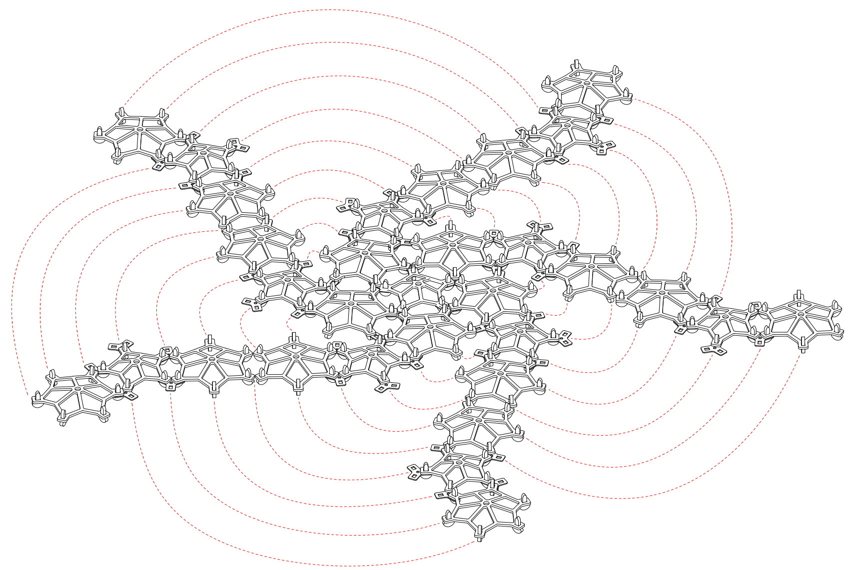
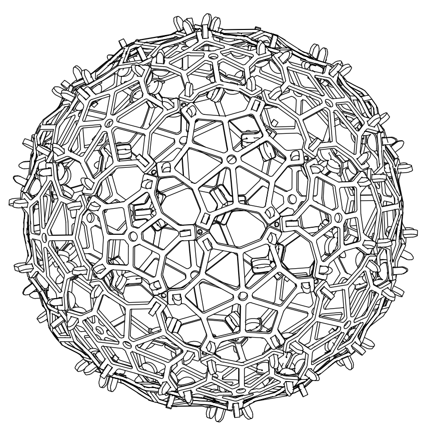
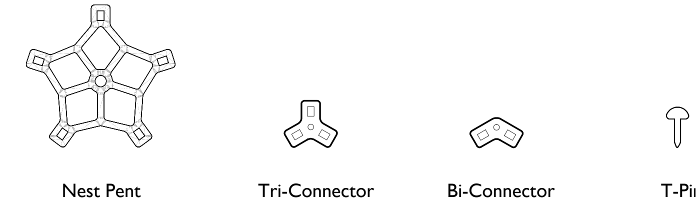
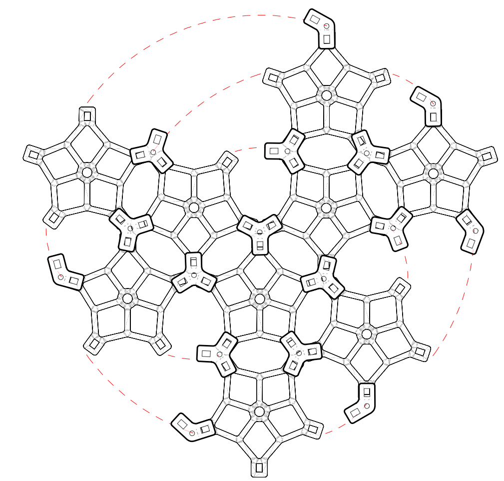


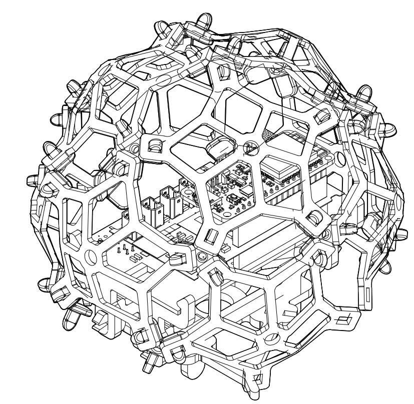




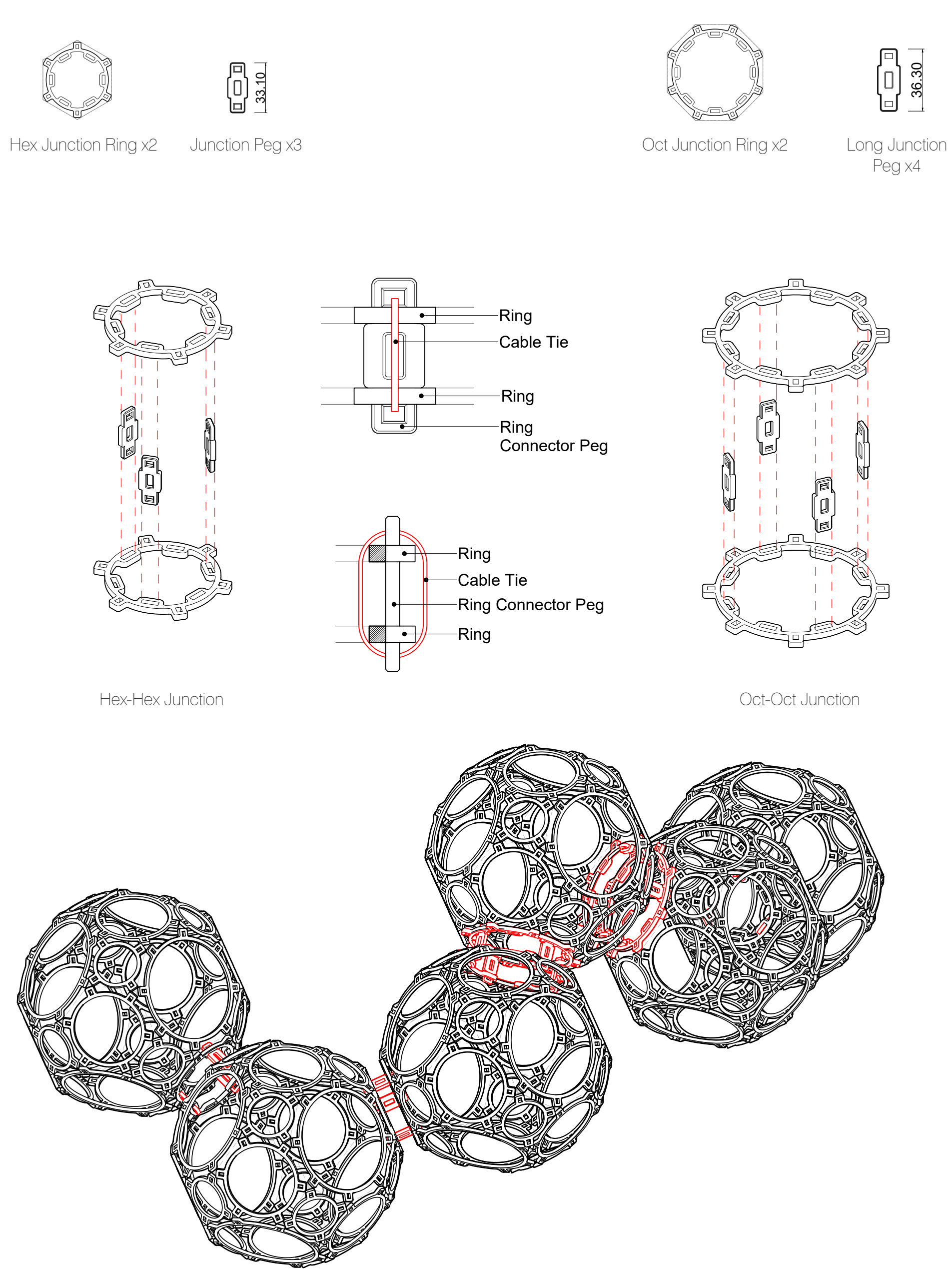
Truncated Icosahedron



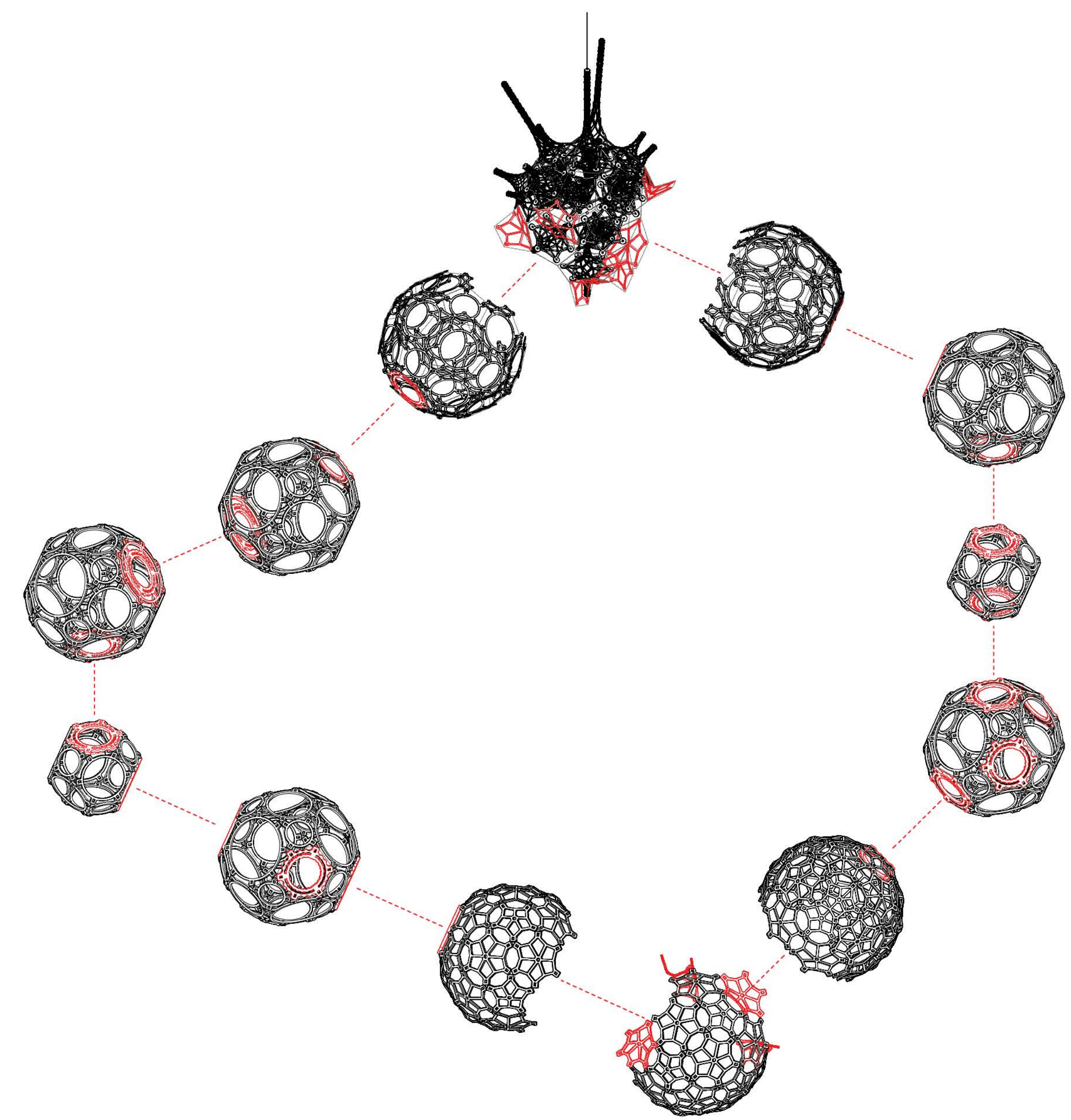




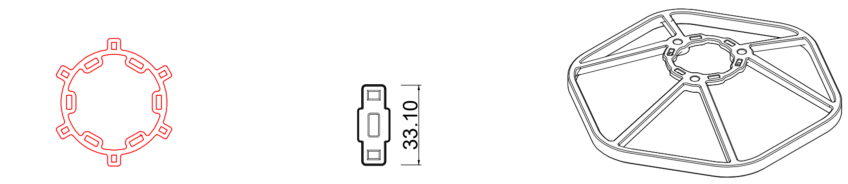
Dodecahedron Nest Scaffold

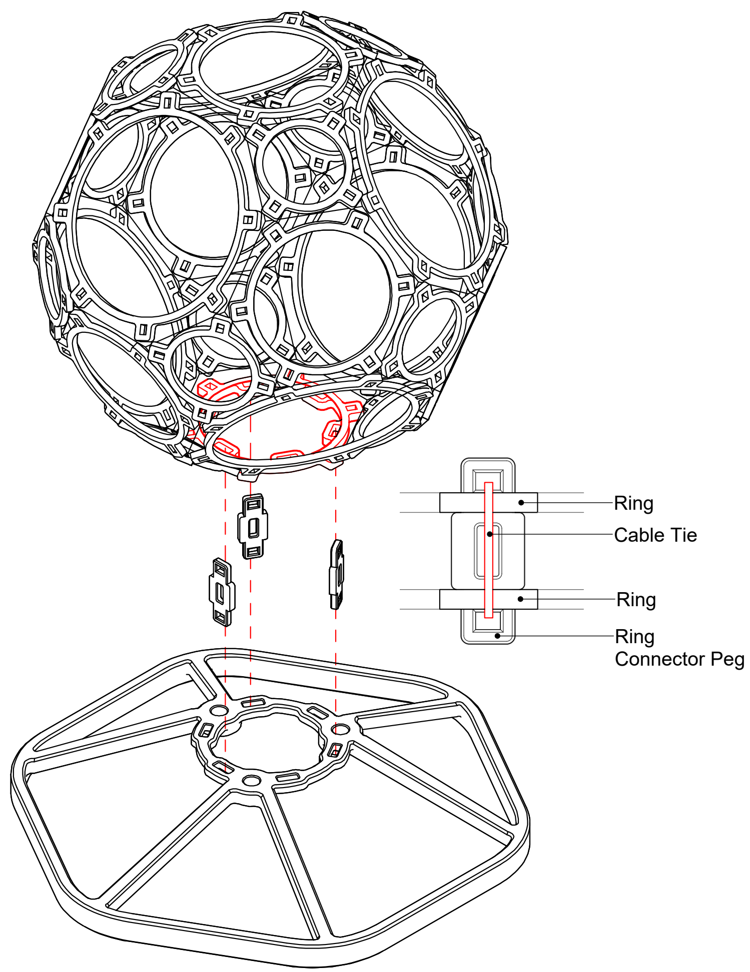


Sphere Junction Rings

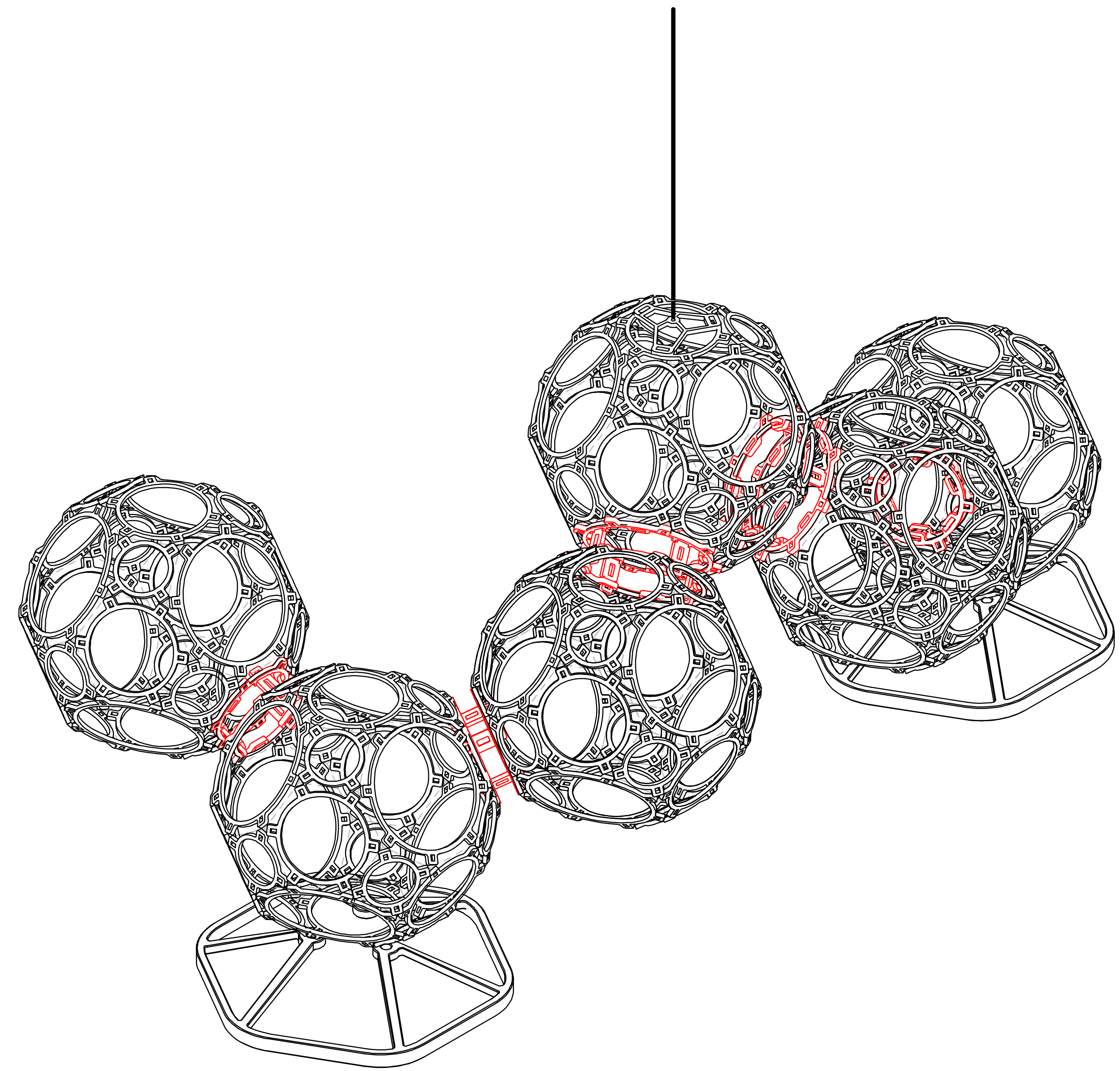


Sphere Junction Types

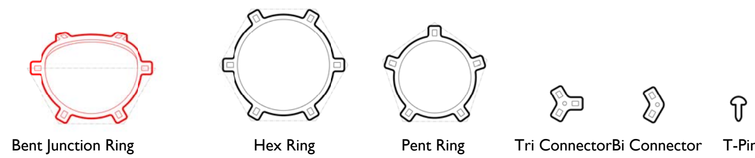


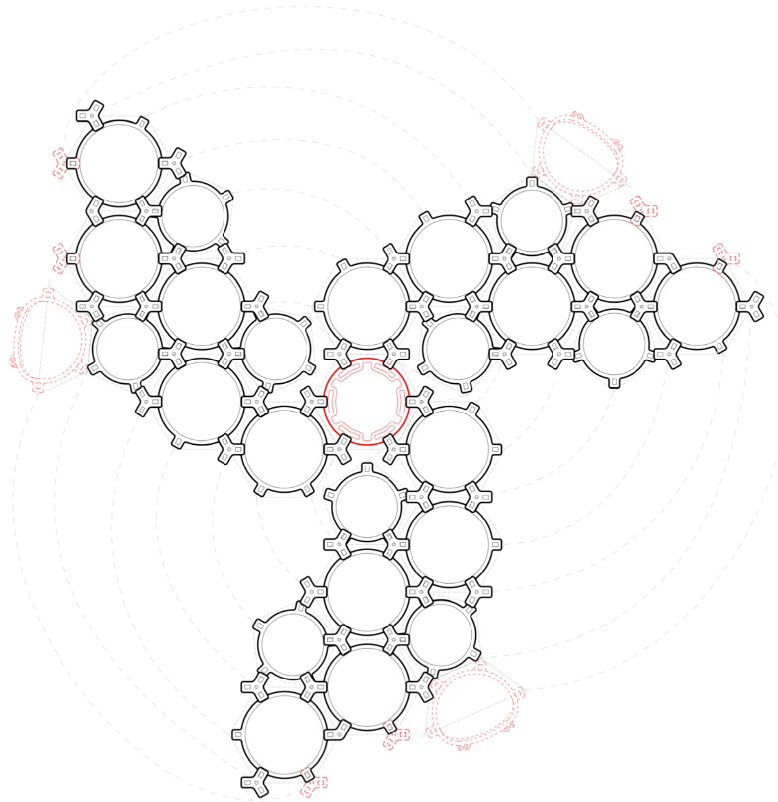


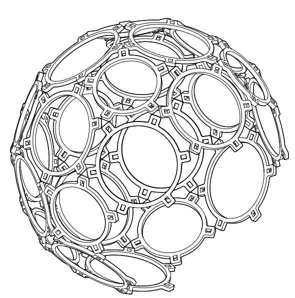
Base Stand



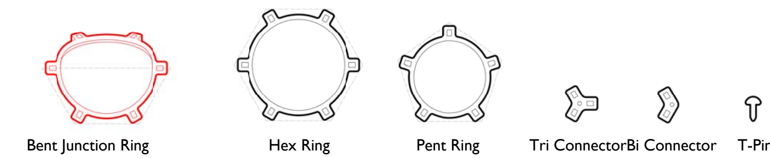
Base Stand Assembly Example

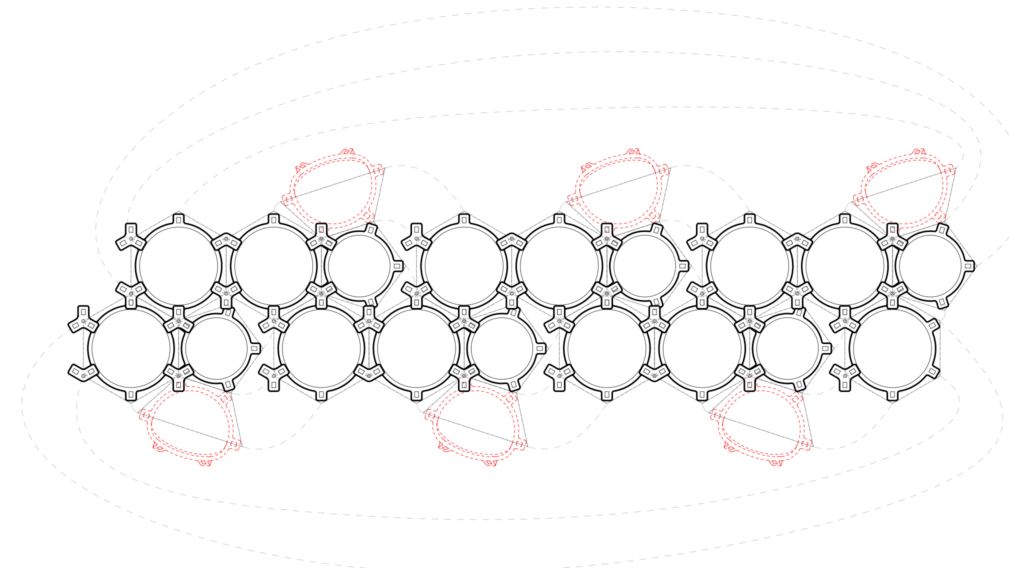


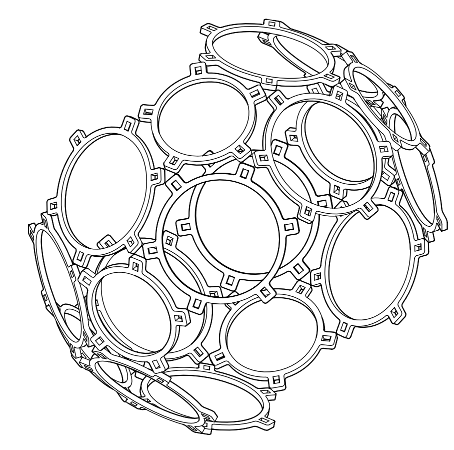




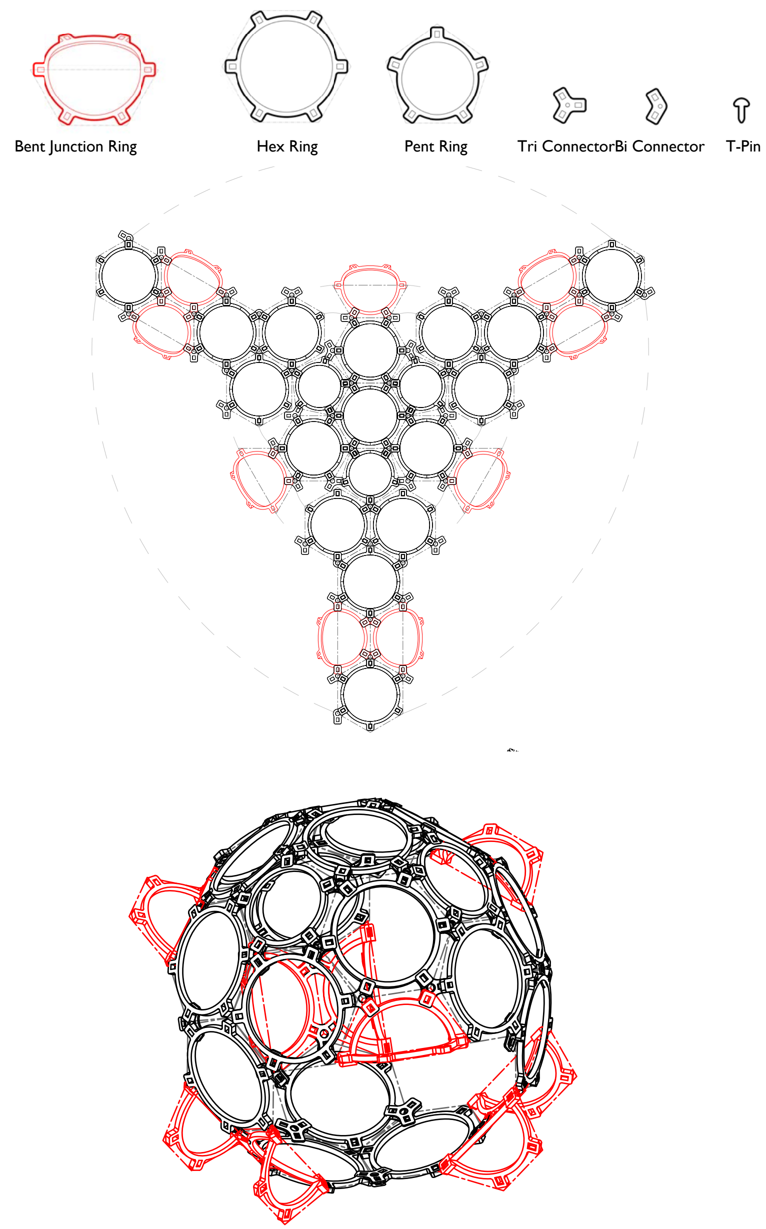
Truncated Icosahedron Terminal



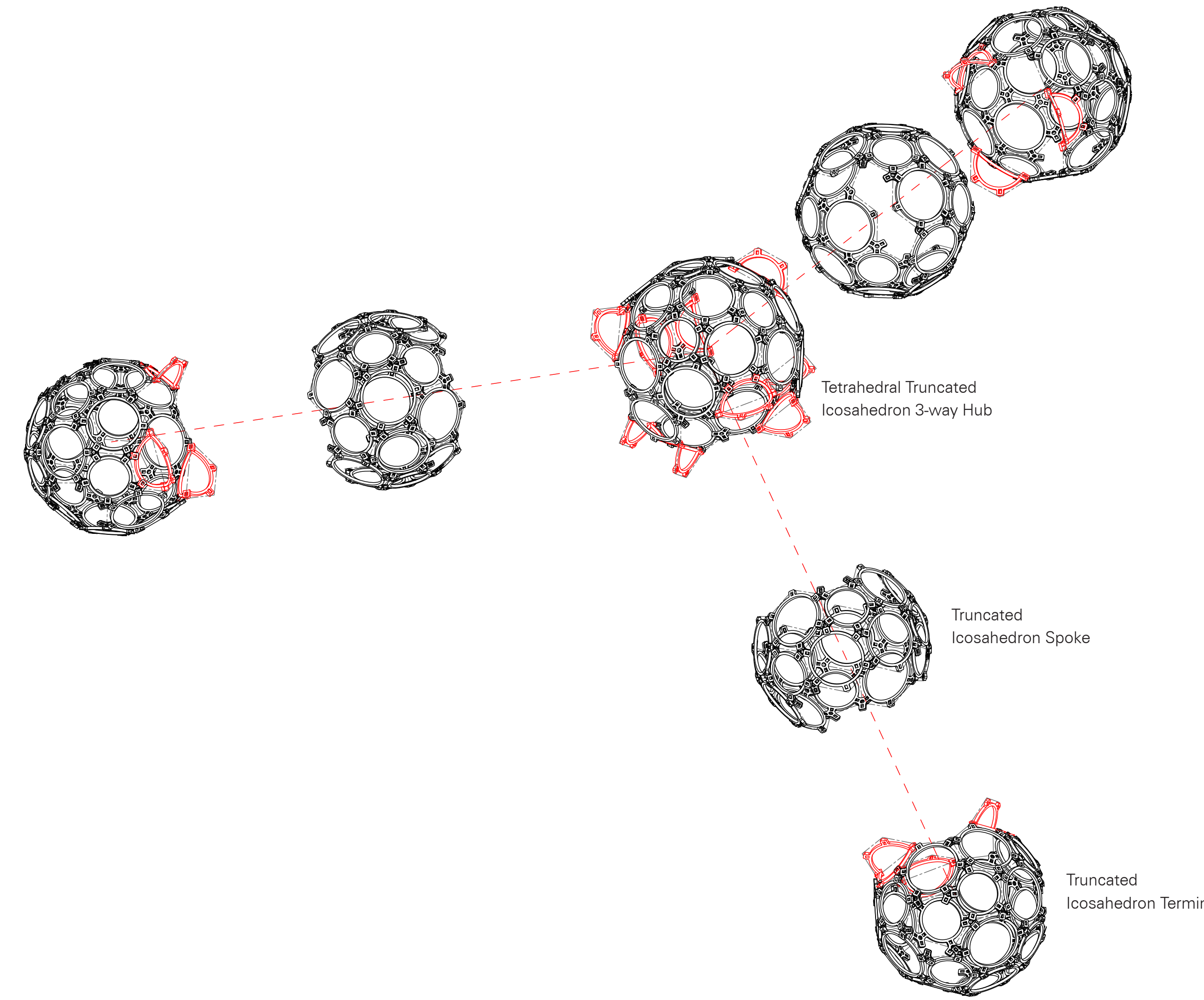




Truncated Icosahedron Spoke Scaffold



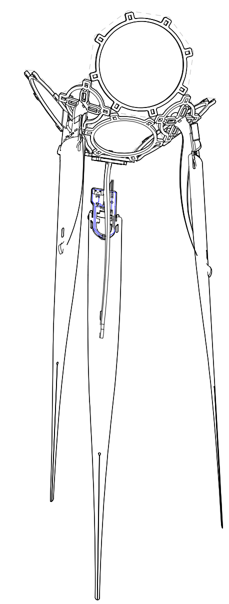
Tetrahedral Truncated Icosahedron 3-way Hub Scaffold

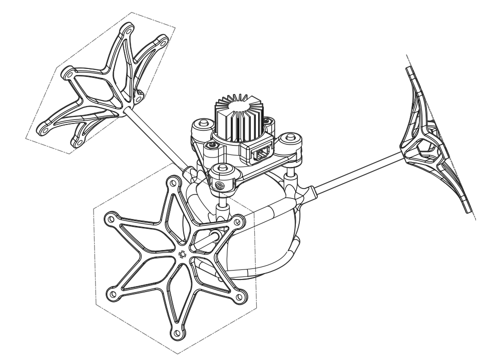


Sphere Triad Assembly

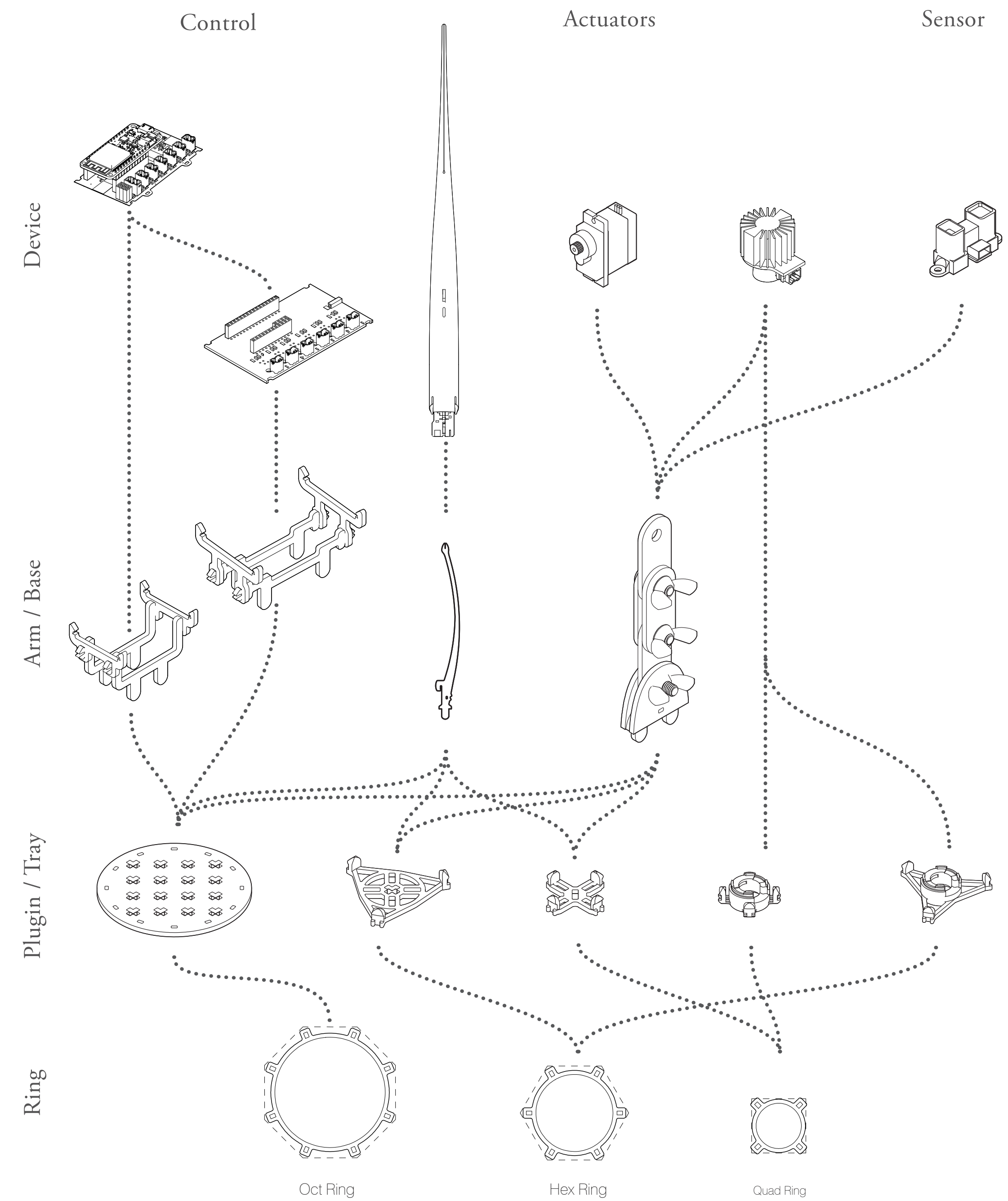
Actuators & Sensors

The Actuators & Sensors included in the kit provide the building blocks to explore responsive behaviours through expressive motion, light, and sound. Actuators can be set up in simple demonstration circuits controlled with switches and push buttons, or connected to the digital ecosystem of the larger testbed through a node controller.

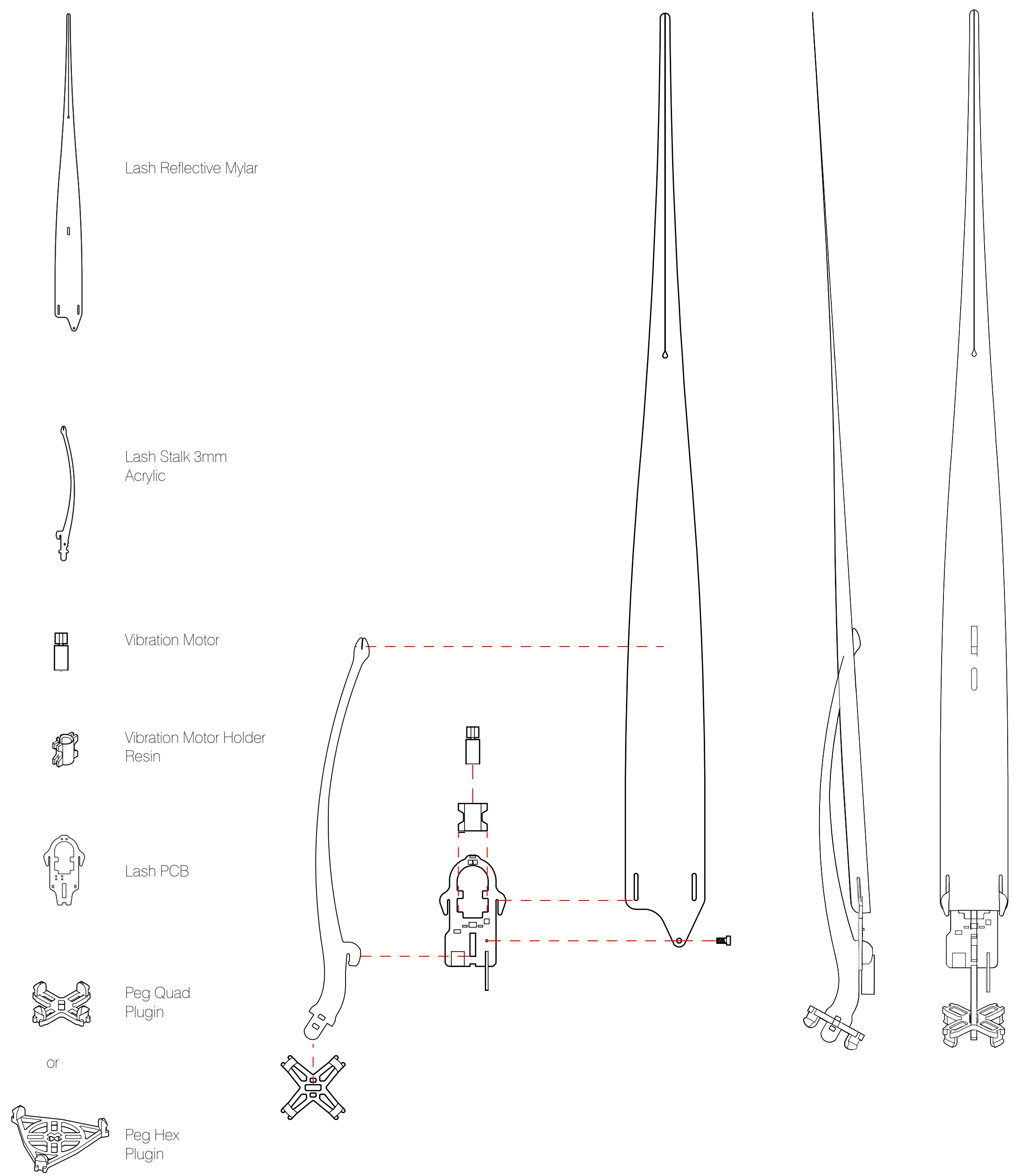




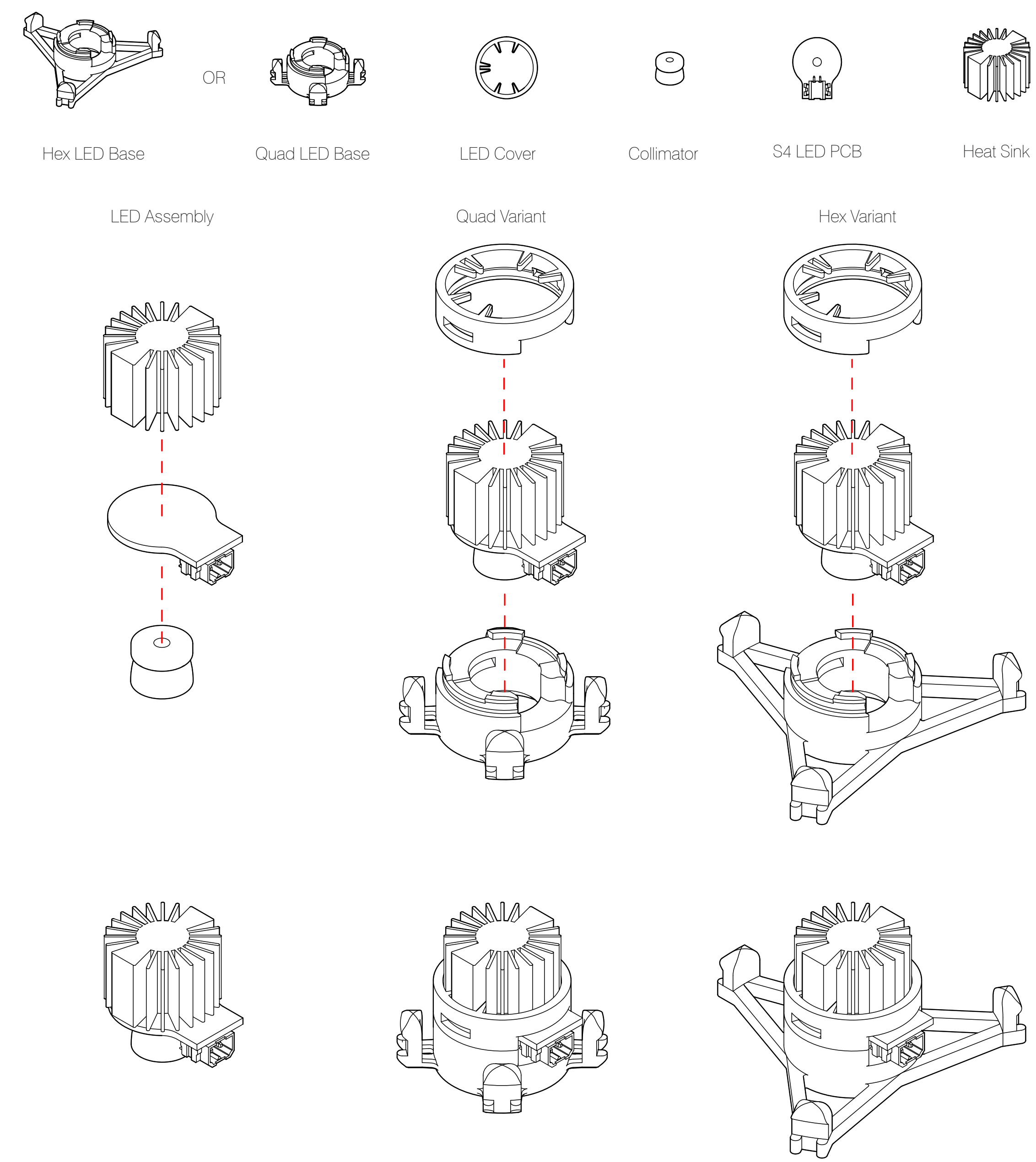
Actuator and Sensor Components



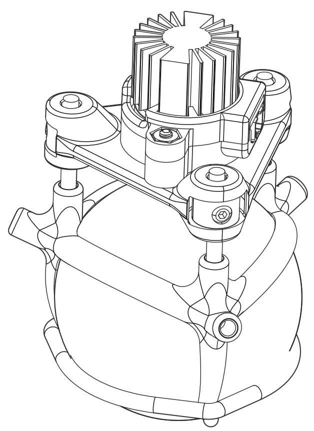
Device Attachment System



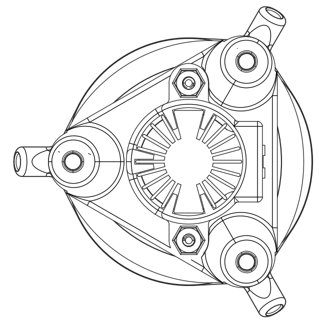
Vibrating Lash



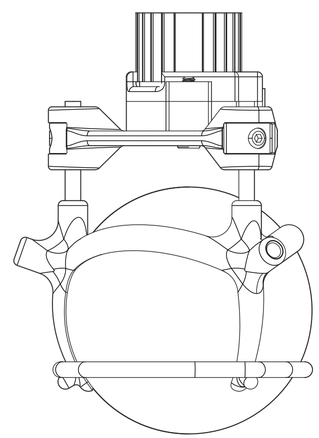
LED Light



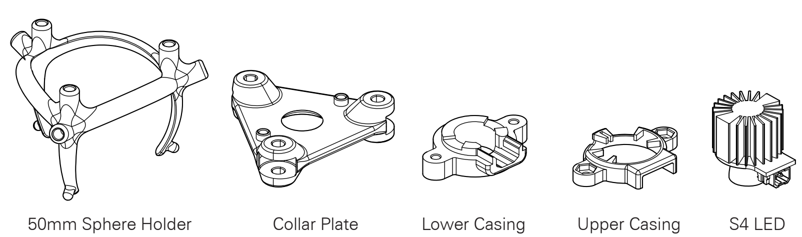
Isometric View



Top View

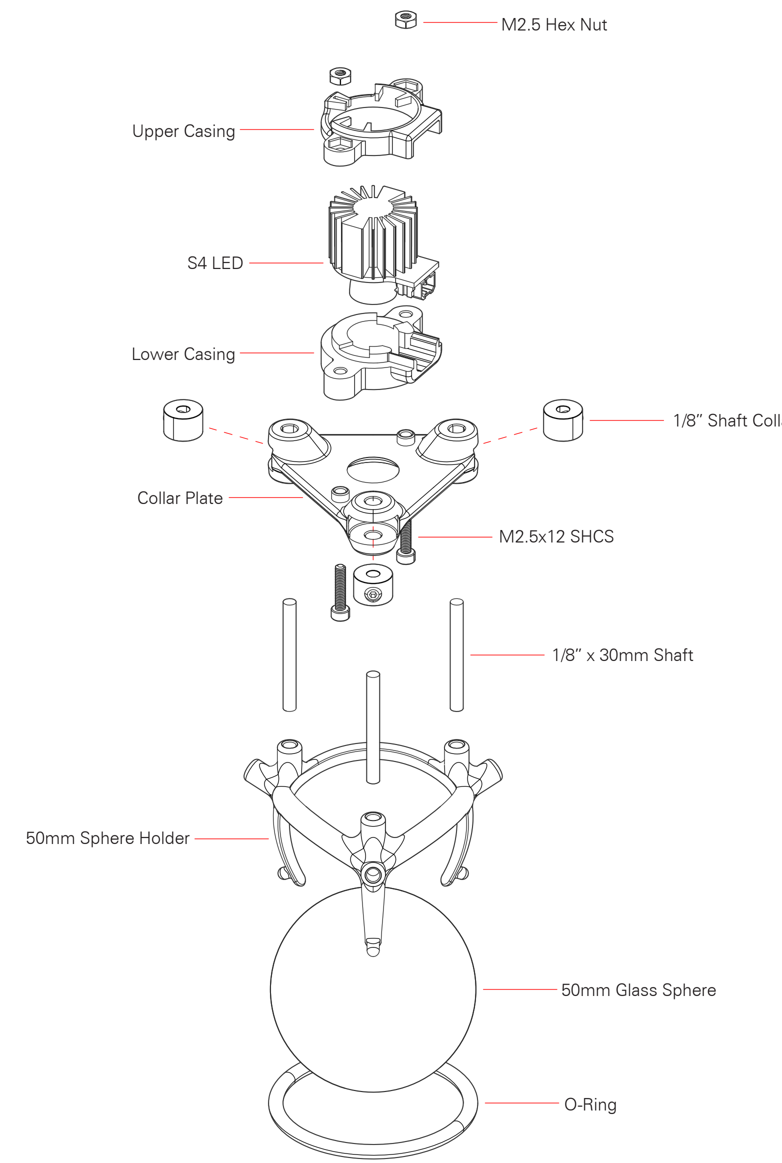


Front View

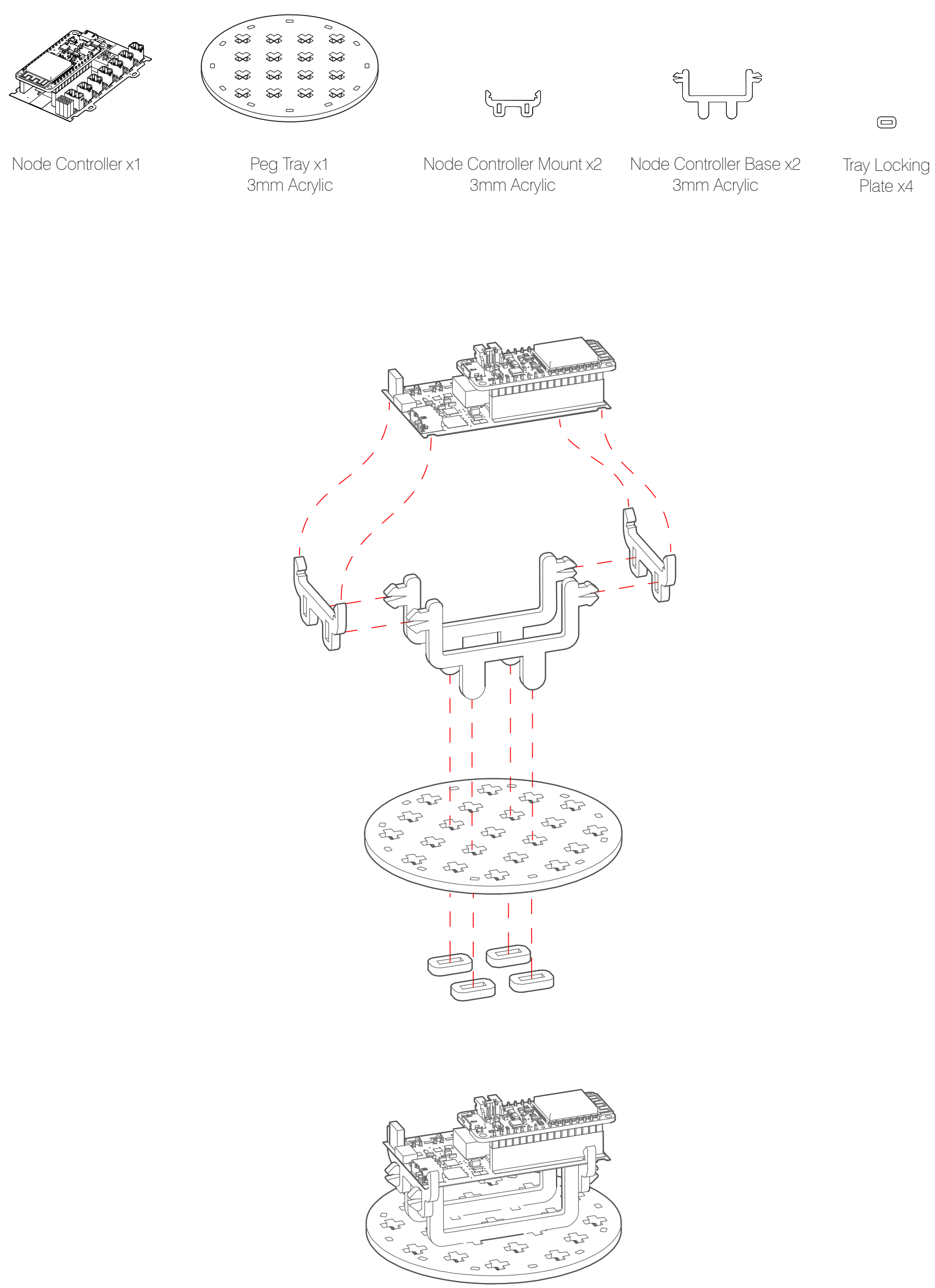


Components Lexicon

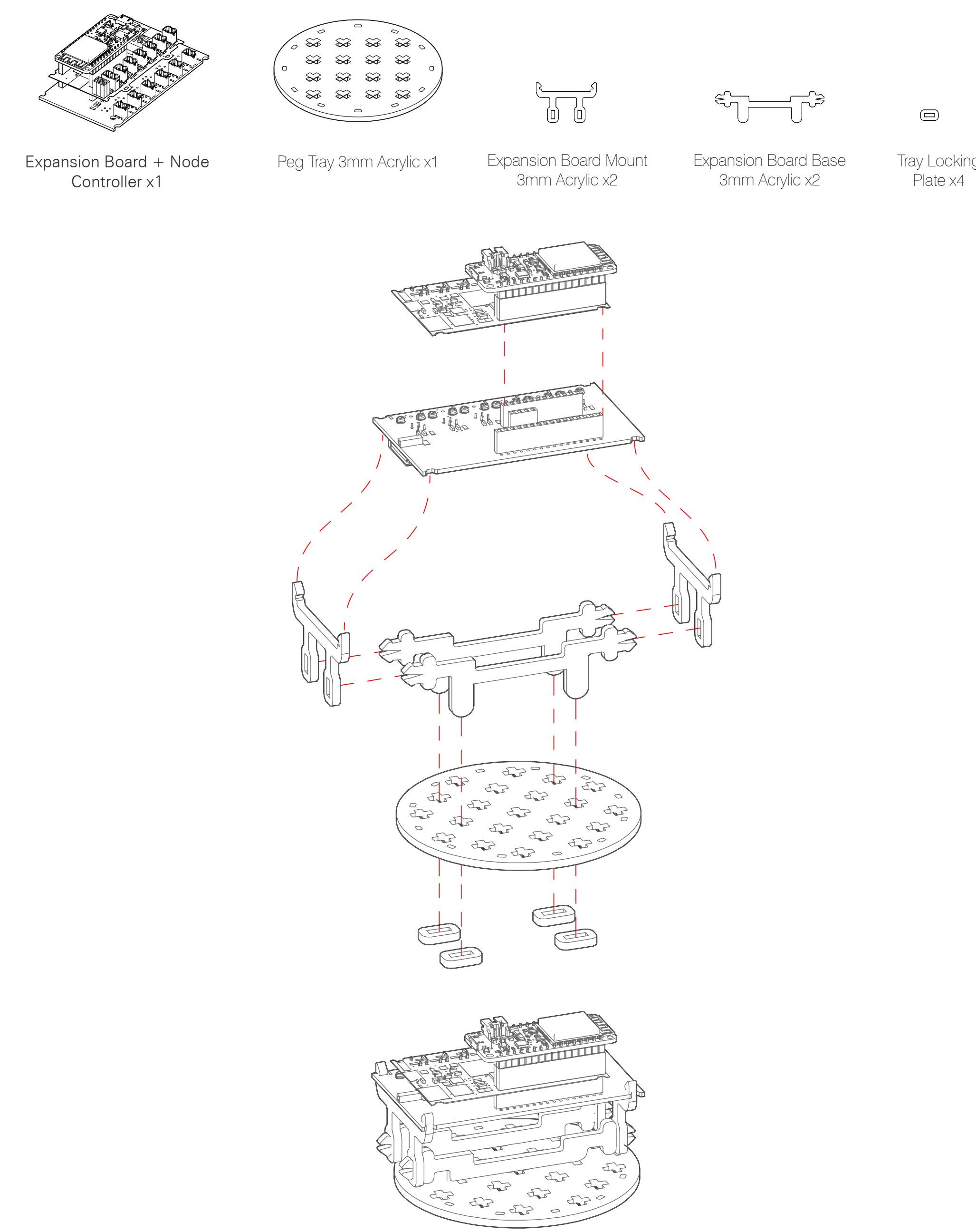
LED Sphere Pinspot



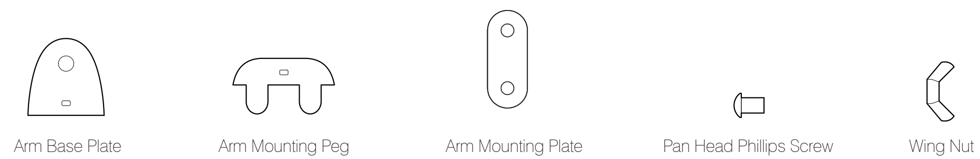
LED Sphere Pinspot Assembly

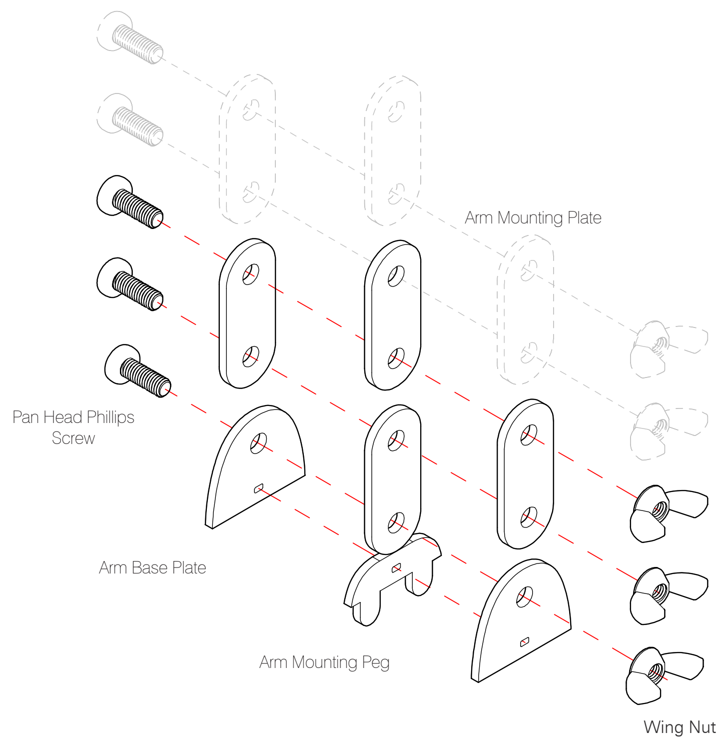


Node Controller Tray

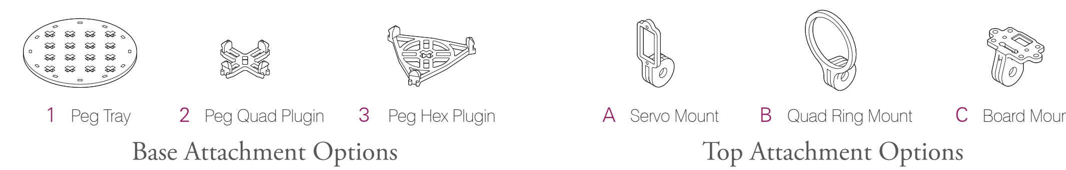


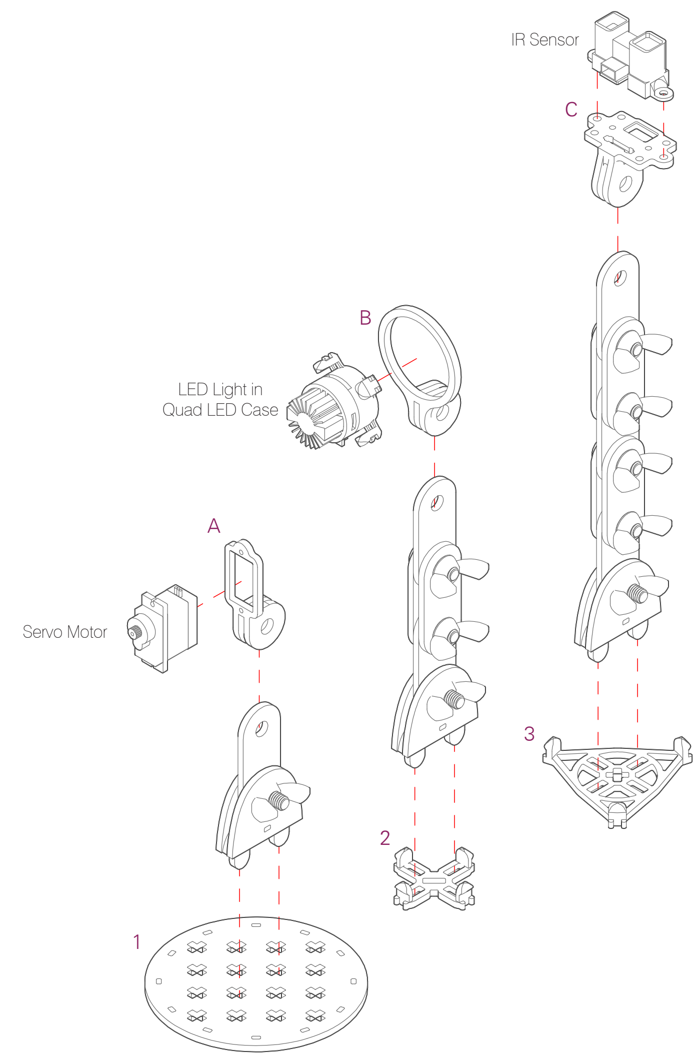
Node Controller Tray with Expansion Board



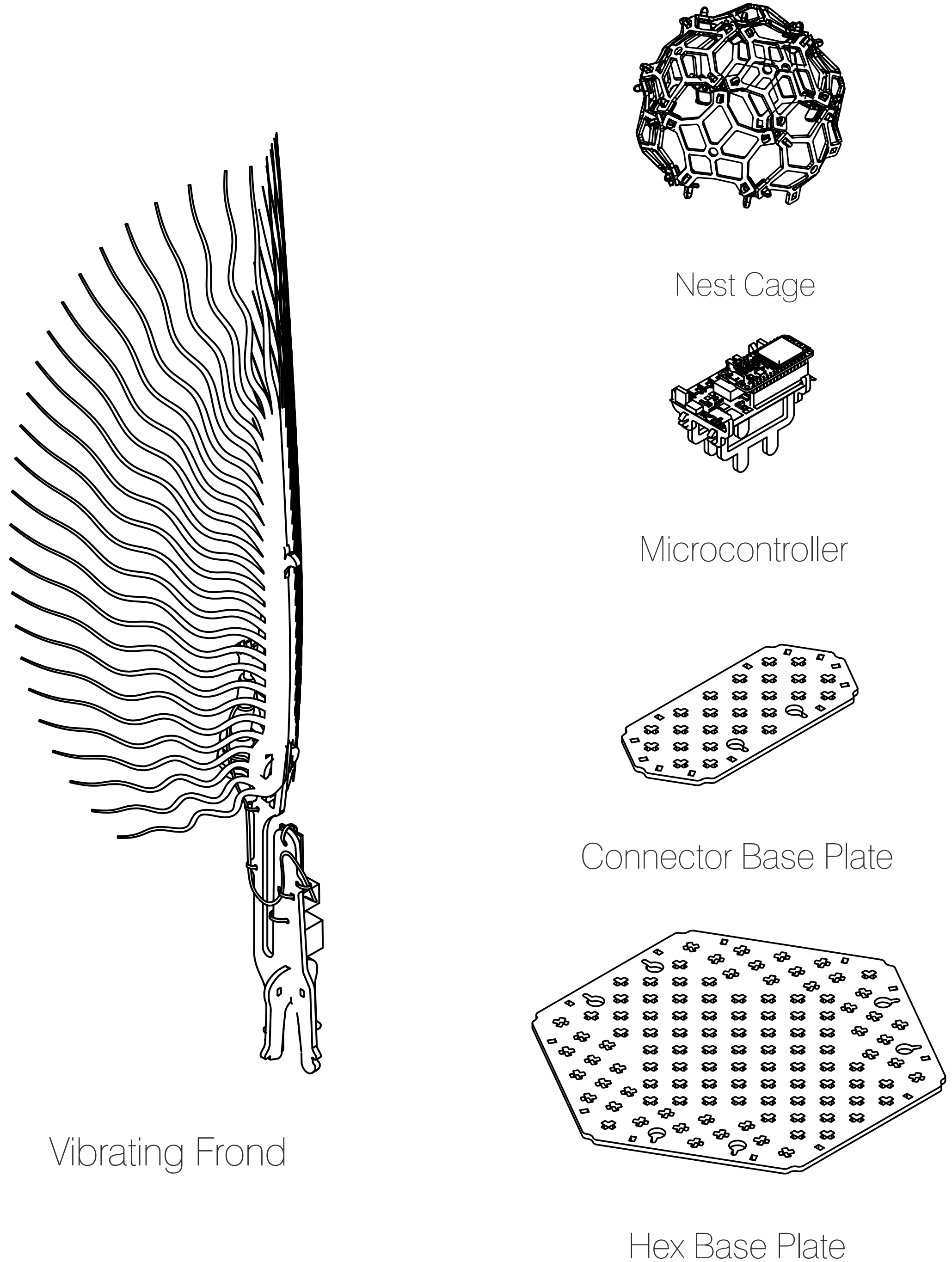


Extensible Rotating Arm

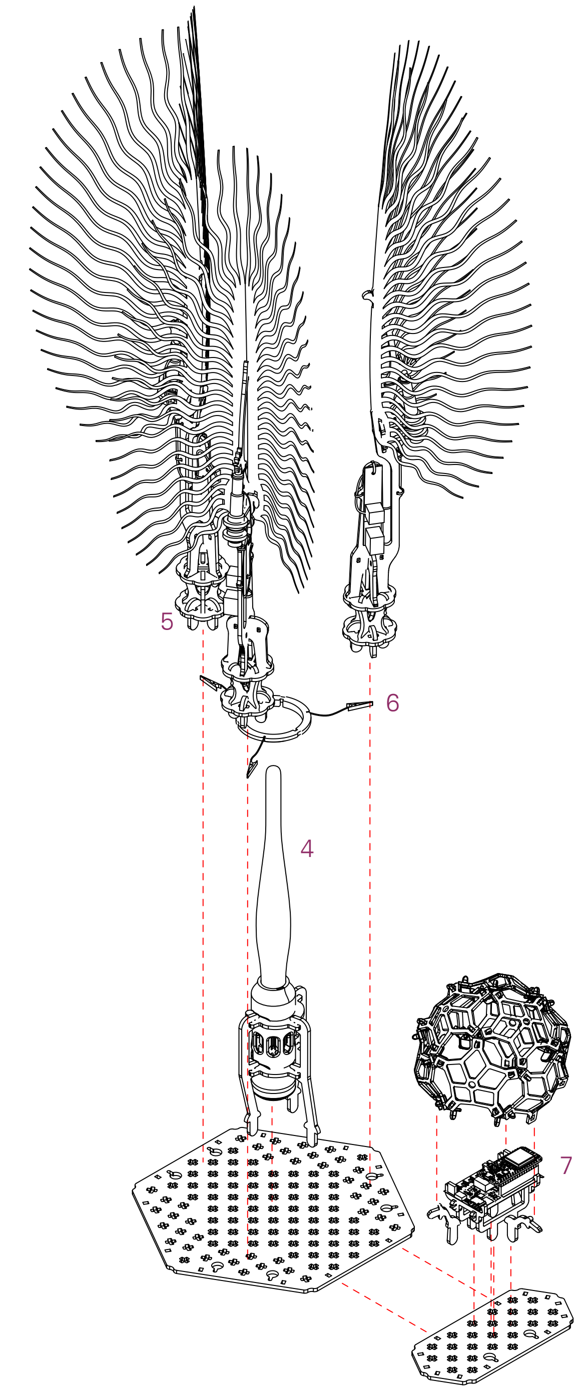




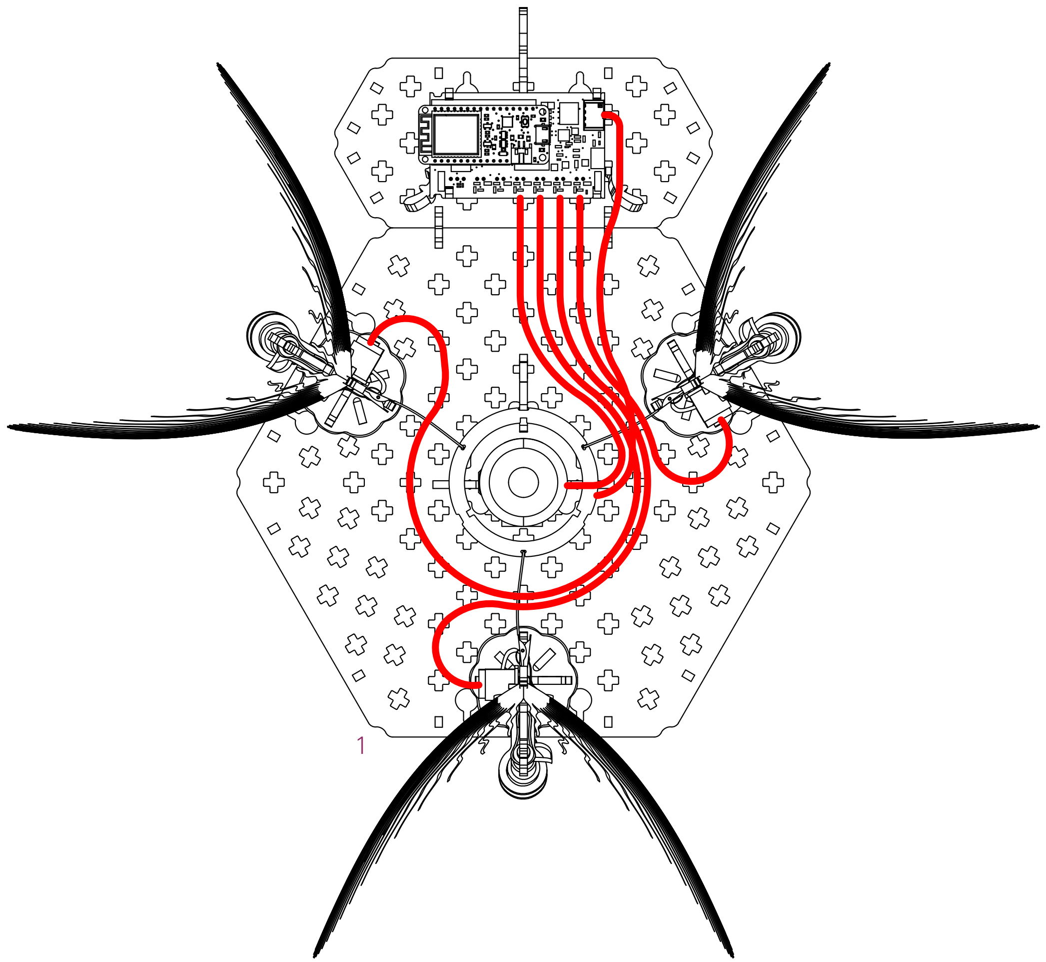
Extensible Rotating Arm Attachments



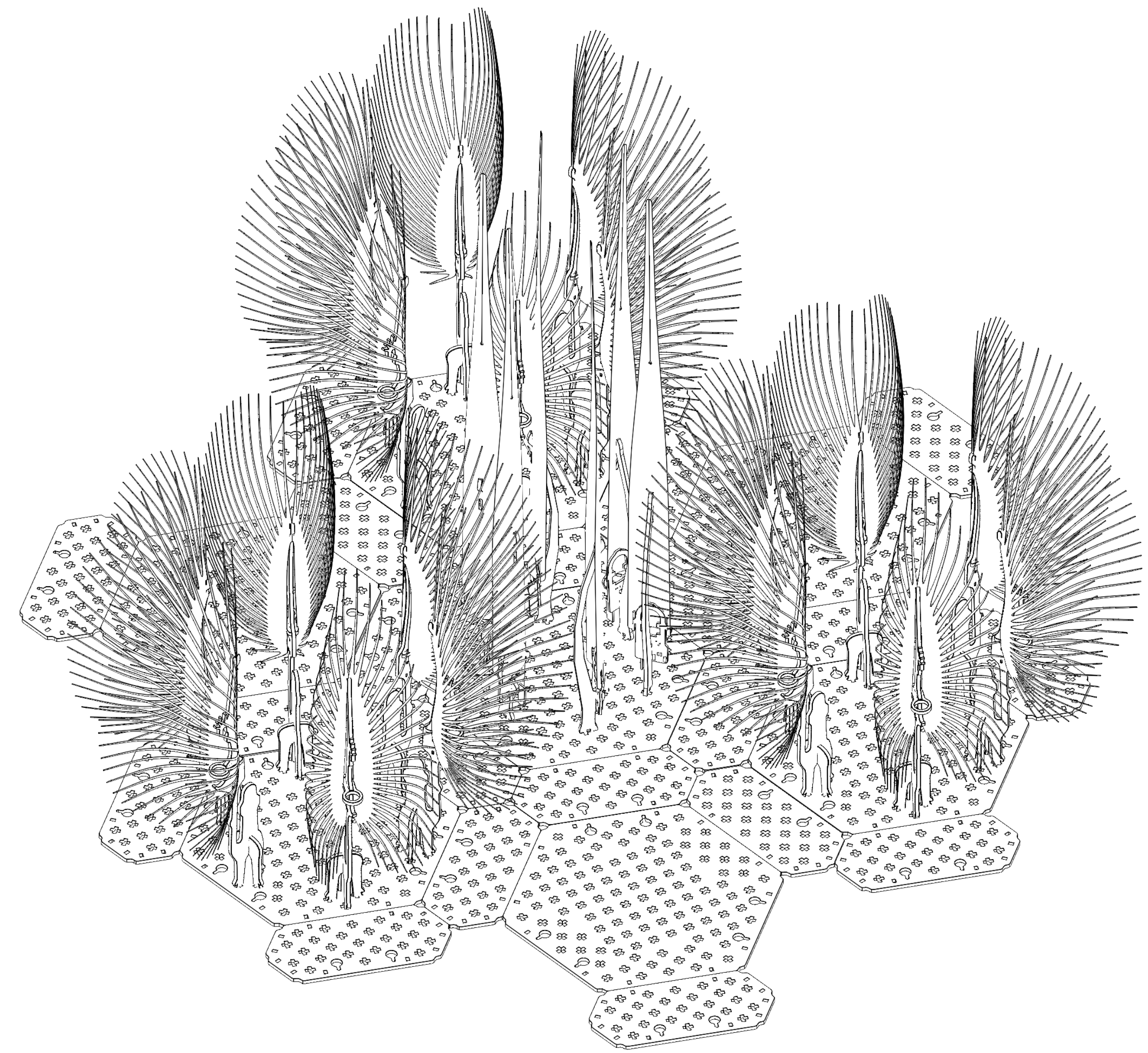
Actuator Desktop Kit System



Actuator Desktop Kit System Assembly



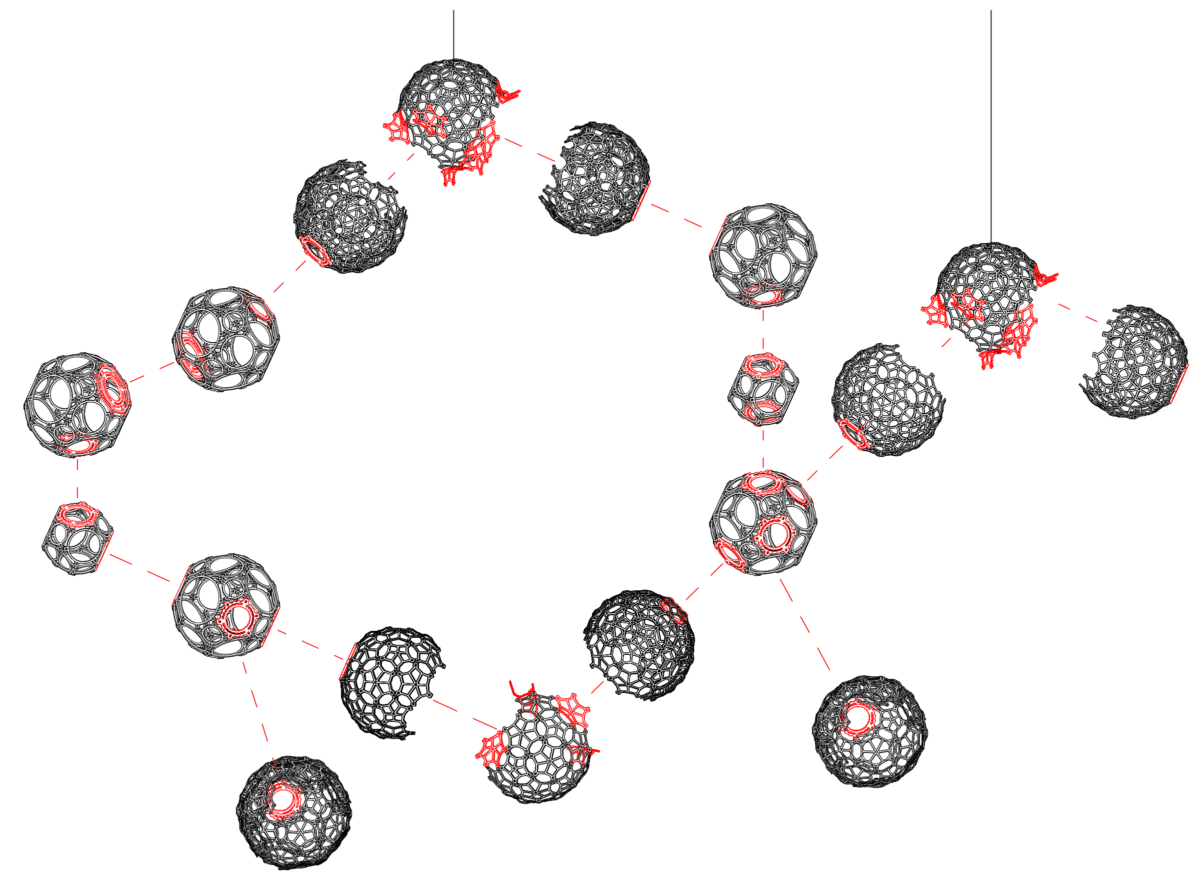
Actuator Desktop Kit System Cabling

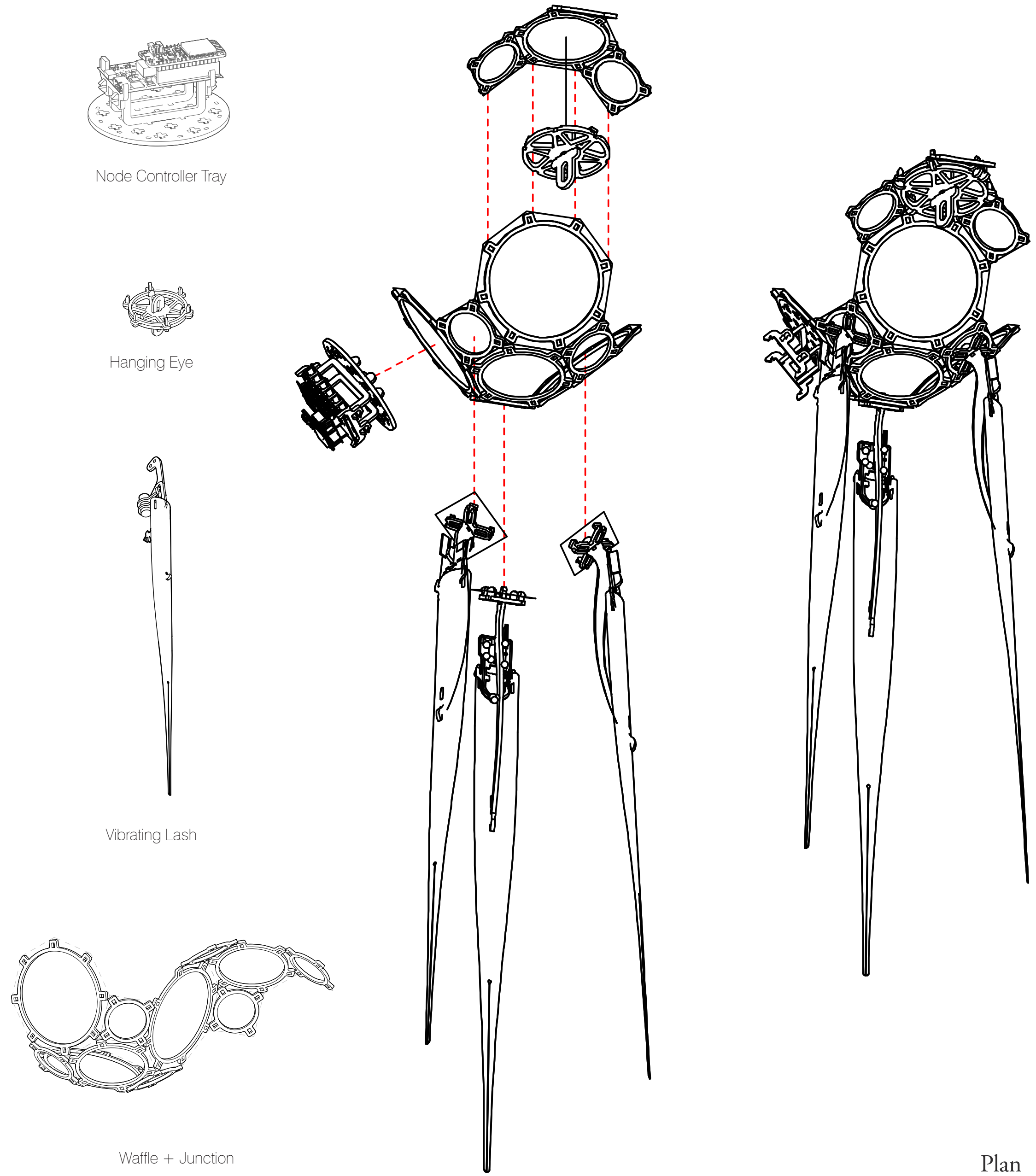


Actuator Desktop Kit System

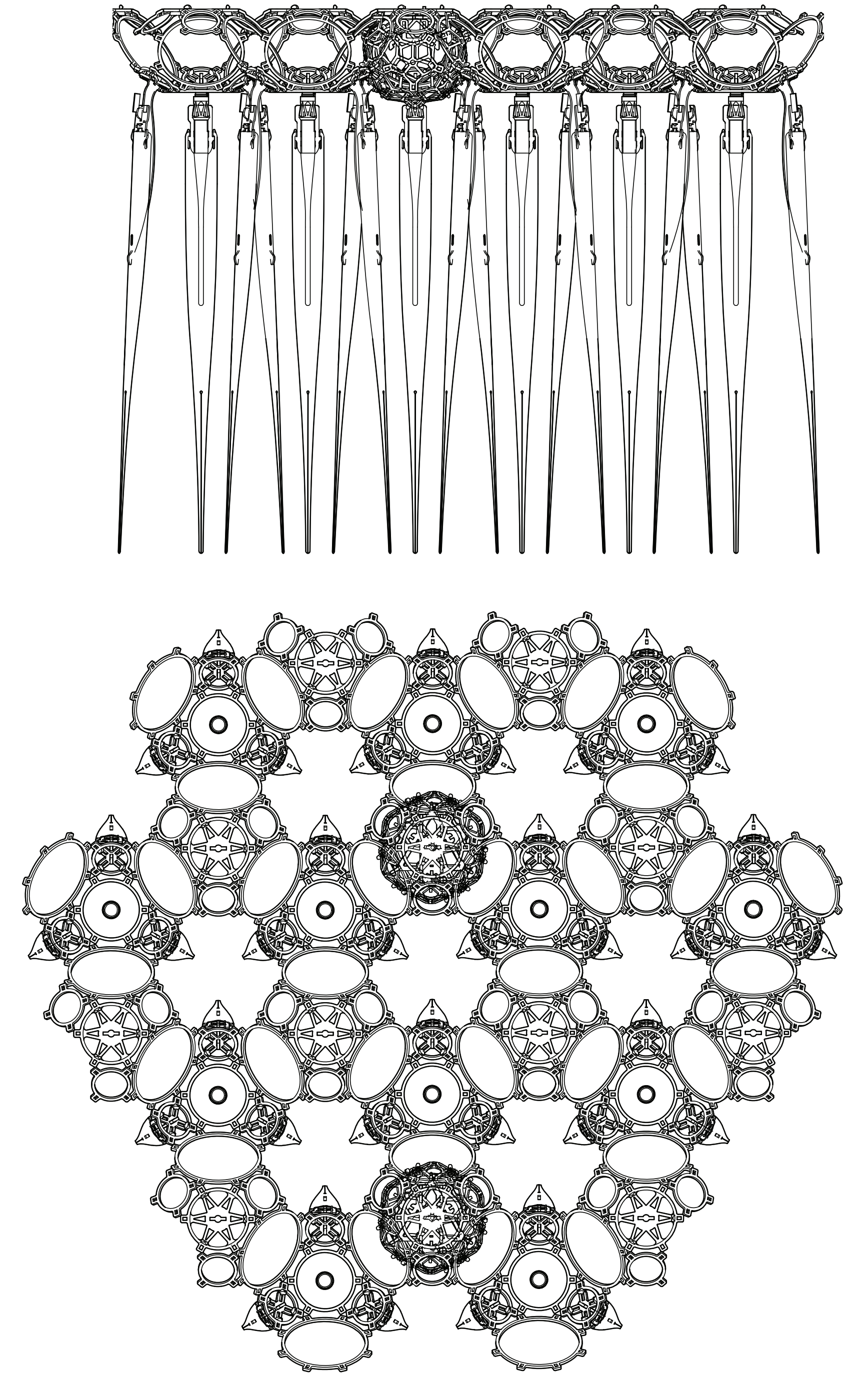
Integrated Assemblies

The Integrated Assemblies combine expressive geometric scaffolds, dynamic actuators and proprioceptive sensors to form responsive fragments of near-living architecture.

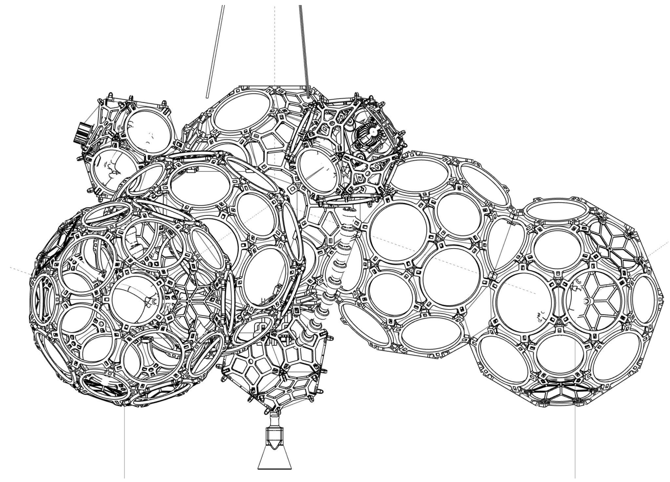




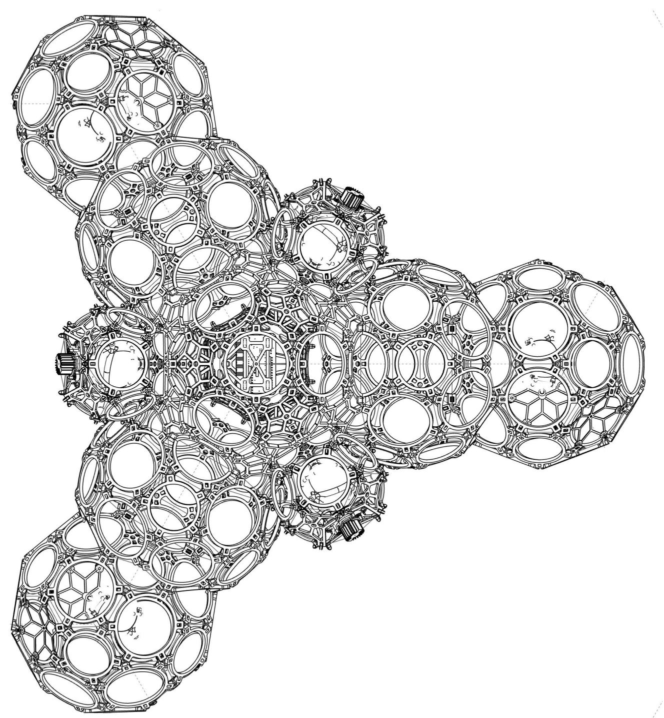
Waffle Cell Assembly



Canopy System Assembly

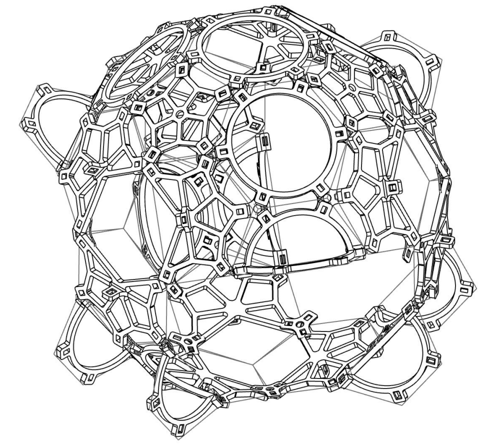


Elevation

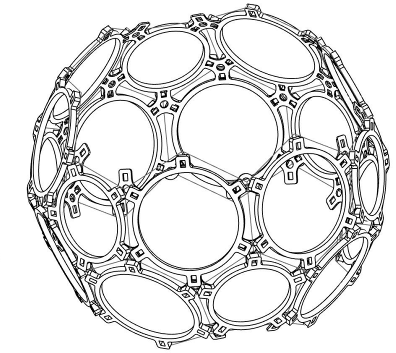


Plan

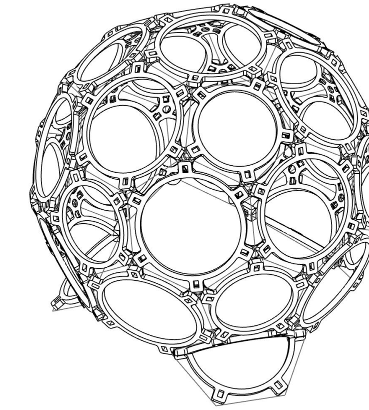
Ringed FDM Extended Cell Cluster



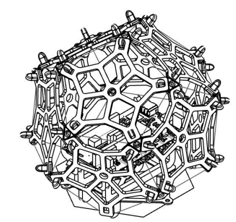
Tetrahedral Truncated Icosahedron Structural FDM 3-way Hub (Ringed)



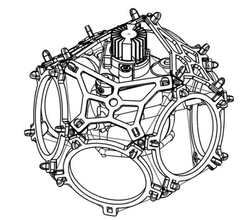
Truncated Icosahedron FDM Spoke (Ringed)



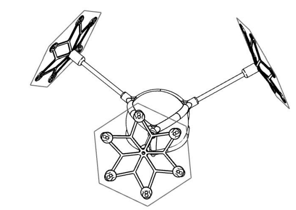
Truncated Icosahedron FDM Terminal (Ringed)



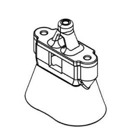
Node Controller FDM Nest Assembly



LED Sphere Pinspot FDM Nest Assembly

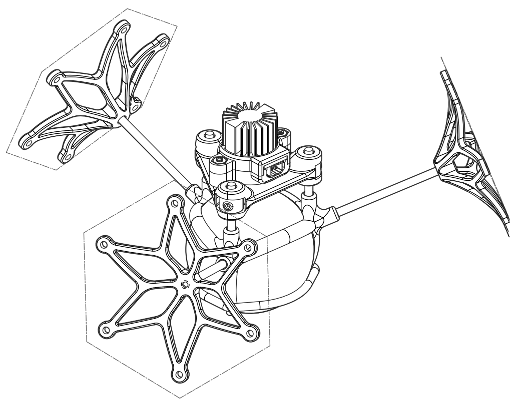


50mm Glass Sphere

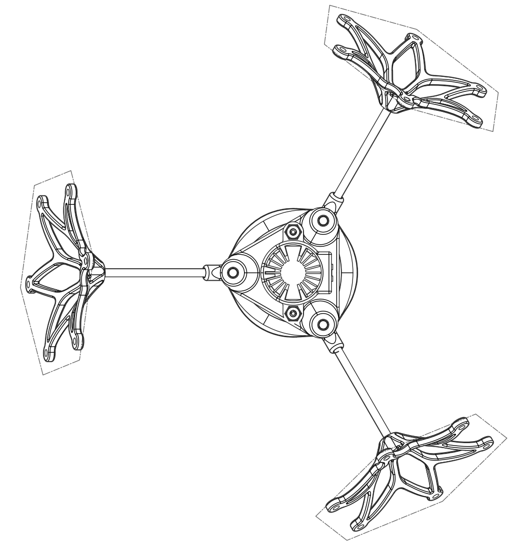


IR Sensor

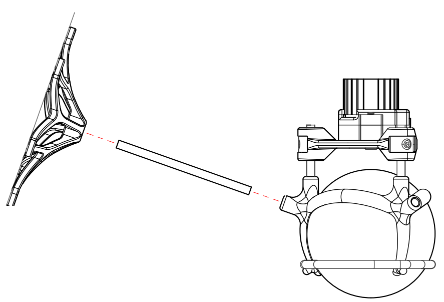
Ringed FDM Extended Cell Cluster Extensions



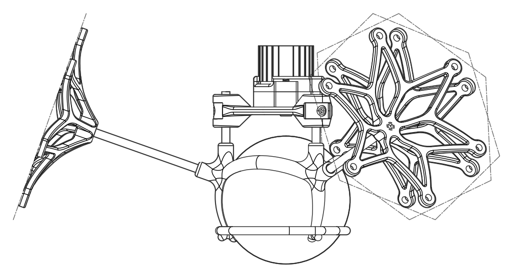
Isometric View



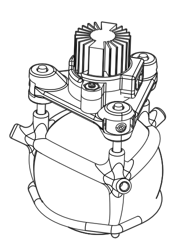
Top View



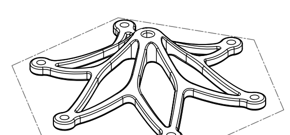
Assembly



Front View



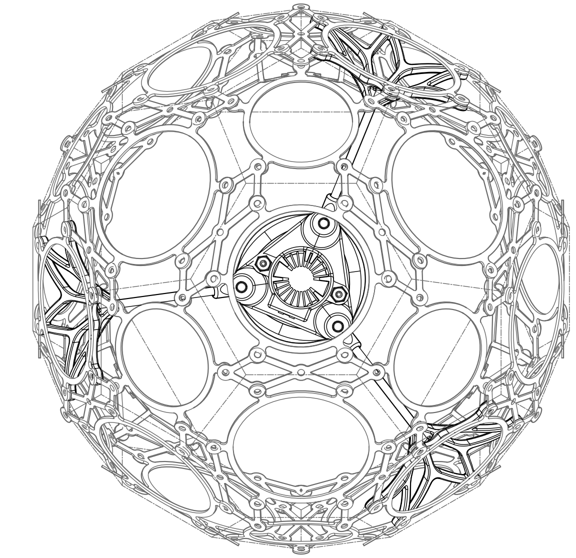
S4.2 LED Sphere



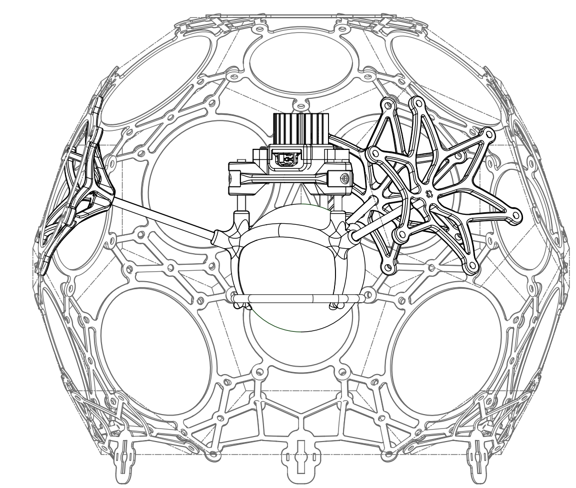
Metal Sphere Garland Mount Spider

Component Lexicon

LED Sphere Pinspot with Garland System Cell Mount

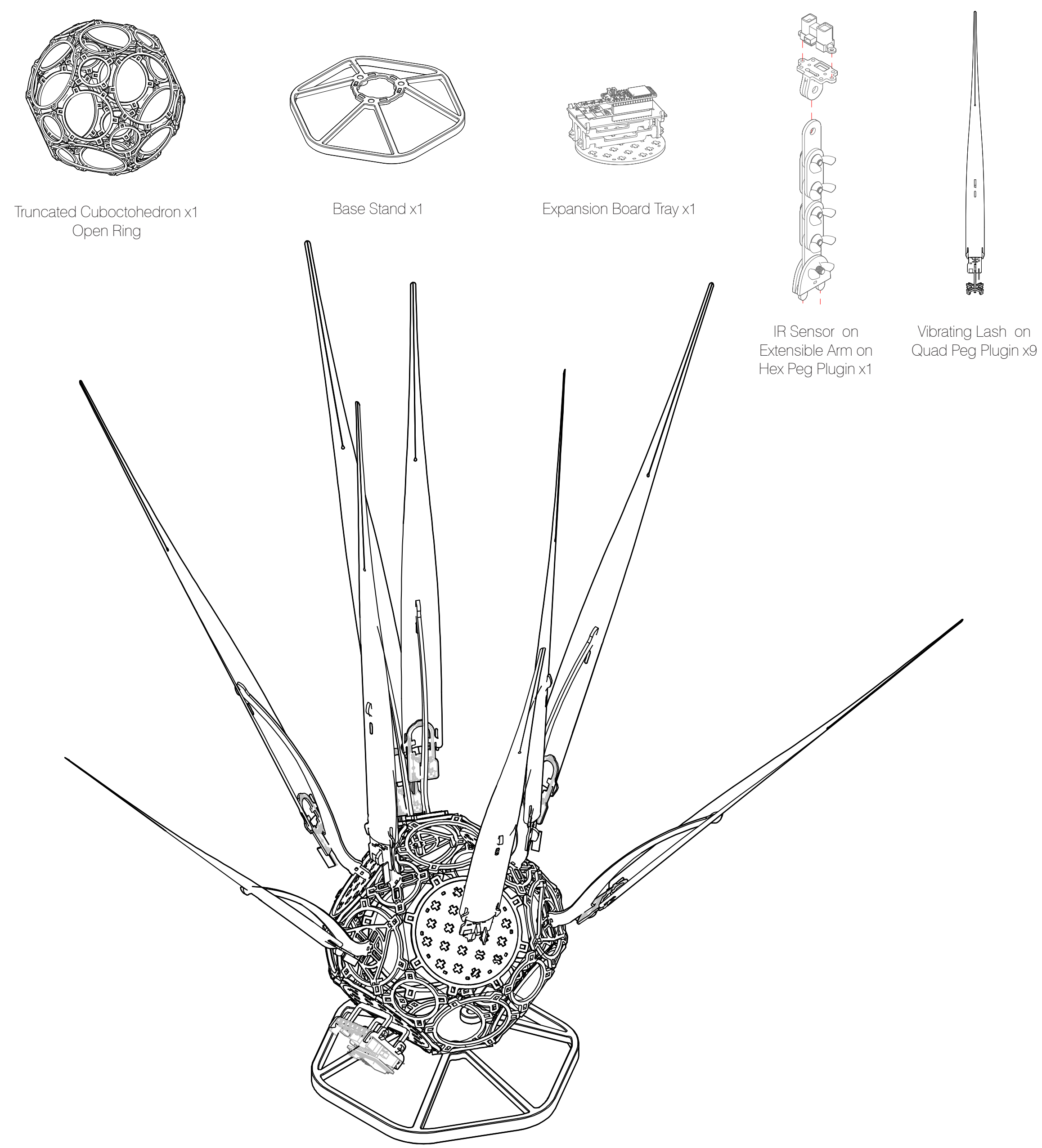


Top View

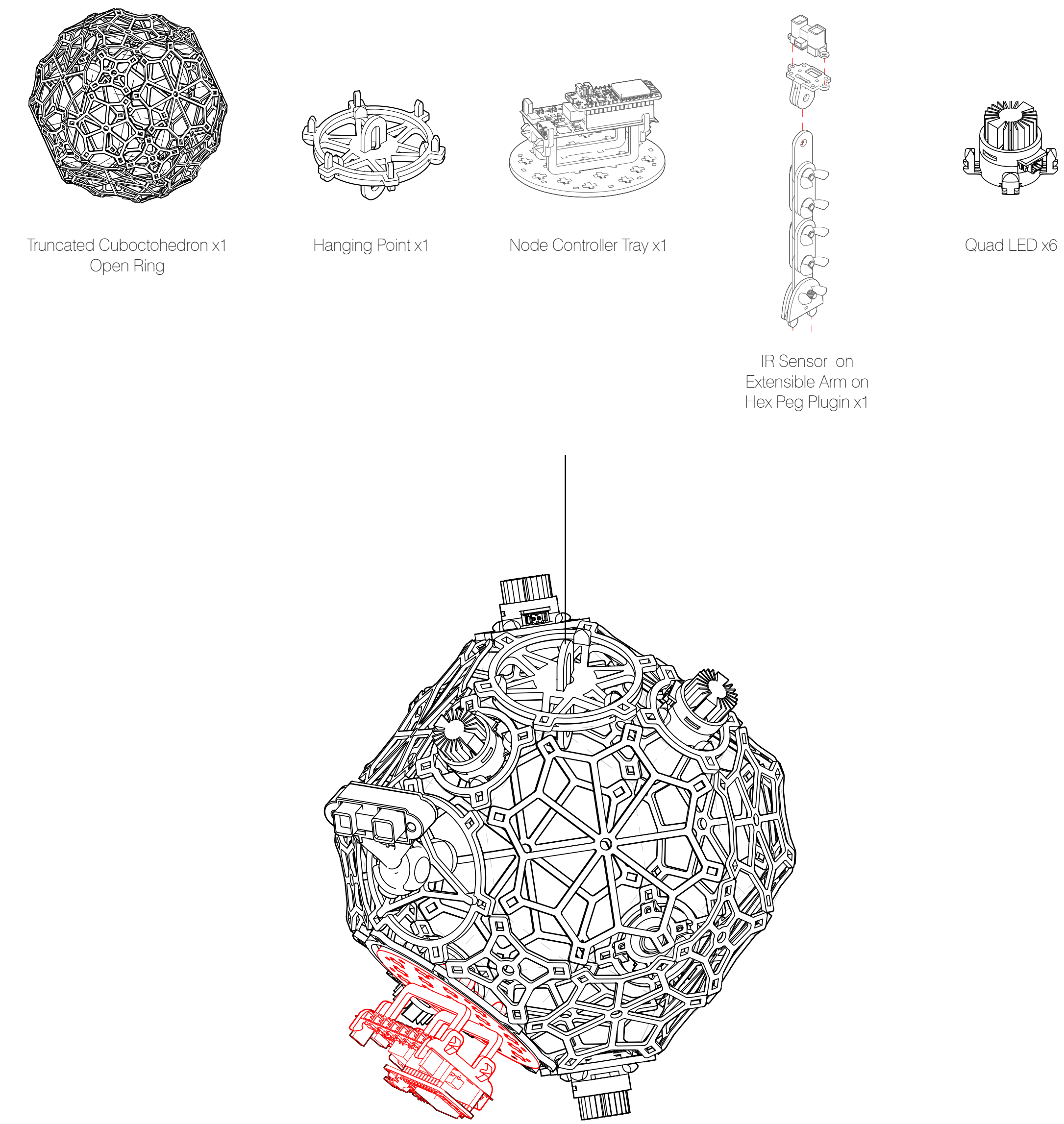


Front View

LED Sphere Pinspot within Scaffold Sphere



Lash Cell Assembly



Light Cell Assembly

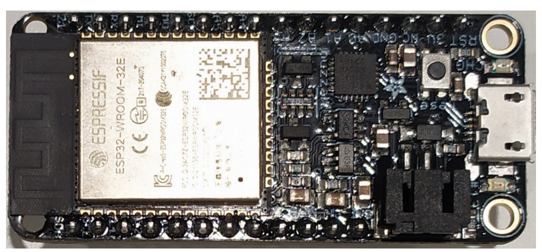
Control Systems

The software, hardware and interfaces that surround a testbed enable engagement with the interactive behaviour systems that animate these works of Living Architecture. This testbed infrastructure supports a specialized digital milieu; a virtual ecosystem populated with influence fields, virtual beings and digital twins of the physical testbed. The digital and physical worlds exchange information, communicating and mutually influencing each other.

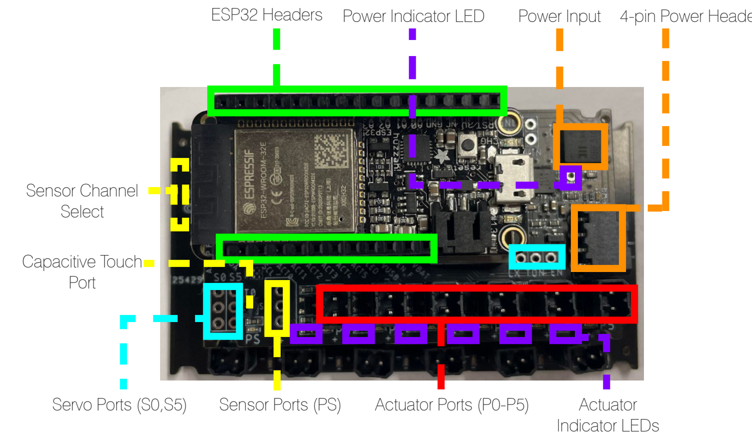
When sharing space with the Living Architecture testbed, Integrated Kit Assemblies, and external systems can join this digital ecosystem. Interfaces, tailored to users with different experience levels, allow for simple adjustment of parameters in the digital milieu, or deeper connection with its underlying algorithms.

Hardware: Node Controllers

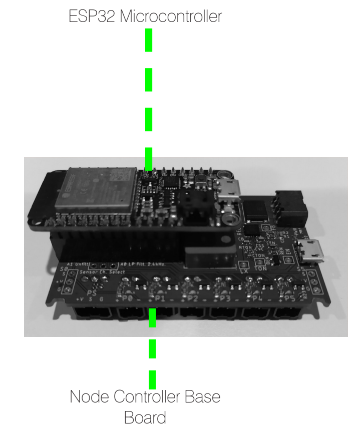
The Node Controller is a custom printed circuit board (PCB) that acts as a bridge between the microcontroller and the actuators and sensors. The microcontroller is the black board sitting on top. Connect its USB port to a USB power supply (any phone power supply or battery pack), or a laptop/computer port to give the board power. Connecting it to a laptop will also allow you to upload SAI profiles to it. It has on-board yellow LEDs that tell you when it is supplying power to an actuator through one of its 6 output ports (or servo ports, which use the same actuation channel as P0 and P5). It also has one LED that comes on to confirm that the board is receiving power. It has one sensor port, and a header for selecting the sensor channel. Channel A1 does not modify the sensor signal. Channel A0 applies a 2.4kHz low pass filter to the sensor signal before it reaches the microcontroller. The actuator, servo, and sensor ports all accommodate the dupont cables included in the kit.



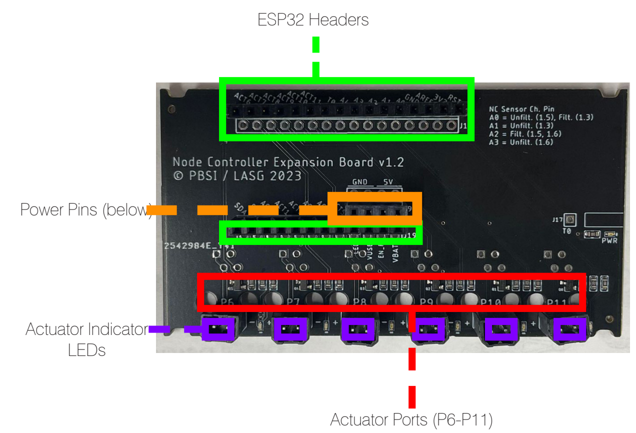
ESP32 Microcontroller



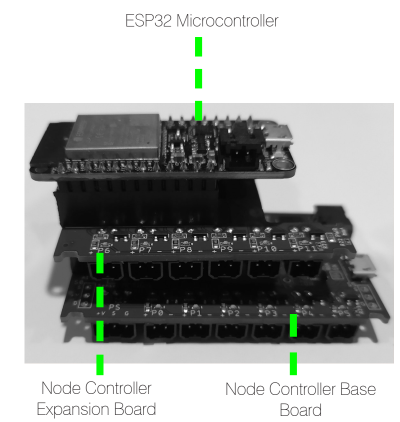
Node Controller Base Board



Base Configuration



Node Controller Expansion Board



Expansion Configuration

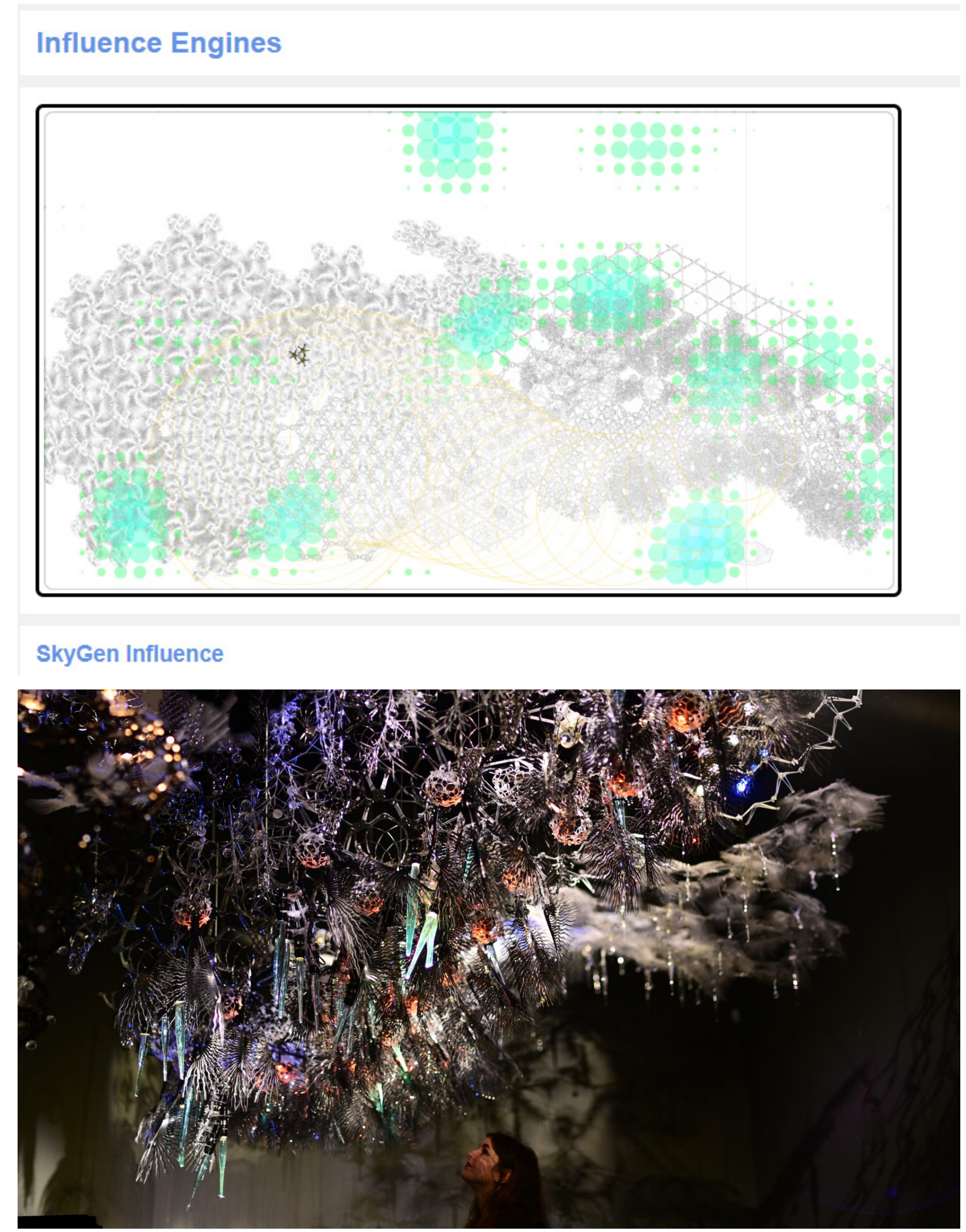
Node Controller Configurations

Global Behaviour: Influence Engines

At the heart of LASG's global behaviour system is the concept of Influence Engines. An influence engine is a piece of software that algorithmically generates 'influences' on the various spatially distributed parts of the sculpture. For example, a simple influence engine might create waveforms that move through the sculpture by determining the amplitude of a wave at various physical locations in the space. A different Influence Engine might use particle dynamics to calculate the trajectory of virtual objects which influence elements within the sculpture.

Key to the concept of Influence Engines is that they are not directly determining what each part of the sculpture should do, but rather 'influencing' the behaviour of the local computational elements. Elements can respond in many ways to the influences they are exposed to. For example, an actuator might glow in the presence of a virtual particle, or, that influence might dampen an already existing glow. This local logic of whether to respond to certain influences, how strong their impact becomes, and how exactly it becomes visible as part of the behaviour of the sculpture is inspired by independent natural lifeforms in a changing environment. Coordinated behaviour might occur if all the elements within an environment are similar (think about fireflies or crickets or ants) but the potential also exists for parts of the sculpture to respond independently as influences shift.

Each Influence Engine runs simultaneously, and their parameters can be adjusted using simple web-browser-based controls. The responses of elements of the sculpture to the influences can be adjusted as well via a browser interface.



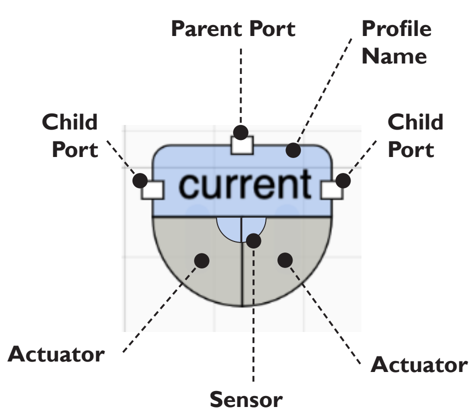
SkyGen Influence Engine Interface

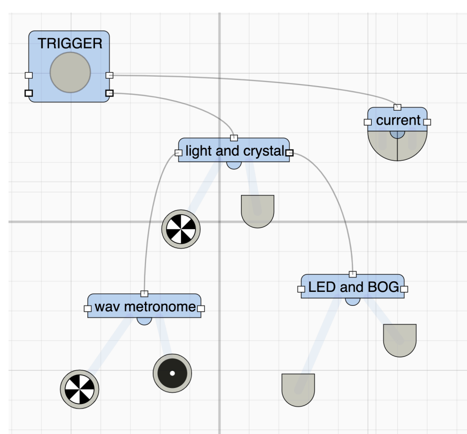
Local Behaviour: Smart Cells

Complementing global Influence Engines, the Smart Cell system has been developed by PBSI/LASG in order to provide individual devices containing actuators and sensors with local “intelligence”. Smart Cells are conceptual units that can store and play back time-based sequences of values, stored in a digital profile.

Smart Cells take both physical and virtual forms. Individual Smart Cells are physical devices that have their own embedded control profiles encoded within special-purpose printed circuit boards. Similarly, several virtual Smart Cells can be positioned within the firmware of microcontrollers. This is the approach used in the TUDelft Science Centre Prototype, with up to 4 Smart Cells in each of the 40 Node Controllers within the sculpture.

Whichever approach is used for Smart Cells, the profiles and arrangement of these virtual devices can be configured through an editor in a web browser, then uploaded to the hardware device.



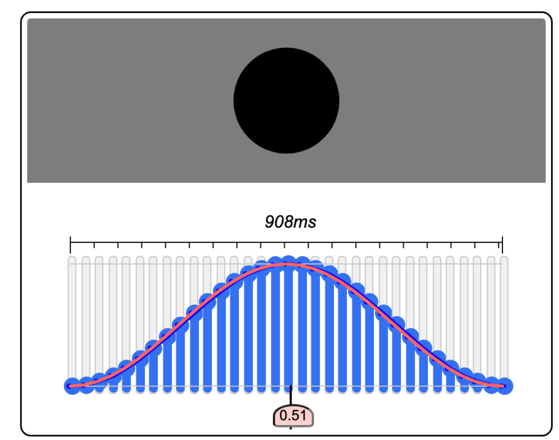


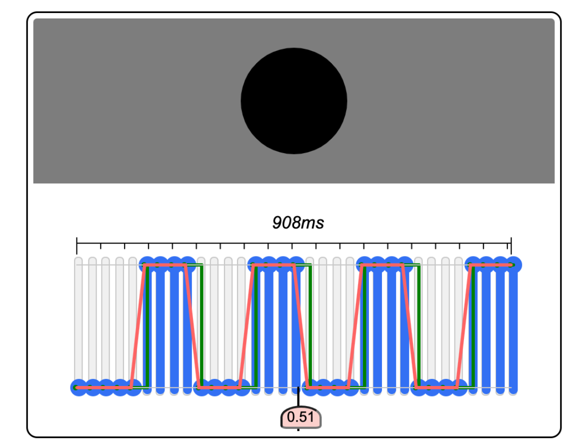
When a Smart Cell receives a trigger, its two stored sequences are played simultaneously through its two outputs. These can be connected to different types of actuators, and are configured using the SAI Profile Editor.

For example, if the sequence is a sine wave, when the Smart Cell is triggered, a connected LED flashlight will get dimmer and brighter. If it is a series of pulses, the light will blink on and off. At a specified point in the sequence, the trigger will propagate, getting passed to any other Smart Cell connected as its children.
Smart Cells can receive these triggers in two ways:

- from environmental stimulii (Influence Engines)
- from an attached physical sensor. Infrared proximity sensors are used to detect interaction, triggering Smart Cell profiles on the ‘chain’ components of the testbed.

Using the web-based software interface, various profiles can be created and experimented with to offer complex local behaviour in response to the dynamic Influence Engines and interaction if individuals with the testbed.

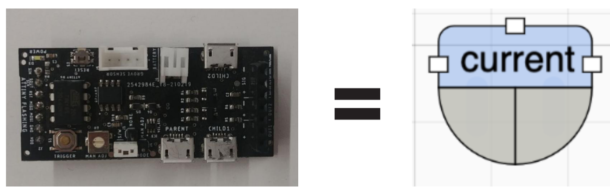




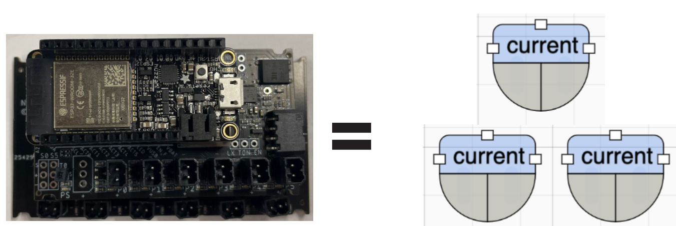
Smart Cell Implementation: Physical or Virtual?

While the sensors and outputs are real in both cases, the Smart Cell and

all its capabilities can be either physical or virtual. A physical Smart Cell is a small circuit board with one micro-USB parent port, two micro-USB child ports, two actuator output jacks and a sensor input jack. A tiny microcontroller runs firmware which stores the profiles and reacts to triggers by playing the sequences to its outputs, then triggering its children



A virtual Smart Cell uses the same firmware, running on a more powerful microcontroller that can effectively "host" multiple Smart Cells at the same time. They are still connected together using parent and child ports, just like several physical Smart Cells could be, but their 'wiring' is virtual. Each virtual Smart Cell can store a unique profile and control different kinds of actuators. This is the method used in this kit, with three virtual SAIs running on a node controller.



Smart Cell Editor Interface

The Smart Cell Editor software is a tool for creating profiles for an Smart

Cell creating virtual arrays of devices to plan large systems. The editor can be used to upload configuration data to a microprocessor-based Node Controller, which hosts the virtual Smart Cells.

Smart Cell Mapper Interface

1 **Tips & Keyboard Shortcuts**
Tips & Keyboard Shortcuts Are Shown at the top of the page

2 **Saved Maps**
"Current" refers to the map you were working on when you last reloaded.

Your maps will be saved under your account. You can see your own maps, as well as public maps, and the maps of an assigned project partner.

You can only save over or delete your own maps, so don't worry about changing others data.

3 **Trigger Box**
Connect the inputs of SAIs to this box and you can trigger them by pressing the button.

4 **A, B, C labels**
Green SAIs with labels correspond to the virtual SAIs in the Node Controller. The A, B, and C keys can be used to reassign these to any SAIs in the map.

5 **Smart Cell/SAI Header - Profile Name**
The SAI header shows the name of the profile for this Smart Cell.
You can also click and drag the header to move the Smart Cell.

Note: "Curent" refers to the active profile being worked on, use the "Saved Maps" dropdown, or the "Save As" button to reload or create a named profile.

6 **Sensor Indicator**
A Smart Cell with a Blue or black half circle has a sensor.

Use the "S" key with your cursor over the Smart Celll to toggle whether it has a sensor or not.

Blue indicates the sensor is ready. Black indicates it is not able to trigger (in cool down)

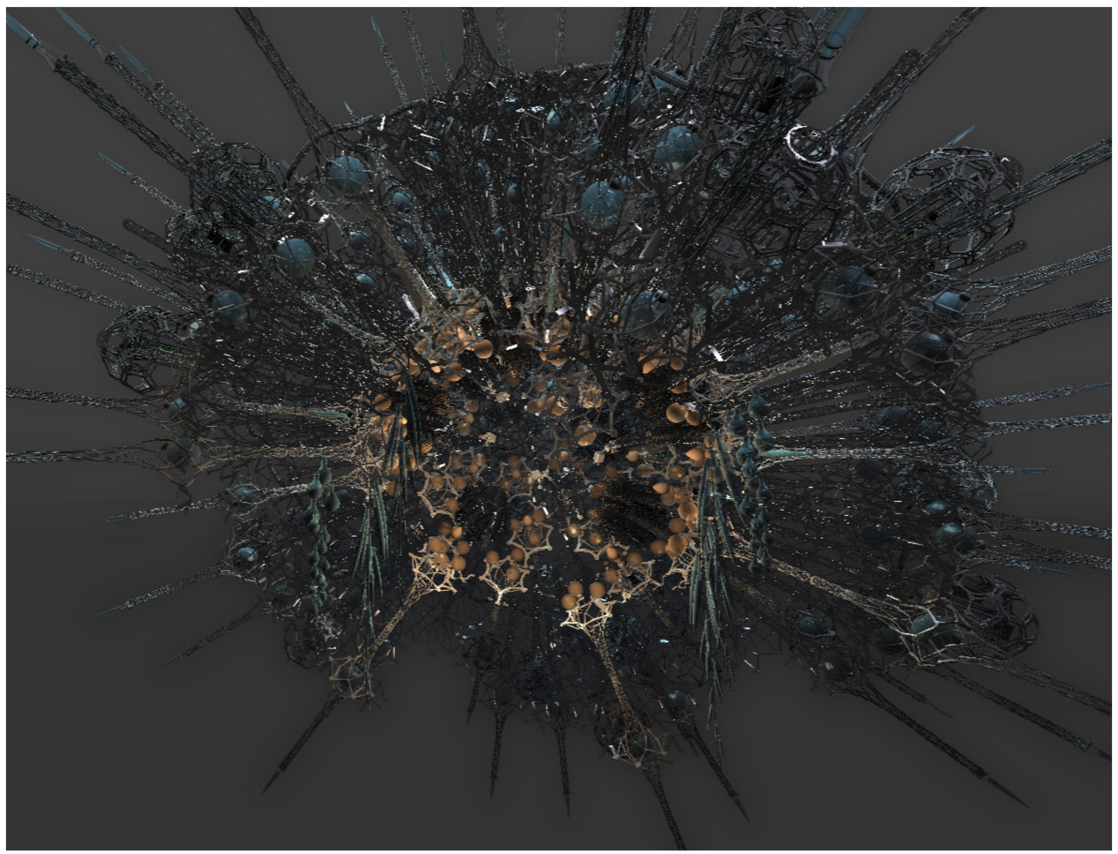
7 **Actuator Indicator**
The quarter Circle or Shield Shapes indicate the actuators of the Smart Cell.

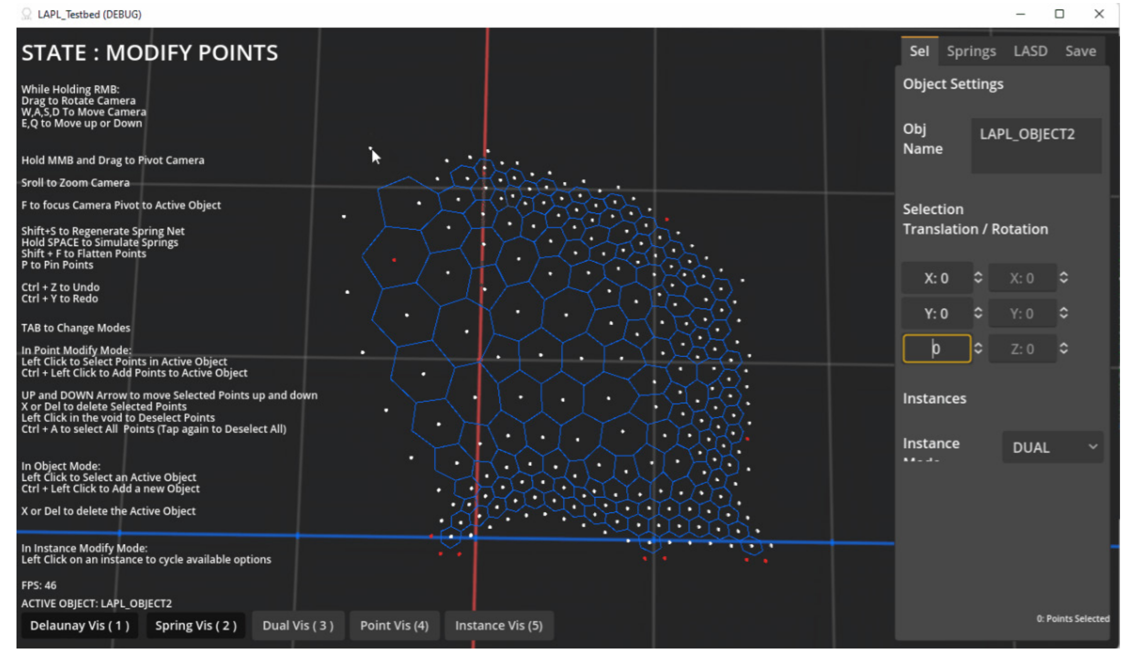
You can click and drag to move actuators around. They will still move with the Smart Cell header when you move it.
The rings around the actuator show its area of incluence. (you can toggle the display of these with the "showInfluences" setting.

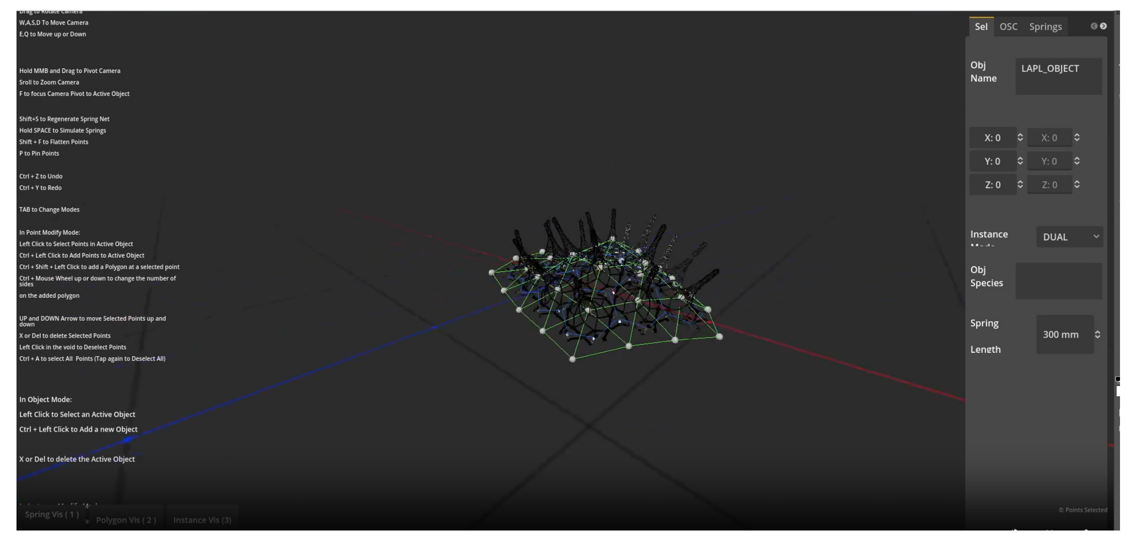
Smart Cell Mapper Interface Parameters

Future Interfaces

Ongoing control system development has focused on a next generation of interfaces that could provide a window into the virtual world surrounding a living architecture testbed. This interface development is exploring game engine, and augmented reality, frameworks to support the creation, operation and exploration of digitally twinned ecosystems.







The 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 objects* 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.

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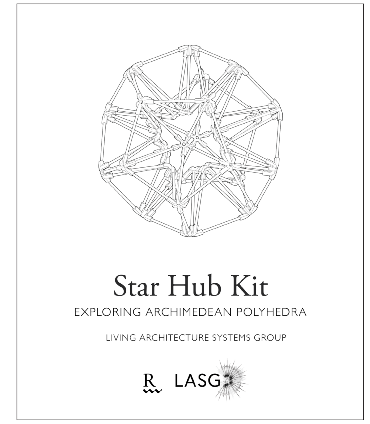

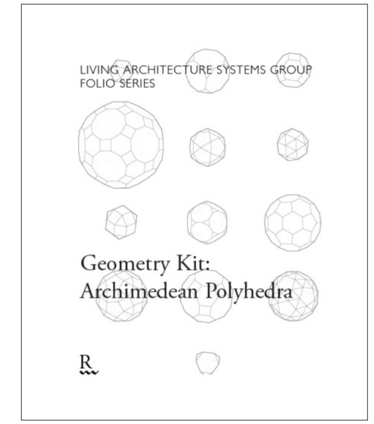

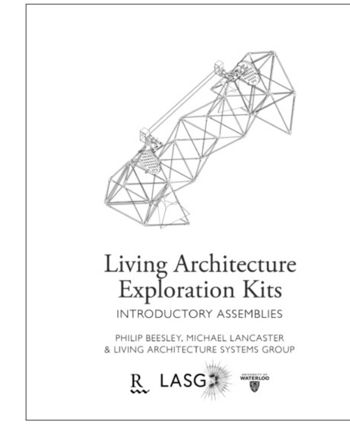

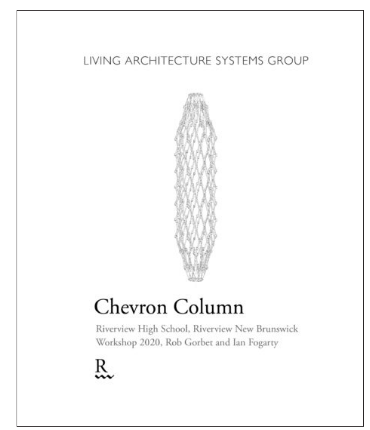

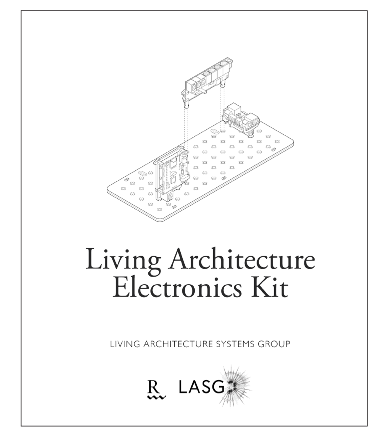

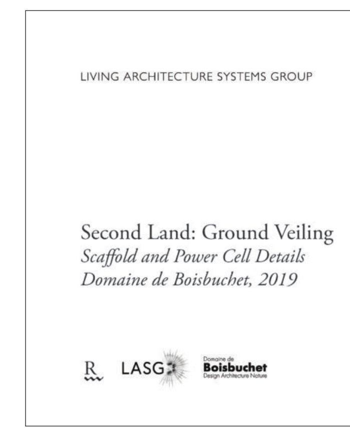

References

Bowker, Geoffrey C. and Susan Leigh Star, *Sorting Things Out: Classification and Its Consequences.* Cambridge, Mass: MIT Press, 1999.

Bullivant, Lucy. *4dsocial: Interactive Design Environments*. London: AD/John Wiley & Sons, 2007.

Fox, Michael and Miles Kemp. *Interactive Architecture*. Princeton: Princeton Architectural Press, 2009.

"Living Architecture LIAR," accessed February 2, 2022, https://livingarchitecture-h2020.eu/.

Negroponte, Nicholas. *Soft Architecture Machines*. Cambridge, Mass.: MIT Press, 1975.

Oosterhuis, Kas and Xin Xia. *iA #1, Interactive Architecture*. Rotterdam: Episode Publishers, 2007.

Spiller, Neil. *Digital Architecture Now: A Global Survey of Emerging Talent.* London: Thames & Hudson, 2009.

Delft Science Centre Testbed Sculpture

Ecosystem of Exploration

Delft University of Technology
Living Architecture Systems Group
Philip Beesley Studio

This publication provides detailed documentation of current research and discovery kits developed by the Living Architecture Systems Group. The Living Architecture Systems Group has developed a series of flexible discovery and creation kits that combine interactive electronics, geometric constructions, modular software, and expressive patterns of sound, light, and motion. These kits can help enrich the experience of visiting an immersive Living Architecture testbed sculpture. The kits are designed for a range of viewers and users including members of the public, artists, performers and composers, students and teachers, and advanced researchers.

The material is designed to engage a wide range of users interested in exploring next-generation living architecture in imaginative world-making workshops, expressive performances involving sound, light, and motion, modeling of complex geometric structures, and development of interactive electronic systems. Advanced scientific research can be undertaken using professional editions of the kits. Users can employ dashboards for editing and exploring the interactive behavior of these systems. 'STEAM' (Science, Technology, Engineering, Arts and Mathematics) concepts oriented to elementary and secondary school students are integrated within this material.

ISBN 978-1-988366-71-5

https://media.lasg.ca/exploration

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