Towards a Soft Architecture: Approachable Kit-of-Parts for Soft Interactive Architecture

by
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Master of Architecture

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.



Abstract

This thesis looks at an approachable kit-of-parts that allows for the rapid prototyping and creation of a new interactive architectural tectonic that is decentralized and compliant by using distributed microcontrollers and actuators. How can an extendable open kit-of-parts allow for easy access in designing soft interactive architecture? Previous work has been proprietary, expert facing and had a high barrier of entry; this work explores how DIY, open source and digital fabrication methods allow for rapid prototyping and the exploration of interactive architecture to be more accessible. By using compliant patterns and digital fabrication, an aspect of this new tectonic would be the emergence of a distributed 'soft architecture.' This thesis seeks to examine the current exclusionary barriers surrounding interactive architecture and to disseminate a design framework that enables an increase of accessibility on who can participate in the design of responsive environments. By looking at DIY creation methods, open source and the use of compliant materials, this thesis explores an interactive soft architecture through the prototyping and creation of architectural fixtures that employ an approachable kit-of-parts framework which would be disseminated in a manual that documents its creation and methods.

Keywords: *responsive environments, maker culture, do-it-yourself, open source, digital fabrication, STEAM, kit-of-parts.*

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To all the new Waterloo friends I made during the perfetto times -
From Roman holiday to a dungeon dragon:
I got them scared, shook, panicking
Overseas, church, Vatican

To my day ones, I just want to say something,
Could not have done it without you.
Could not have done it back then, Could not have done it now.

Dedication

Dedicated to my Mom inspires me
To my Dad who inspired this
And to my brothers who bother me



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Preface

Where I come from, people made
something from nothing
My brother once had a school project in
grade six
My dad worked with him on it

Where my dad would grab bits and
pieces
From here and there
And they created some kind of demo
With gizmos and gadgets
That would whizz and whirr

I won't say if my brother ever got to
present it
I won't say what mark he got on it
And I won't say whether there was a
mercury switch on it
Is that soft architecture?
I don't know, but I always thought that it
was hard

↳ Fig. 0 cybernetic_prototype0,
c. 2004. Photo by author.

power on indicator
on/off switch
mercury switch
slow speed indicator
magnetic switch
motor

CH.0

INTRODUCTION

"My house is diaphanous, but it is not of glass. It is more of the nature of vapor. Its walls contract and expand as I desire. At times, I draw them close about me like protective armour... But at others, I let the walls of my house blossom out in their own space, which is infinitely extensible."

Gaston Bachelard, citing Georges Spyridaki's lines from 'Mort Lucide', *The Poetics of Space*

Towards a Soft Architecture presents a guide and lexicon for a kit of parts that could be used as a pedagogical making tool for aspiring designers, researchers and artists. It seeks to critique current methods of making and design in interactive architecture while also translating them into an approachable and open kit of parts. This thesis is an exploration of the ability to engage with the field of interactive architecture in an open and easy manner. Through the act of critical making,[1] the elements of interactive architecture can be evaluated against the principles established in this thesis. This thesis has two main objectives: expressing a renewed distributed cybernetic architectonic using compliant material while distilling it into an approachable kit of parts. It will investigate methods of making interactive architecture more accessible through DIY, digital fabrication and open-source methods. This will intersect with fields like STEAM, cybernetics, soft robotics and maker culture, and how architecture can be integrated with wireless networks akin to the Internet of Things. Two main research approaches will be used in this thesis: First is a background survey of a variety of fields relating to the history of interactive architecture, cybernetics

1. "The use of the term critical making to describe our work signals a desire to theoretically and pragmatically connect two modes of engagement with the world that are often held separate—critical thinking, typically understood as conceptually and linguistically based, and physical "making," goal-based material work." Matt Ratto, "Critical Making: Conceptual and Material Studies in Technology and Social Life," *The Information Society* 27, no. 4 (July 2011): 252–60, https://doi.org/10.1080/01972243.2011.583819, 253.

and maker movement and then analysing important precedents that are relevant to the components of a soft architecture. This helps identify critiques and gaps in interactive architecture, and what problems could be addressed if a potential kit-of-parts were to be created to update the cybernetic principles to contemporary times. In the second part, the design will test ideas to create a kit-of-parts as an act of critical making.

The latter half of the thesis will investigate a potential architecture that can be formed after analysing the written and built work that underlies this field. To create an environment that is conducive to learning, a variety of modular kit-of-parts are to be designed to create potential forms of interactive architecture. As the purpose of this thesis is to empower people to become designers themselves, the kit-of-parts would be designed for designers; a meta-design exercise meant to instill the essence of key concepts of interactive architecture within the constraints. This thesis seeks to create a framework to make the field of interactive architecture more accessible and inclusive to a wider demographic of people as the designer of the kits, the author would have the ability to curate tools and content in the set, framing the conceptual and physical ideas and explorations possible. To express this, each kit presented will come in a standard format showing its contents as individual pieces, some components that could be constructed, and how those components can come together to form an assembly. The creation of this assembly could become a prototype interactive installation or part of a workshop, to see how it performs in real-life situations. A workshop will be held to see what is possible from the use of the kit and gain

opinions and feedback from the target demographic of students, researchers and artists. This will refine the pedagogical aspects of the kit in design intuition, and how best to properly communicate instructions in an educational context. By drawing from principles of Open Source, the publications and kit will be disseminated in the hopes of engaging with students, researchers, interactive artists and the community, creating a critical discourse about making and design research.

SOFT

Middle English, from Old English *sōfte*, alteration of *sēfte*; akin to Old High German *semfti* soft. First use before the 12th century, in the meaning defined at definition 1.

Adjective

1. pleasing or agreeable to the senses; bringing ease, comfort, or quiet

2. demanding little work or effort; easy

3. having curved or rounded outline; not harsh or jagged

4. emotionally suggestible or responsive; impressionable

a. or unduly susceptible to influence; compliant

5. yielding to physical pressure

6. biodegradable

Select definitions from "Soft." Merriam-Webster, https://www.merriam-webster.com/dictionary/soft.

CH.1

TOWARDS A SOFT ARCHITECTURE

"If [...] the environment is malleable and adaptive the results can be very potent indeed."

Gordon Pask, "The Architectural Relevance of Cybernetics," 1969

ARCHITECTURE + SENSORS = SOFTNESS

In Michael Fox's book, *Interactive Architecture - Adaptive World*, he states that in order for the practice of architecture to reaffirm itself as the intersection of arts and science, it must embrace the rise of new emerging technology that has become pervasive in our everyday lives.[2] As new technologies mature and become more integrated, their influence on design will allow the built environment to become engaging spaces and be able to interact with people. By connecting architecture to sensors, much like we ourselves have senses, it can now react to both people and the environment that surrounds it. By adding responsiveness, architecture is no longer passive and static but can be animate in its shaping of space, and informing of human behaviour.[3] Building upon the theories of cybernetics, the emergence of an interactive architecture has allowed for the birth of a paradigm shift in how the built world interacts with people.[4] This seemingly living 'softer' architecture is counter to the Eurocentric canon of stone and brick, which praises a stoic firmness and permanence.[5] While Vitruvius defined the key attributes of Occidental 'hard' architecture as being strength, utility, and beauty;[6] what

2. Michael Fox. *Interactive Architecture – Adaptive World*, (New York: Princeton Architectural Press, 2016). 10.

3. Fox. *Interactive Architecture – Adaptive World*, 10.

4. Michael Fox, "Catching up with the Past: A Small Contribution to a Long History of Interactive Environments," *Footprint*, no. 6 (2010), https://doi.org/10.7480/footprint.4.1.716, 8.

5. Fox and Kemp. *Interactive Architecture*, 250.

6. Vitruvius, *The Architecture of Marcus Vitruvius Pollio*, trans. Joseph Gwilt (London: Lockwood, 1874).

would be the key attributes of soft architecture? How would one define 'soft architecture'? What does the word 'soft' mean in the context of architecture?

Within design circles of the 1960s, there was a general association of 'soft' structures to malleable light materials like inflatables, foams and rubber. Against the rigidity of the built environment, there was a countercultural quality to these ephemeral, spontaneous, and sensuous creations.[7] The term 'soft architecture' can be traced back to the early cyberneticists of the 1960s. Cybernetics was the study of self-regulating systems based on the principles of feedback, control and communication usually applied to the field of human-machine interaction.[8] The roots of cybernetics can be traced to Gordon Pask and Norbert Wiener.[9] Pask's work as one of the fathers of cybernetics resulted in him influencing and collaborating with many architects like Nicholas Negroponte and Cedric Price. Price later would design the influential *Fun Palace* (Fig. 1.1) with Joan Littlewood, which imagined a flexible spatial framework that catered to the user's leisurely desires. Pask's Conversation Theory resulted in a foundation of interactive architecture, in which he proposed that architects should think of spaces as users as complete feedback systems.[10] 'Soft architecture' as a defined term first cropped up in this context with the 1967 publication of Warren Brodey's article "The Design of Intelligent Environments: Soft Architecture," where he proposes that architecture should be equipped with sensors to therefore dynamically respond to change, creating a homeostatic environment.[11] Brodey

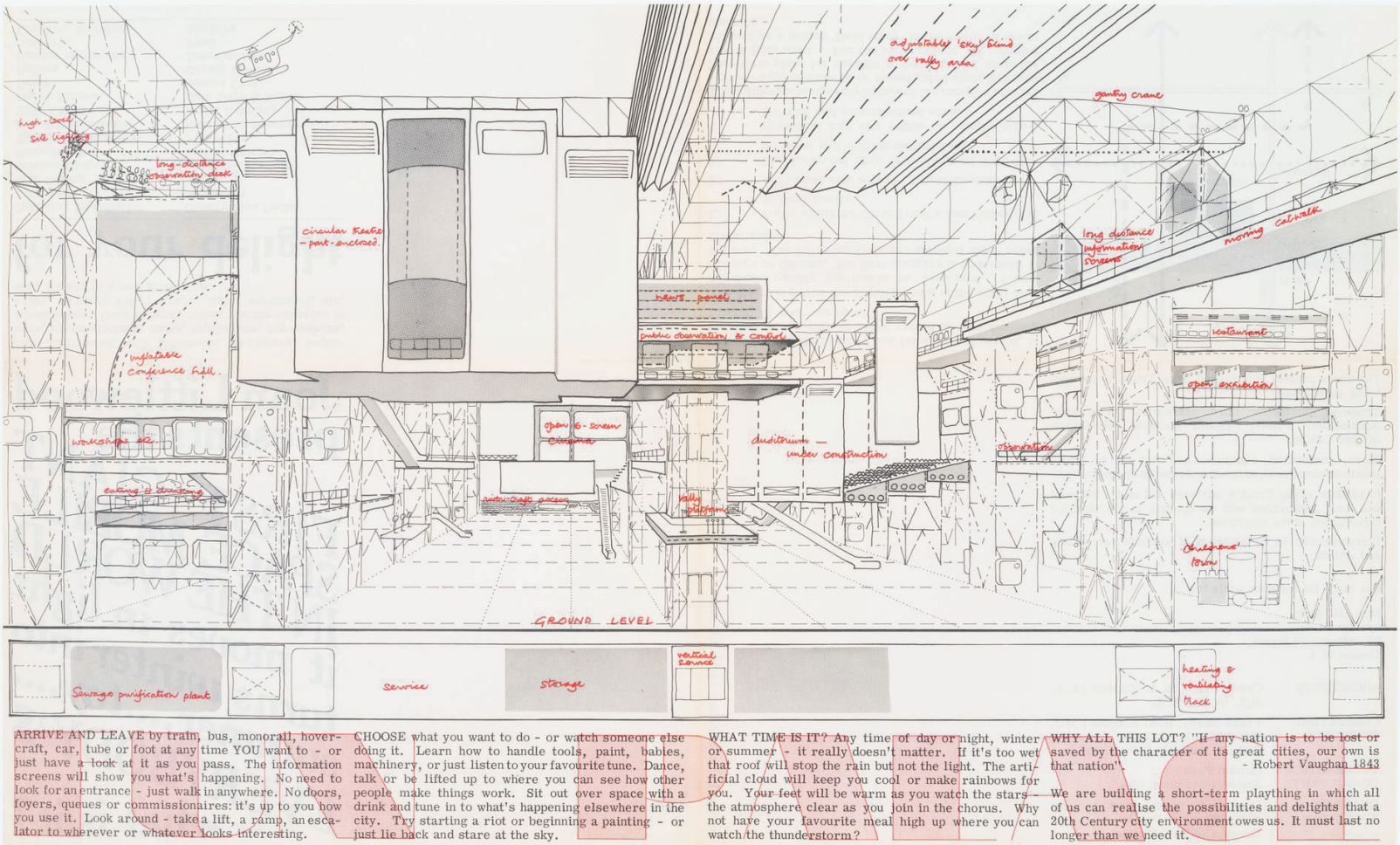
7. Larry D. Busbea, *The Responsive Environment: Design, Aesthetics, and the Human in the 1970s* (Minneapolis, Minnesota: University of Minnesota Press, 2020), 144.

8. Norbert Wiener, *Cybernetics: Or Control and Communication in the Animal and the Machine* (Cambridge, Massachusetts: The M.I.T. Press, 1971).

9. Fox. *Interactive Architecture – Adaptive World*, 10.

10. Fox, "Catching up with the Past," 5.

11. Warren M. Brodey, "The Design of Intelligent Environments: Soft Architecture," *Landscape* 17, no. 1 (1967): 8–12, 12.



ARRIVE AND LEAVE by train, bus, monorail, hovercraft, car, tube or foot at any time YOU want to - or just have a look at it as you pass. The information screens will show you what's happening. No need to look for an entrance - just walk in anywhere. No doors, foyers, queues or commissionaires: it's up to you how you use it. Look around - take a lift, a ramp, an escalator to wherever or whatever looks interesting.

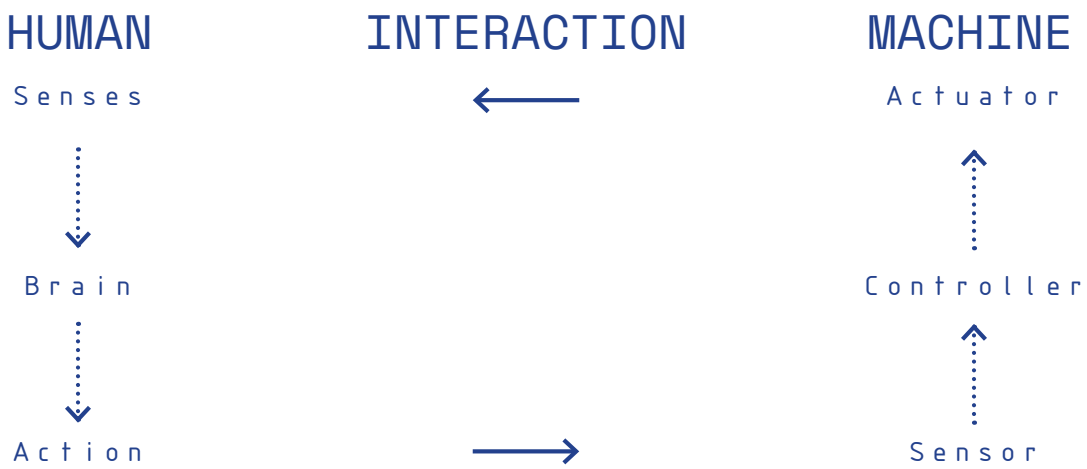
CHOOSE what you want to do - or watch someone else doing it. Learn how to handle tools, paint, babies, machinery, or just listen to your favourite tune. Dance, talk or be lifted up to where you can see how other people make things work. Sit out over space with a drink and tune in to what's happening elsewhere in the city. Try starting a riot or beginning a painting - or just lie back and stare at the sky.

WHAT TIME IS IT? Any time of day or night, winter or summer - it really doesn't matter. If it's too wet that roof will stop the rain but not the light. The artificial cloud will keep you cool or make rainbows for you. Your feet will be warm as you watch the stars - the atmosphere clear as you join in the chorus. Why not have your favourite meal high up where you can watch the thunderstorm?

WHY ALL THIS LOT? "If any nation is to be lost or saved by the character of its great cities, our own is that nation". - Robert Vaughan 1843

We are building a short-term plaything in which all of us can realise the possibilities and delights that a 20th Century city environment owes us. It must last no longer than we need it.

↑Fig. 1.1 Cedric Price and Joan Littlewood. *Fun Palace* promotional brochure, 1964. CCA



↑Fig. 1.2 Human-Machine Interaction. Diagram by author.

conceptualized this as both environment and human having animacy, and articulates this concept by drawing an analogy to

> "... the effect of an infant's mattress or of his crib on the child. The balance of the mattress will affect the movement of the child - it will control him. It will teach him by subduing some movements and reinforcing others."[12]

Building on Brodey and others, Nicholas Negroponte would apply the ideas of cybernetics to architecture and explored his ideas on 'softness' in his seminal publication *The Architecture Machine* and its follow-up, *Soft Architecture Machines*.[13] It is through the early cybernetic movement that the meaning of soft architecture shifts "... from the malleability of a material to the flexibility of a system. In so doing they developed new characteristics of soft that aligned the term as a verb."[14] The property of softness was not a material or formal descriptor but was rather a way of describing a new paradigm of mutual interaction.[15]

12. Brodey, "The Design of Intelligent Environments", 9.

13. Matthew G. Gorbet, "The Spatialized Digital Milieu: An Infrastructure Approach to the Design of Responsive Environments" (dissertation, 2023); Busbea, 146.

14. Neeraj Bhatia and Lola Sheppard, *Bracket 2: Goes Soft* (Barcelona: Actar, 2012), 8.

15. Busbea, 145.

FUNCTION > FORM > FORM > INTERACTION

SOFT =/= MATERIAL MALLEABILITY

SOFT = BEHAVIOURAL MALLEABILITY

Tectonics of Softness

So how might a soft architecture function, look and be built? What are the tectonics of dynamism and interaction? If one accepts the idea that form follows function, therefore the tectonics of a soft architecture would be based on its functionalism in response to human interaction. This idea of functionalism is first suggested by Pask himself,

> stating that in cybernetics … the concept of functionalism can be usefully refined in a humanistic direction. The functions, after all, are performed for human beings or human societies. It follows that a building cannot be viewed simply in isolation. It is only meaningful as a human environment. It perpetually interacts with its inhabitants, on the one hand serving them and on the other hand controlling their behaviour. In other words, structures make sense as parts of larger systems that include human components and the architect is primarily concerned with these larger systems; they (not just the bricks and mortar part) are what architects design.[16]

16. Gordan Pask, "The Architectural Relevance of Cybernetics," *Architectural Design*, September 1969, 494–96.

Other more environmentally moderating projects show more architectural applications that complex sensing and interaction can create. As cybernetic buildings continually interact with its users, it therefore needs to be able to accommodate those interactions and responses dynamically. A consequence of this is that architects will have to think of designing dynamic entities as opposed to static ones. "Clearly, the human part of the system is dynamic. But it is equally true though less obvious that the structural part must be imaged as continually regulating its human inhabitants."[17] Due to material qualities and the reality of physics, parts of these structures must therefore be strong yet lightweight to accommodate dynamic transformability. This may take the form of hinges or ironically even flexible soft materials. Negroponte thought there was a natural affinity in inflatables or what he called the 'softs,' as they exhibit motor reflexes through simple controls.[18] He further elaborates that cellular pneumatic had an untapped potential due to the ability to select certain cells to inflate and deflate, allowing for a wide range of forms.[19] While he agreed with his contemporary, Charles Rusch, quoting him on his view of using the 'softs' "... is only one alternative. 'Hard architecture' can be responsive as well... However, 'hard architecture that is almost by definition harder to make responsive."[20] By their definition, the 'soft' in 'soft architecture' did not relay that the material had to be soft,[21] nonetheless, it did not preclude it from utilizing soft materials.

17. Pask, "The Architectural Relevance."

18. Nicholas Negroponte, *Soft Architecture Machines* (Cambridge, Massachusetts: MIT Press, 1975), 145.

19. Negroponte. *Soft Architecture Machines*,

20. Charles W. Rusch, "On Responsive Environments," *DMG-DSR Journal, Design Research and Methods* 6, no. 1 (1972): 14–16. Quoted in Nicholas Negroponte, *Soft Architecture Machines* (Cambridge, Massachusetts: MIT Press, 1975), 149.

21. Busbea, 145.



Soft Ware

A transformable structure is not enough for a responsive architecture, but by connecting architecture to sensors, much like we have senses, it can now react to both people and the environment that surrounds it. Couple this with actuators that take the processed conditions detected by the sensors into action and a purpose, an inchoate 'soft architecture' can be seen to begin forming.[22] Certain ideas of cybernetics trickled down and made possible due to massive advances in the economization and miniaturization of technology. Inflated by the prowess of Silicon Valley and Shenzhen, the concept of the 'Internet of Things' may soon be a reality that humans and machines will coexist in a shared networked environment.[23] So, it is not the question of if it is possible, but how it is possible? And in what way will these components behave? Gordon Pask's *Colloquy of Mobiles* (Fig. 1.3) was the physical manifestation of the details of machine-to-machine interaction and human-to-machine interaction explored in his Conversation Theory.[24] Conversation Theory outlines that in that there was a feedback loop between the user and the machine, where users interacted with the machines, that modified the environment which would influence the behaviour of the user. This feedback loop was also present in pure machine interactions in which machines would impact and change the environment which would be sensed by itself or other machines, leading to a further modification of action and conditions which

22. Tristan d'Estrée Sterk, "Using Actuated Tensegrity Structures to Produce a Responsive Architecture," *Proceedings of the 23th Annual Conference of the Association for Computer-Aided Design in Architecture (ACADIA)*, January 2003, 86–92, https://doi.org/10.52842/conf.acadia.2003.085, 87.

23. Fox. *Interactive Architecture–Adaptive World*, 11.

24. Usman Haque, "The Architectural Relevance of Gordon Pask," *Architectural Design* 77, no. 4 (2007): pp. 54-61, https://doi.org/10.1002/ad.487, 54.

↩Fig. 1.3 Reconstruction of Gordon Pask's *Colloquy of Mobiles*. Paul Pangaro.

would spread and repeat.[25] Haque further compounds this in his review of Pask's importance of interactive design, expressing that

> "If we think of having conversations with our environments in which we each have to learn from each other, then Pask's early experiments with mechanical and electrochemical systems provide a conceptual framework for building interactive artefacts that deal with the natural dynamic complexity that environments must have without becoming prescriptive, restrictive and autocratic."[26]

While the basics of Conversation Theory are simple, it serves as the fundamentals of a more complex cybernetic architecture that can continuously evolve, change and adapt to its inputs by varying its output.

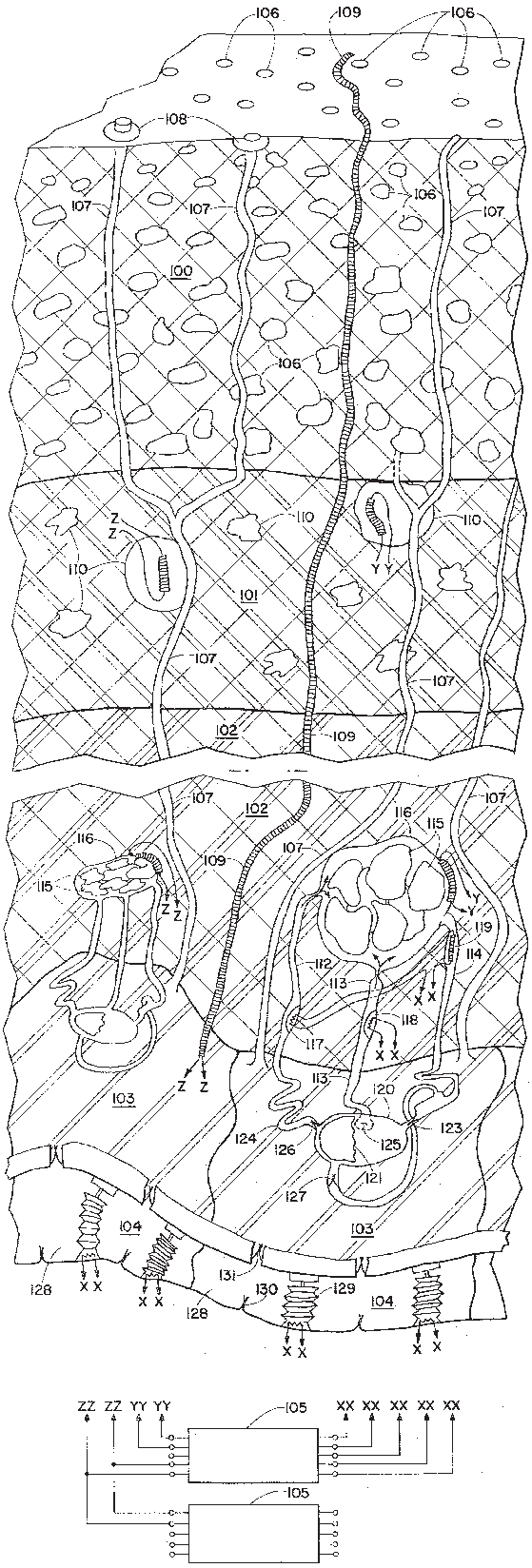
In Warren Brodey and Avery Johnson's patent for Soft Control Material (SCM), the description for its control was described as such: "The material is self-organizing; it uses distributed, self-referent, and majority control of regions of the material, which allows greatly reduced amounts of information to be transmitted between units for communication therebetween"[27] SCM was designed to have distributed control through independent 'units' transmitted to each other. (Fig. 1.5) While most computer researchers were looking at how to increase computation and model complexity, Brodey and Johnson wanted to create physical systems

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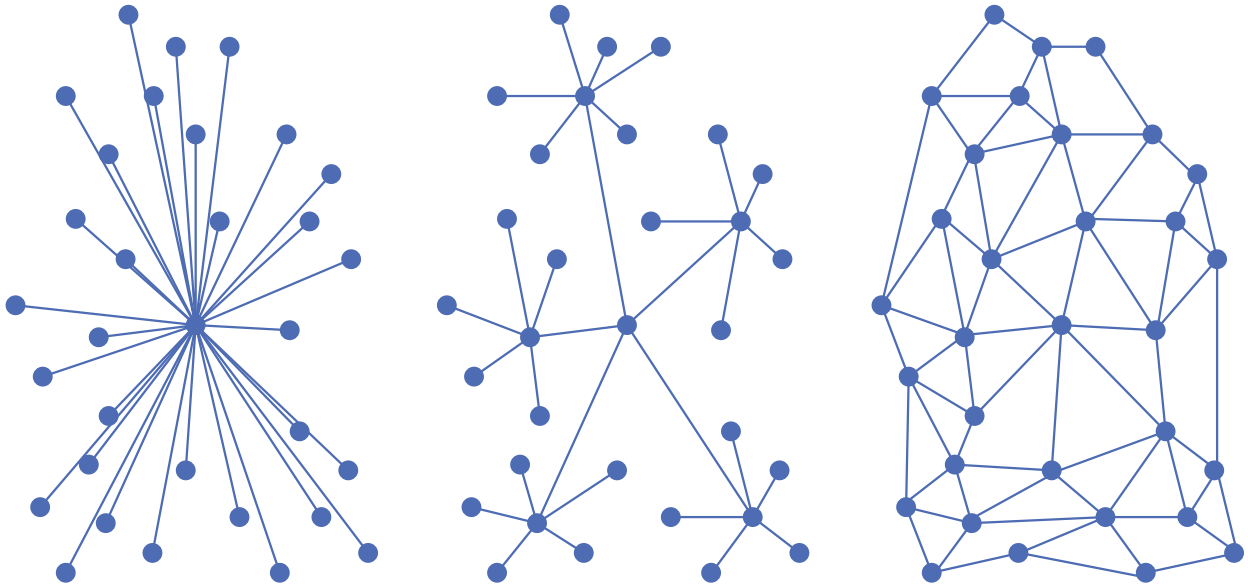
25. Haque. "The Architectural Relevance of Gordon Pask," 54.

26. Haque. "The Architectural Relevance of Gordon Pask," 55.

27. Warren M. Brodey and Avery Johnson, Soft control materials, issued June 18, 1974. US3818487A. Abstract.



→Fig. 1.5 Section through Soft Control Material from Brodey and Johnson's Patent. X, Y, Z were electrical signals between the peripherals and the control system (105). The variety of channels represented tubes, valves and bladders. The dark hatched strips (109) are thermosensitive strips that are akin to sensors. Illustration by Warren Brodey and Avery Johnson.



CENTRALISED DECENTRALISED DISTRIBUTED

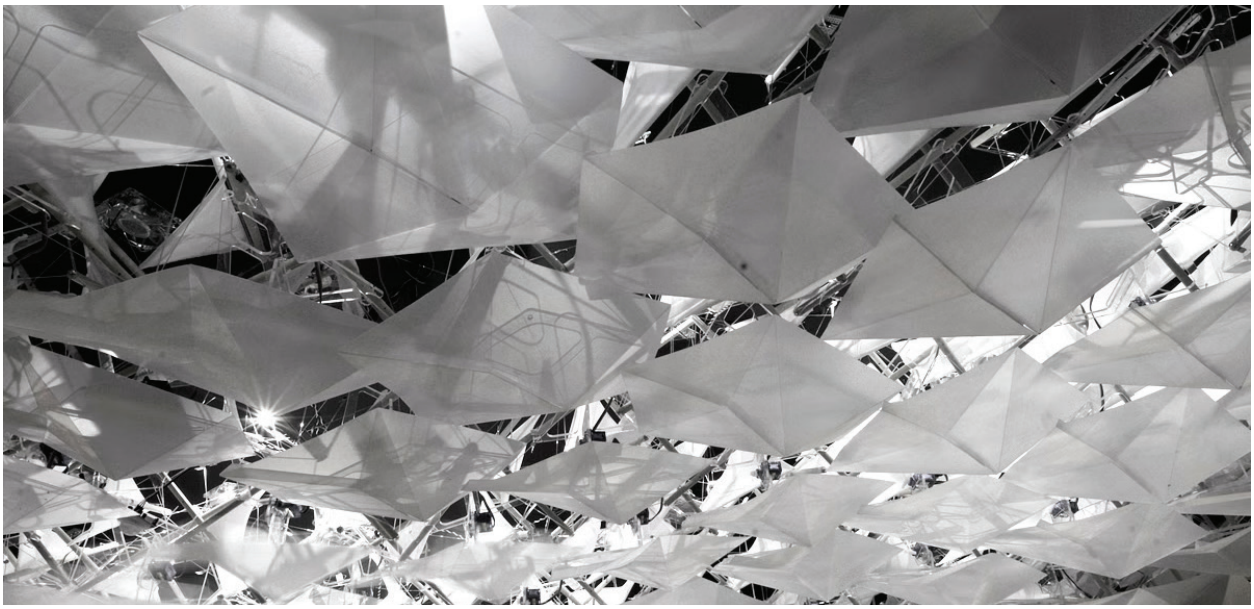
↑Fig. 1.4 Different structures of control. Diagram by author.

that have the lowest form of 'behaviour': "response to stimuli, and elementary forms of 'learning.'"[28] The patent explicitly states that SCM was decentralized and that 'units' could transmit to each other. Applying cybernetic theory, individually each 'unit' had a simple feedback loop, but as a system, the multiple feedback loops might coalesce, which could result in complex emergent behaviours.[29] Kas Oosterhuis and the Hyperbody group at TU Delft, build upon this with their *swarm architecture*, which he defines as "the idea that all building elements operate as intelligent agents. [...] They monitor their mutual positions, they measure distances towards their neighbours in real-time. Members in a swarm are always calculating. [...] The building is the swarm."[30] If a swarm architecture project was to be actualized at a true architectural scale, there could be thousands of embedded microprocessors, but since they are part of this expansive mesh network,

28. Busbea, 147.

29. "An emergent behavior can be described as a process whereby larger patterns arise through interactions among smaller or simpler entities that themselves do not exhibit such properties."
Iva Bojic and Kristian Nymoen, "Survey on Synchronization Mechanisms in Machine-to-Machine Systems," *Engineering Applications of Artificial Intelligence* 45 (October 2015): 361–75, https://doi.org/10.1016/j.engappai.2015.07.007;
Kas Oosterhuis, *Hyperbodies: Towards an E-Motive Architecture* (Basel: Birkhäuser, 2003), 51, 91

30. Oosterhuis, 51.



↑Fig. 1.6 *Stratus Project* when fins open to breathe. rvtr.

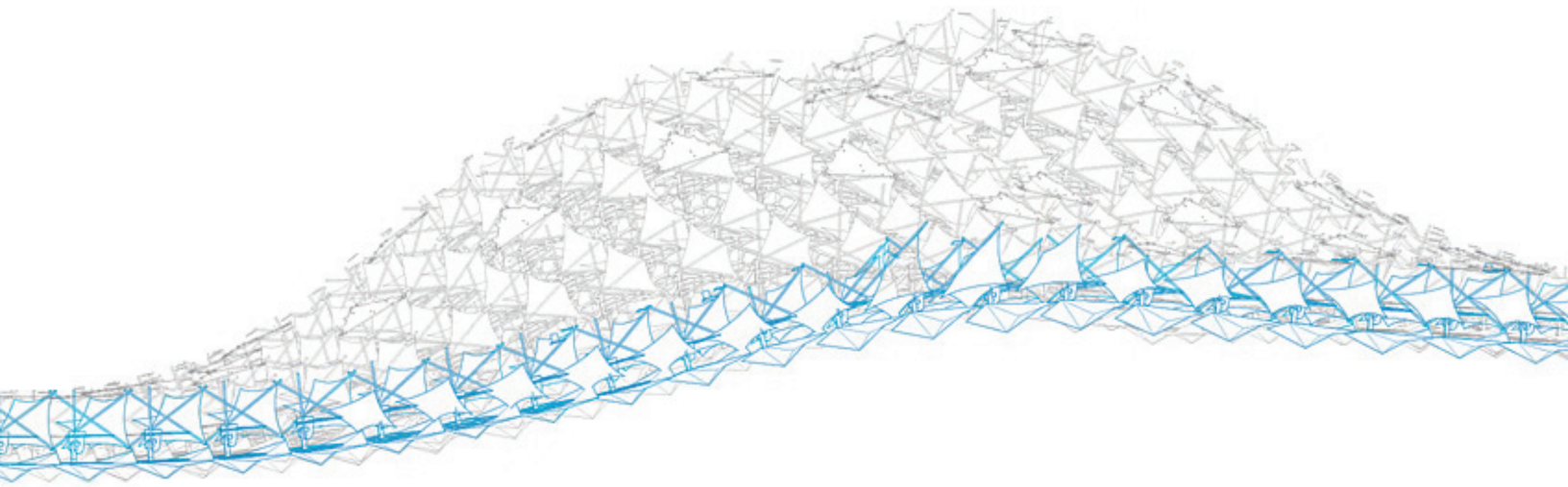
most likely would each have a light computational load. These simple microprocessors could then be programmed with very basic rule-based programs as if they were a bird part of a flock.[31] With this, the building comes alive, constantly subtly responding to occupants, the environment and itself in real time.

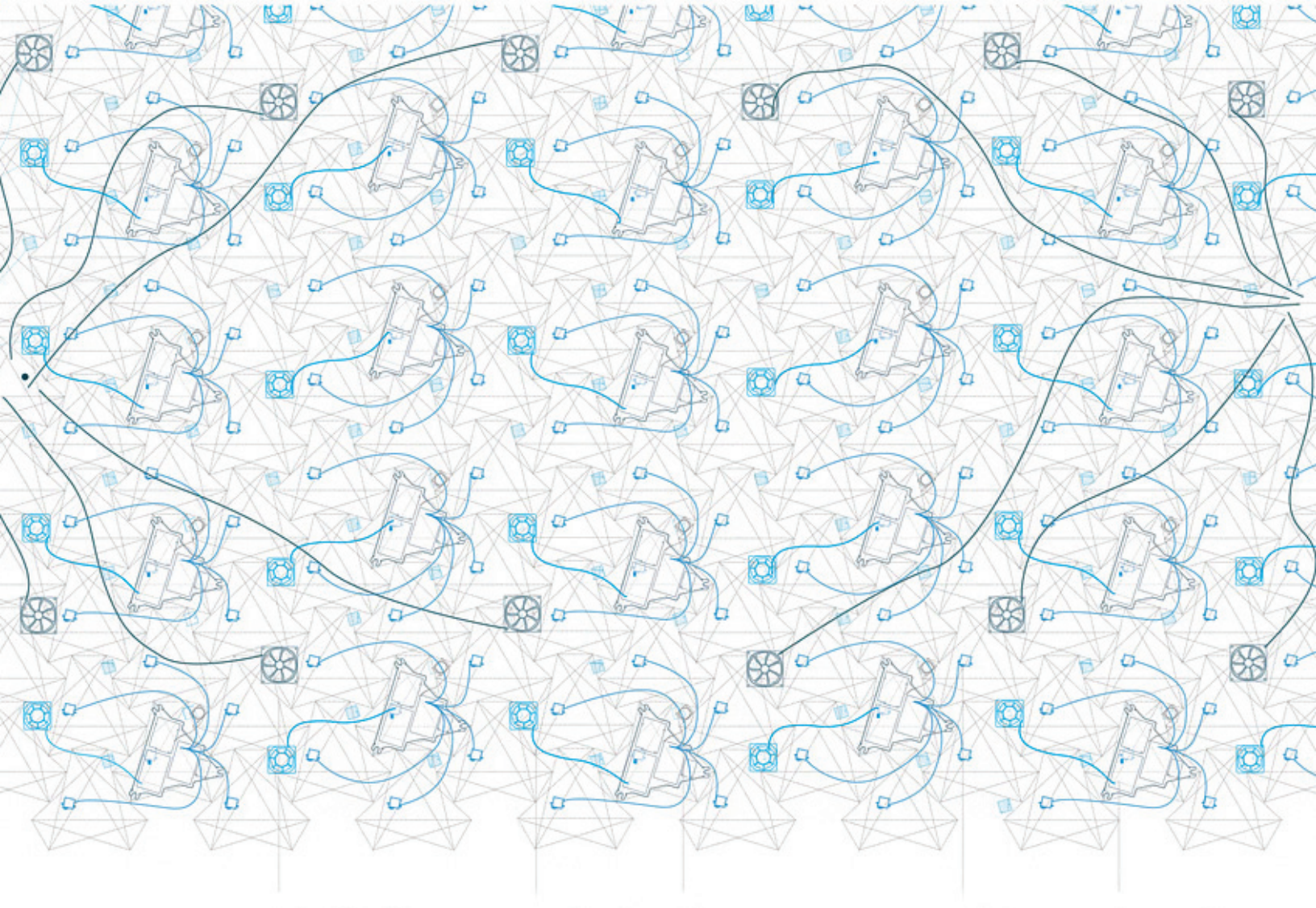
rvtr's *Stratus Project* shows how we can create complex environment-responsive interior envelope systems by using a variety of material assemblies, sensors, and actuators. The installation moderates an air-based environment to create feedback between the atmosphere and users. The installation is an aggregate of similar components whose structural mechanical and communication systems are distributed which allows for a localized, more personal response.[32] This distributed pattern of control could only be achieved in recent years due to the miniaturization of electronics and advent the of embedded computation, and wireless mesh networks. (Fig. 1.7)

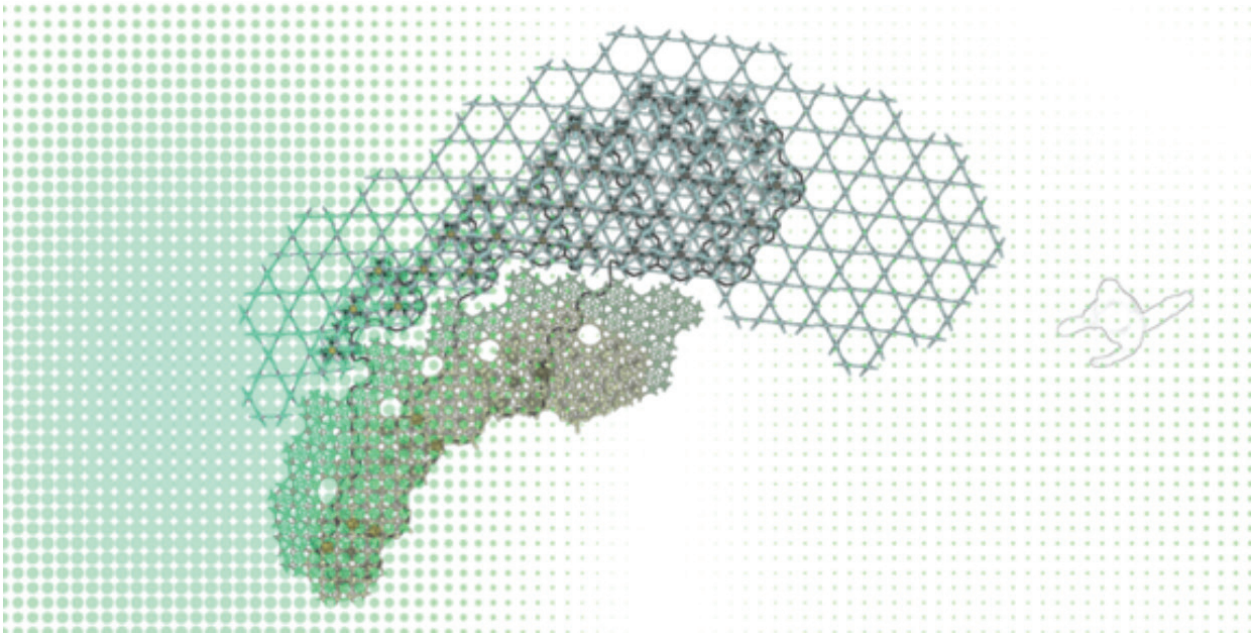
31. "This flocking behaviour can be adequately described in 3 simple rules: 1] Cohesion: Fly towards your centroid of your local flock mates, 2] Separation: Keep a certain distance away from nearest flock mates, 3] Alignment: Align your velocity vector with that of the local flock." Oosterhuis, 51.

32. Colin Ripley, Geoffrey Thün, and Kathy Velikov, "The Stratus Project: Responsive Interior Atmospheres," *Interiors* 3, no. 1-2 (2012): pp. 43-58, https://doi.org/10.2752/204191212x13232577462538.

↳Fig. 1.7 Illustration of individual components needed to make a unit. Units together form an aggregate. Illustration by rvtr.




extraction fan
cooling fan
pir sensor
micro-servo
temperature



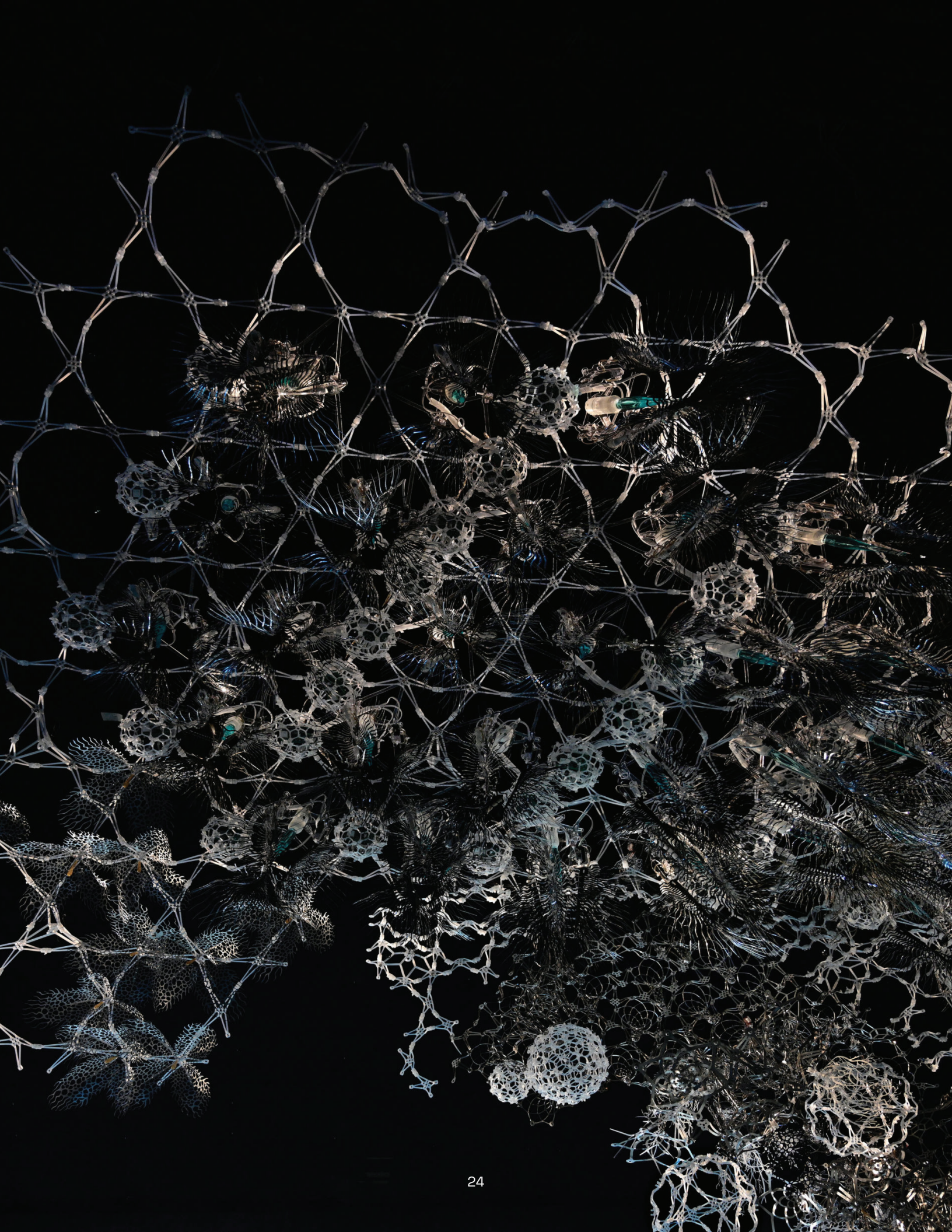
↑Fig. 1.8 View of Gorbet's Influencer Engine Interface. Note the splats of green represent areas of actuation. As these splotches move across, actuators come alive based on how intense the colour is on them.

↳Fig. 1.9 Worm view of the first iteration of *Poeitic Veil*. Note the small spheres in rows, those are the nests that hold the microcontrollers. LASG, Philip Beesley.

33. Gorbet, 128.

34. "Influence Engines are independent pieces of software that algorithmically generate influence levels to be applied to the characteristics of the digital milieu. For example, a simple Influence Engine might create the appearance of waves that move through the space, by evaluating the amplitude of a virtual waveform at various physical locations."
Gorbet, 56.

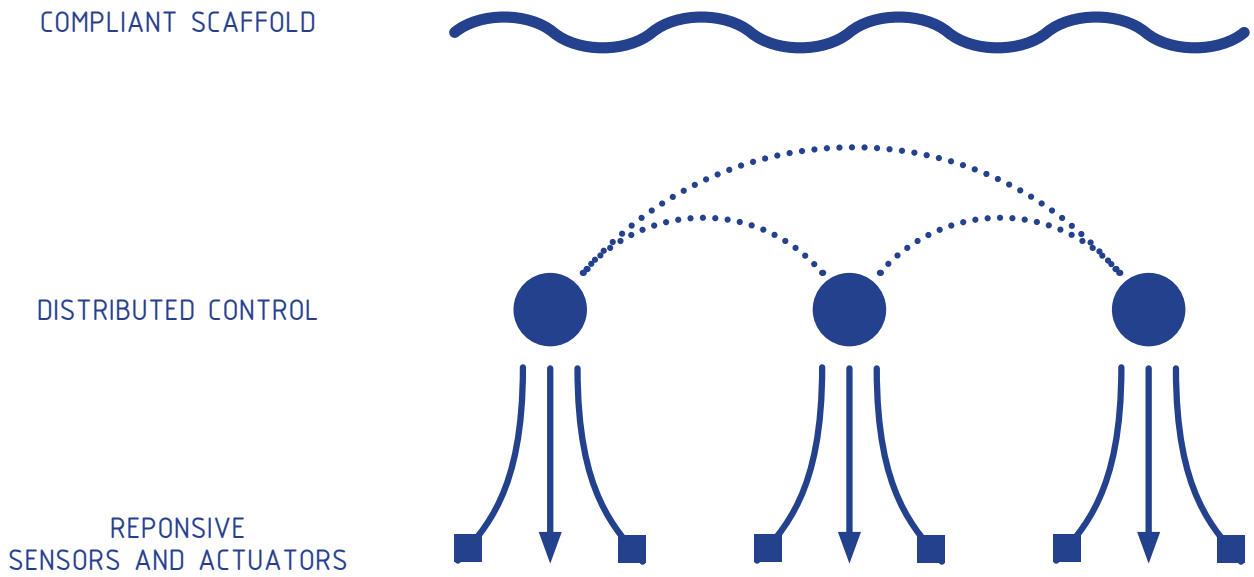
The Living Architecture Systems Group (LASG) has been developing a distributed control for their immersive installation for the past few years. This new system was first applied in an inchoate form in 2020 for *Meander* and only reached full maturity as a truly distributed system in 2022 for *Poeitic Veil* using Wi-Fi-enabled microcontrollers. *Poeitic Veil* consists of 40 microcontrollers each in charge of their actuators and sensors. They have information on their location within the space while the real-time behaviour of their actuators is calculated locally.[33] A central server also communicated with them a global signal that created activation based on a pattern known as Influencer Engines.[34] (Fig. 1.8) This structure of having a wireless swarm of connected microcontrollers that can act locally but be triggered globally really shows the powerful capabilities that are possible.



By defining what ‘soft’ means in ‘soft architecture’ as a means of responsiveness in an environment, allows for more interesting possibilities beyond physical qualities of materiality. Soft architecture is a responsive architecture; it has a tectonic that reflects this responsiveness by being lightweight and compliant and can be hard, soft or anything in between, Negroponte succinctly summarizes the ideas of cybernetic architecture as “... the configuration is one where many parts, human and mechanical, are communicating with themselves and with each other, while the consortium as a whole is somehow communicating with the real world.”[35] It is through a swarm of microprocessors that have simple programming, that the sum of these results in a more intriguing meta-behaviour of emergence. With its material flexibility and emergent behaviour via distributed control, a soft tectonic allows for spaces to seem alive.

35. Nicholas Negroponte, “Toward a Theory of Architecture Machines,” *Journal of Architectural Education* (1947-1974) 23, no. 2 (March 1969): pp. 9-12, https://doi.org/10.2307/1423828, 11.

↓Fig. 1.10 Three layers of a soft tectonic. Diagram by author.



manifesto for soft architecture

soft architecture is a response
it is a response to hard architecture
it is a response to people
it is a responsive environment

soft architecture is not firmitas,
it is diaphanous as in compliant
it is diaphanous as in light
it is diaphanous as in impermanent

soft architecture is not utilitas
it is adaptable as in reconfigurable
it is adaptable as in responsive
it is adaptable as in decentralized

soft architecture is not venustas
it is approachable as in inexpensive
it is approachable as in easy
it is approachable as in open

CH.2

FRAMEWORK FOR AN APPROACHABLE INTERACTIVE ARCHITECTURE

"It is about designing tools that people themselves may use to construct – in the widest sense of the word – their environments and as a result build their own sense of agency."

Usman Haque, Architectural Relevance of Gordan Pask, 2007

MAKER MOVEMENT = OPEN

MAKER MOVEMENT =/= OPEN

In *Soft Architecture Machine,* Negroponte and Yona Friedman use an entire chapter of the book to examine and imagine how the use of new emerging software and cybernetic theory could make design more accessible by including the participation of users.[36] Ideas of inclusivity and how to engage with the broader public in design through the usage of new technologies were of interest to key thinkers of the cybernetic movement. Historically, research and participation in the field of interactive architecture required one to have access to tools and knowledge only obtainable at the forefront of research at institutions of higher learning. Major figures that were instrumental to the foundation and development of interactive architecture like Gordan Pask and Kas Oosterhuis have all done their research at prestigious universities and skewed towards a certain demographic: white males.[37] Yet these traditional barriers of entry seem to be no longer as exclusionary with the further progress of technology and the development of the internet. The advancement of technology and its rapid economization, results in technology being the most accessible and democratized it has ever been.[38] Michael Fox states in *Interactive Architecture - Adaptive World*, that

36. Nicholas, Negroponte. Soft Architecture Machines. 92-119.

37. While there is no demographic information specifically about the field of interactive architecture, we can gleam general patters when we look at statistics about the related fields of Technology, Architecture and the Maker Movement. According to the Equity in Architecture Survey 2018 done by Equity by Design, only 0.02% of architects in the USA are African-American females, in contrast to their percentage of 6.5% of the general population. In tech, both Black and Hispanic share of the industry (7.4% and 8% respectively) are noticeably lower than their share of the general American population (13 and 18%). Despite narratives of openness and inclusivity, the maker movement does not fare well either, with a report on the subscriber base of Make magazine in 2010 being 90 percent male and 75 percent are college-educated, with an average annual household income of over $100,000 and an average age of 40.
Annelise Pitts et al., rep., *Equity by Design: Voices, Values, Vision!*

"designing interactive architecture in particular is not inventing so much an understanding what technology exists and extrapolating from it to suit an architectural vision."[39] Further democratizing access to technology is the access to knowledge through the use of the Internet which has allowed for the rapid exchange and dissemination of ideas to happen at a relatively low cost.[40] The utilization of cheap micro-computers like Arduino and Raspberry Pi, and the adoption of open standards allow for platforms in which people can exchange knowledge freely while remaining compatible and highly customizable. Carlo Ratti in his book *Open Source Architecture* summarizes the potential effect of this on society:

> That is, there is a shrinking distinction between the physical and the digital world, and Creative Commons is the enabler of fluid sharing within and across them. The tiny, open-ended microprocessor is igniting a sea-change in production and design mentality, a shift toward so-called 'physical computing.' Arduinos have become the base unit of personal fabrication (or "hacking," to use the popular terminology), allowing any gadget to sense its environment, get online, control other electronic devices, or communicate with one another.[41]

- *2018 Equity in Architecture Survey Early Findings Report* (San Francisco, California: The American Institute of Architects, 2019), 15.; United States Census Bureau, *ACS Demographic and Housing Estimates: 2011-2015 American Community Survey 5-Year Estimates* § (2010).; Equal Employment Opportunity Commission, *Diversity in High Tech* § (2014).; *Make Media Kit*, 2010, http://www.makezine.com/images/advertise/SellSheets2010-MAKE-Magazine.pdf. Quoted in Susan Currie Sivek, "'We Need a Showing of All Hands': Technological Utopianism in MAKE Magazine," *Journal of Communication Inquiry* 35, no. 3 (June 10, 2011): 187–209, https://doi.org/10.1177/0196859911410317, 7.

38. Fox. *Interactive Architecture – Adaptive World,* 12.

39. Fox. *Interactive Architecture – Adaptive World*, 12.

40. Fox. *Interactive Architecture – Adaptive World,* 12.

41. Carlo Ratti and Matthew Claudel, *Open Source Architecture* (London: Thames & Hudson, 2015), 87.

This has allowed thriving online communities to flourish and spread knowledge related to the utilization of these technologies in their home life and hobbies in novel ways to them. With the spread of online dissemination via multimedia webpages that include text, drawings, images, videos, 3D models, and code (all for free!), the accessibility to the knowledge base required to do something akin to interactive architecture at an amateur level in homes seems possible. As stated by Matthew Fuller and Usman Haque, "Even the technical complexity of electronics and batch manufacturing projects are tamed and popularized in a new breed of magazines such as *Make* and *ReadyMade* and websites such as *Instructables* that provide resources for independent designers who often have not been professionally trained."[42]

The usage of everyday items can become a tectonic that challenges the art and architecture worlds to use the new and custom to achieve a certain level of sophistication and expression. Shih Chieh Huang is a cybernetic artist from Taiwan, whose work consists of 'creatures' that are interactive and almost wholly made from parts bought from common stores like dollar stores, Home Depot and Bed, Bath and Beyond.[43] (Fig. 2.1) The flourishing maker culture has created a marketplace for more consumer electronic modules that cater to artists, tinkerers and amateurs allowing for a complexity of interaction and expression unseen in this field. In using everyday items, Shih Chieh Huang pushes the envelope of what is possible while staying on a budget.

42. Matthew Fuller and Usman Haque, *Situated Technologies Pamphlets 2: Urban Versioning System 1.0*, vol. 2, 9 vols. (New York: The Architectural League, 2008).

43. Mark Jenkins, "Bits and Pieces from the Dollar Store Create an Artistic Universe at Reston Gallery," *The Washington Post*, October 12, 2016, sec. Museums, https://www.washingtonpost.com/goingoutguide/museums/bits-and-pieces-from-the-dollar-store-create-an-artistic-universe-at-reston-gallery/2016/10/12/f7dfbad8-8cb6-11e6-bf8a-3d26847eeed4_story.html.

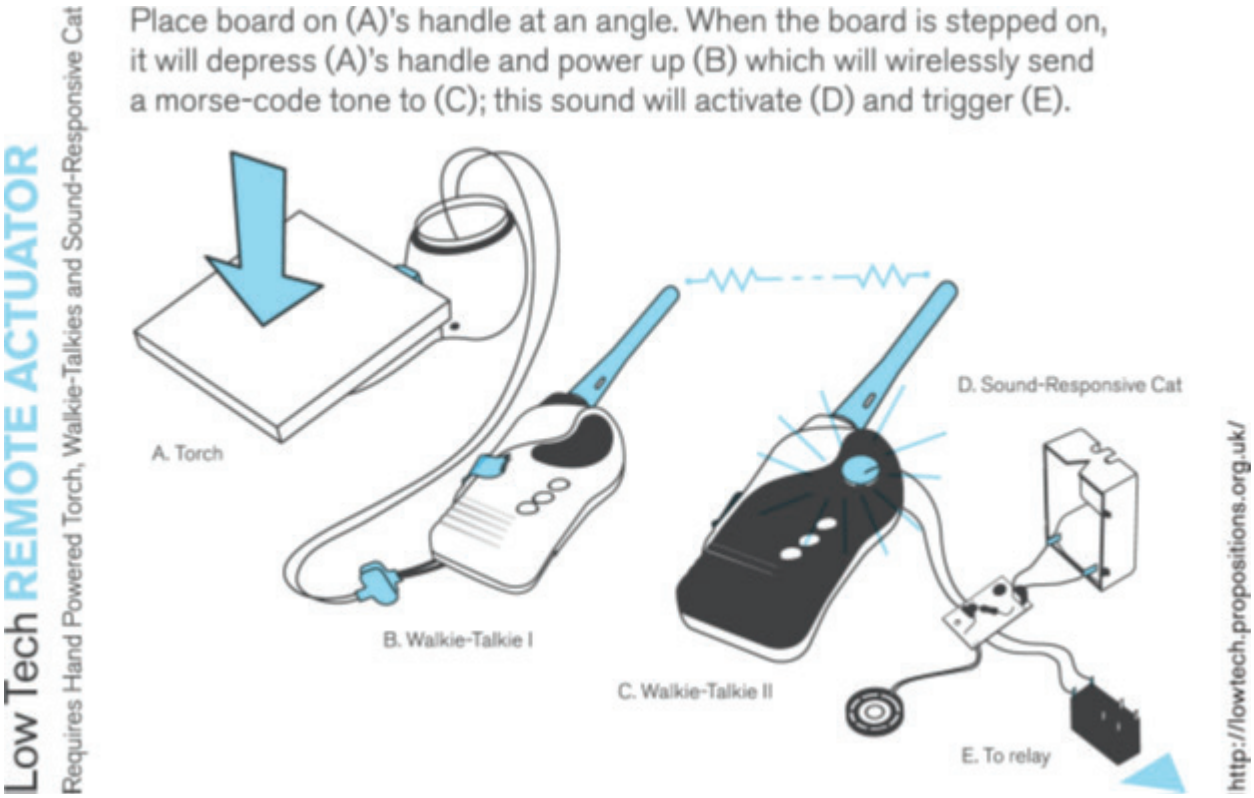


↑Fig. 2.1 Shih Chieh Huang uses everyday electronics and common consumer products to create interactive art, ***Nocturne***, 2011.

Making Do

Since interactive architecture does not require hyper-precision and accuracy to explore interaction and design, it therefore does not require sophisticated components. The issue with using the newest technologies is that they become obsolete very quickly. Technology these days has become more complicated with more moving parts, which puts it at a higher chance of using proprietary software that becomes obsolete at the manufacturer's behest and has a higher chance of failure due to the many parts. "One way of addressing this challenge of obsolescence is to rely on solutions that are already seen as 'obsolete'; as such they won't become obsolete – they already are."[44] At the intersection between this DIY culture and interactive architecture academia sits Usman Haque and Adam Somlai-Fischer's *Low Tech Sensors and Actuators*, which is a research manual into hacking

44. Manuel Kretzer, *ALIVE: Advancements in Adaptive Architecture*, ed. Ludger Hovestadt, vol. 8 (Basel: Birkäuser, 2014), 152.



existing artifacts to get sensors and actuators.[45] (Fig. 2.2) This interestingly contrasts with established interactive architecture production methods which are generally wasteful, the DIY aspect of this project allowed it to be more sustainability-oriented without even trying. The manual consists of a 'kit-of-parts' list of components that can be hacked from everyday objects and toys, thus circumventing the need to purchase these items. Each entry lists the input and output required and what it pairs with for control along with images and instructions on how to extract the desired components if needed. The component list when viewed holistically becomes an instructible on various modules that could be mixed and matched by the user.

↑Fig. 2.2 Images of how to recover electronics from common consumer electronics in *Low Tech Sensors and Actuators.*

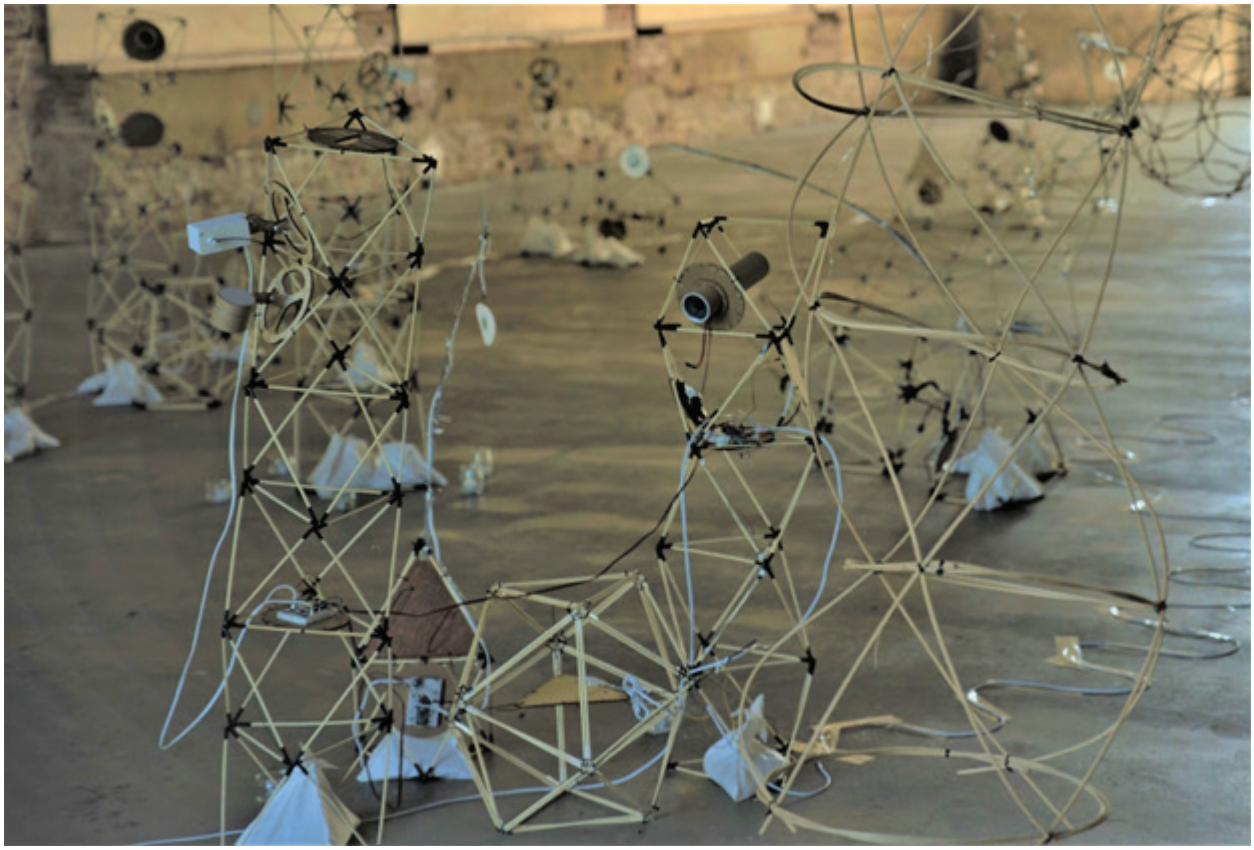
45. Usman Haque and Adam Somlai-Fischer, *Low Tech Sensors and Actuators* (Liverpool, UK: Foundation for Art and Creative Technology, 2004).

This kit-of-parts mentality is echoed in the Living Architecture System Group's (LASG) Reactor Cell Kit. While more focussed on the firm's research rather than being something to distribute to the public, the kit consists of Arduino Nano along with many typical components related to Arduinos like LED lights, PIR sensors and a DC motor among others.[46] What is interesting about this kit is the inclusion of components to create a scaffolding system using standard household items, with a sustainable bent. Wooden skewers and paper straws are paired with laser-cut cardboard disks that interface with MDF movable arms.[47] (Fig. 2.3) This results in a kit that is familiar, expandable, somewhat sustainable and inexpensive. Paired with LASG's freely available *Star Hub Kit* which explains how to create a variety of polyhedra using a consistent tectonic, allows for participants to extend their expression of form when using the kits.[48] The only problem that this kit has is its software, the Smart Cell Kit's Arduinos are hardwired with LASG proprietary Smart Actuator Interface, to simplify control of the components in-house. While this dispenses with the requirement to understand coding, the interface is highly limited in what components (and therefore forms of expression) it can control, and prevents the high customizability of open-source and modifiable software. This is the singular evidence that it was not meant to serve as a framework for a more public release (though it is part of LASG's contribution to *Domain de Boisbuchet* workshops). While this kit was not meant for public use (or has not been released as such) it has many principles of what a potential kit-of-parts for accessible and sustainable interactive architecture could look like.

46. Philip Beesley and Michael Lancaster, *Living Architecture Exploration Kits: Component Catalogue*, ed. Bianca Weeko Martin and Adrian Chîu (Cambridge, Canada: Riverside Architectural Press, 2022). https://livingarchitecturesystems.com/publication/living-architecture-exploration-kits-introductory-assemblies/

47. Beesley and Lancaster, *Living Architecture Exploration Kits: Component Catalogue.*

48. Philip Beesley, ed., *Star Hub Kit: Exploring Archimedean Polyhedra* (Cambridge, Canada: Riverside Architectural Press, 2022). https://livingarchitecturesystems.com/publication/star-hub-kit-exploring-archimedean-polyhedra/



↑Fig. 2.3 SmartCell Kit being used at LASG's Domain de Boisbuchet workshop in 2021. Note the use of skewer and cardboard tubes. Photo by LASG.

In 2007, Haque and Somlai-Fischer built upon the ethos of their *Low-Tech Sensors and Actuators* and created a full-fledged interactive environment called the *Reconfigurable House*. (Fig. 2.4) The most prominent example of some form of interactive architecture that has had some applicable utilization in daily life is the 'smart home.' The *Reconfigurable House* uses thousands of low-tech components that can be reconfigured by occupants, a challenge to the slickly produced smart home devices that are sold commercially with proprietary software and protocols.[49] This prevents the user from fixing or modifying the framework to suit their needs preventing the adaptability of the system, the occupants' own home, from adjusting to their own changing needs

49. Usman Haque, "Reconfigurable House (2007)," Usman Haque, https://haque.co.uk/work/reconfigurable-house/.



↑Fig. 2.4 *Reconfigurable House*, Usman Haque, 2007

and desires over time. The dissemination of *Low-Tech Sensors and Actuators* is free over the web and becomes a seminal resource for those ready to dive into a more approachable and accessible form of interactive architecture, while the example provided in the form of the *Reconfigurable House* creates a proof-of-concept on a hackable low-tech interactive architecture.

The problem with a low-tech ethos of the 'making-the-best-of-what-we-have' approach is that it is only viable on a small scale. Once the scale of the installation requires many components, it becomes a bit ridiculous to buy 20 moving cat toys to salvage its parts. While most components listed were reasonably unique enough to perhaps justify the mass salvaging, there could be a case in which arguing for the purchasing

of the components directly would be ironically less wasteful, though perhaps harder to access or more expensive. Or perhaps more than 15 years later, *Low-Tech Sensors and Actuators* with its ethos of 'making do' no longer apply in today's age where electronic components and Arduino Kits have become so cheap to order, especially in highly developed countries.[50] This becomes an issue of sustainability versus affordability, a dilemma many people of lower income must grapple with. While the burden of climate change should not be pushed onto the shoulders of marginalized and low-income communities, a framework that balances both or provides alternatives to achieve one or the other becomes valuable when addressing the issues of the field of interactive architecture which is often expensive and unsustainable.

50. Or its because I moved to the suburbs and have now become out of touch.

Approachable Framework

The precedents analyzed, help inform a potential framework for an interactive architecture that is accessible. While each precedent provided an example of an approach that tackles a particular issue, none provides an all-encompassing framework that allows for a truly accessible interactive architecture. This thesis seeks to create a framework to make the field of interactive architecture more accessible and inclusive to a wider demographic of people, especially those in the creative and design fields and beyond those already engaged with tech as a hobby. The goal is to disseminate knowledge that allows for the production of interactive architecture at a level close to those done by academia but on a budget. Through the creation of

architectural fixtures that employ this framework, a guide that documents the creation of the fixtures will present the knowledge behind the framework in an accessible manner. While there could be an argument about more accessible software that does not need the understanding of coding, these methods tend to be oversimplified and cannot do complex things that coding offers, and allows for the development of a certain way of thinking and useful skillset. The documentation of the fixtures' creation will therefore be proof–of–concept and serve as example instruction on how to achieve certain simple forms of expression.
In summary, both the document and the kit must abide by these principles:

Accessibility: It must be based on open-source principles to allow for easy access to learning resources and assets to prevent obsolescence. Do people have easy access to the resources needed to use this.

Affordability: It must be inexpensive and accessible to acquire materials and components, this could include reusing existing objects, but an option to buy will be presented if it is within acceptable prices.

Extensibility: The methods and modules presented must allow for high customizability to allow for the extension of the kit and a limitless form of expression.

Approachability: It must be approachable so that most people can learn how to do it quickly and intuitively. Novices can understand how things come together and work.

Reconfigurability: It must consist of pieces that can be easily and quickly rearranged and reused. Pieces should never have a one-time use lifespan. Therefore, connections must be designed securely yet enable ease of disassembly. Can things be rapidly reorganized to prototype new arrangements to address new ideas.[51]

Following these principles, one can begin to imagine a system of an approachable, affordable and inclusive ethos of making and designing interactive architecture as a means of expressing one's agency over their own space.

51. This was originally a metric for sustainability, but became hard to achieve after a certain point while balancing other factors without resorting to the cliché greenwashing arguments. While I still think this is an important metric, unfortunately it is very hard to design in a meaningful way when balanced against my other objectives. It also was hard to use as an evaluating metric when analysis existing products in this space. Inspired by the first 'R' of sustainability, this morphed it into 'reconfigurability' as a metric which directed the design of components better later on. Regardless, an under current of sustainable thinking was still present during the development of this thesis, so there will be footnotes scattered through out that relay my perspective through a sustainability lens.

CH.3

KITS AND BITS

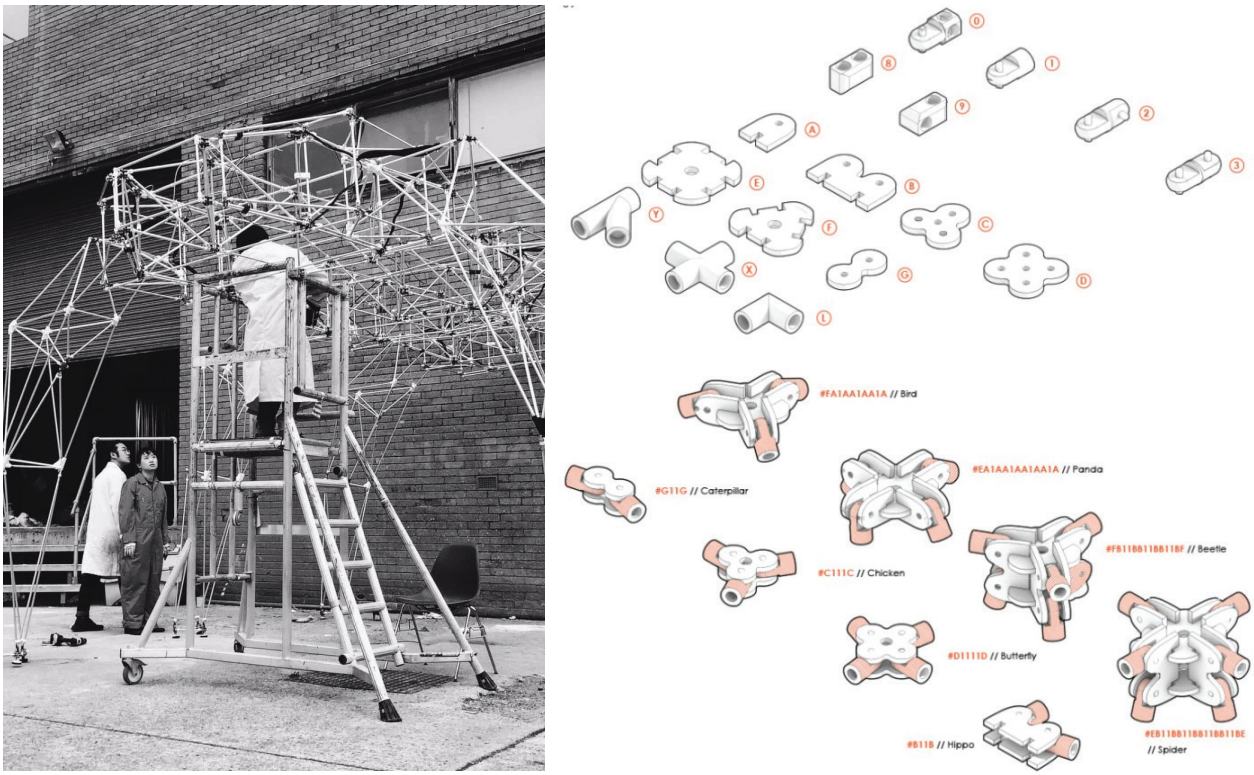
For architecture to be considered interactive, it consists of three layers. Firstly, it must have a physical presence that has spatial qualities. This manifests itself as the structure or scaffold that holds the architecture together.[52] This 'scaffold layer' of an emergent tectonic would be compliant to allow for movement and actuation, reifying a soft architecture that is flexible and porous, challenging the rigid solid and clearly demarcated architectural canon found in the West. Secondly, it must be able to be active. The scaffold holds a variety of peripherals (i.e., sensors and actuators) that change the state of the architecture through actuation. These peripherals could range from lights and speakers that change sensorial atmospheric qualities to larger kinematic devices like motors and linear actuators that can change the space itself, resulting in the 'actuation layer.' The last layer is the immaterial 'control layer,' which dictates behaviour and responses. This usually takes the form of coding but also in a decentralized architecture, this would include the wireless network mesh that allows for communication between nodes. By breaking down interactive architecture into these layers, we can more minutely analyze how precedents of different kits

52. Philip Beesley, ed., *Near-Living Architecture: Work in Progress from the Hylozoic Ground Collaboration*, 2011-2013 (Toronto, Canada: Riverside Architectural Press, 2014), 11.

perform this function. This allows for the inclusion of a wider breadth of materials so that one may look at different types of kits that are only related to one layer. The next section analyses a series of precedents of each layer to be case studies. This analysis establishes the current state of comparable technologies and methods for an interactive architecture, and would help see how they compare to the principles established in the previous section. At the end of each section that details each layer, an evaluation of each precedent to the Framework allows for a broad overview of which aspect needs focus.

Scaffolds

This category collects various structural systems that could be used in a hypothetical (but possible) interactive architecture of the near future. Emerging research of lightweight tensile structures that allow for kinematics will enable an architecture that can transform. As the main structure and passive expression of tectonics, the scaffold of an emerging cybernetic soft architecture would have joints that allow for movement or would be made of compliant materials or junctions to naturally respond to structural stress without breaking. This allows for a lightweight porous expression of structure that counters the stereotomic Western canon. The ability to be resilient yet compliant is needed in an architecture that is adaptable as it changes to the various factors that inform its response.

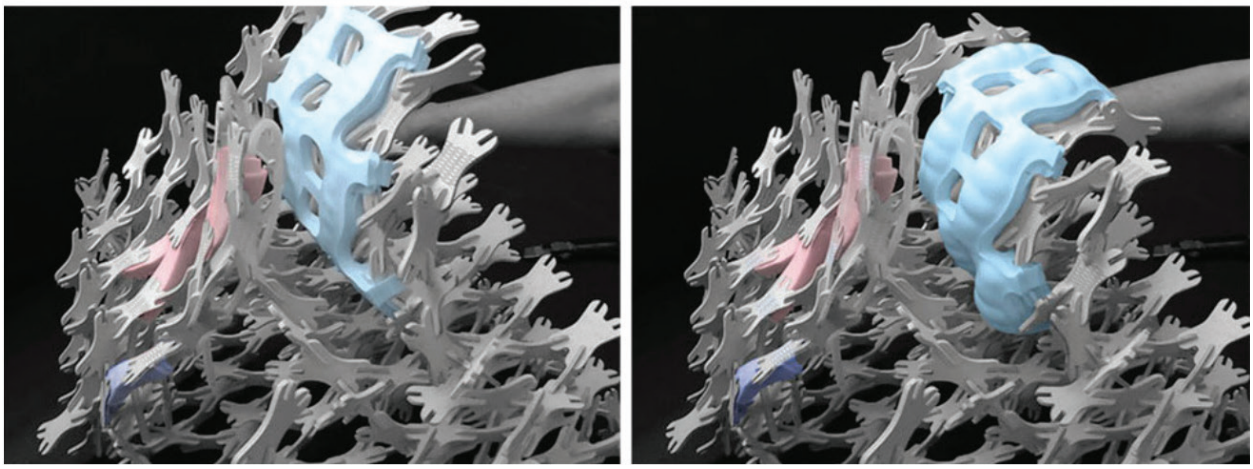


↑Fig. 3.1 *Golem Kit*, Interactive architecture Lab

The Interactive Architecture Lab at University College London has been working on the issues of how to make pneumatic structures easily. *Golem Kit* is a lightweight, low-cost and open-source pneumatic toolkit, to "Invent with Air Power" that takes advantage of low-cost 3D printing and open hardware tools such as Arduino.[53] It comes with a variety of joints made from assemblages of laser-cut pieces that allow for a variety of movements in three-dimensional space. (Fig. 3.1) The research group followed this up with a similar project two years later by releasing *Rapid Kinetic*, which is described as an educational toolkit for prototyping lightweight dynamic structures using DIY pneumatic artificial muscles, and a custom pneumatic control and simulation system. They replace the joints with 3D-printed snap-fit joints, while the structure changes from wooden dowels to aluminum conduits.[54]

53. Jing, Siyuan, Lydia Zhou, and Juncheng Chen. "Golem." *Interactive Architecture Lab*. University College London, March 23, 2016. http://www.interactivearchitecture.org/lab-projects/golem.

54. Enrico Cacciapuoti, Dhruv Kumar and Min. "Rapid Kinetic," 2018. http://www.interactivearchitecture.org/lab-projects/rapid-kinetic



↑Fig. 3.2 *Pneu*, Vera Parlac

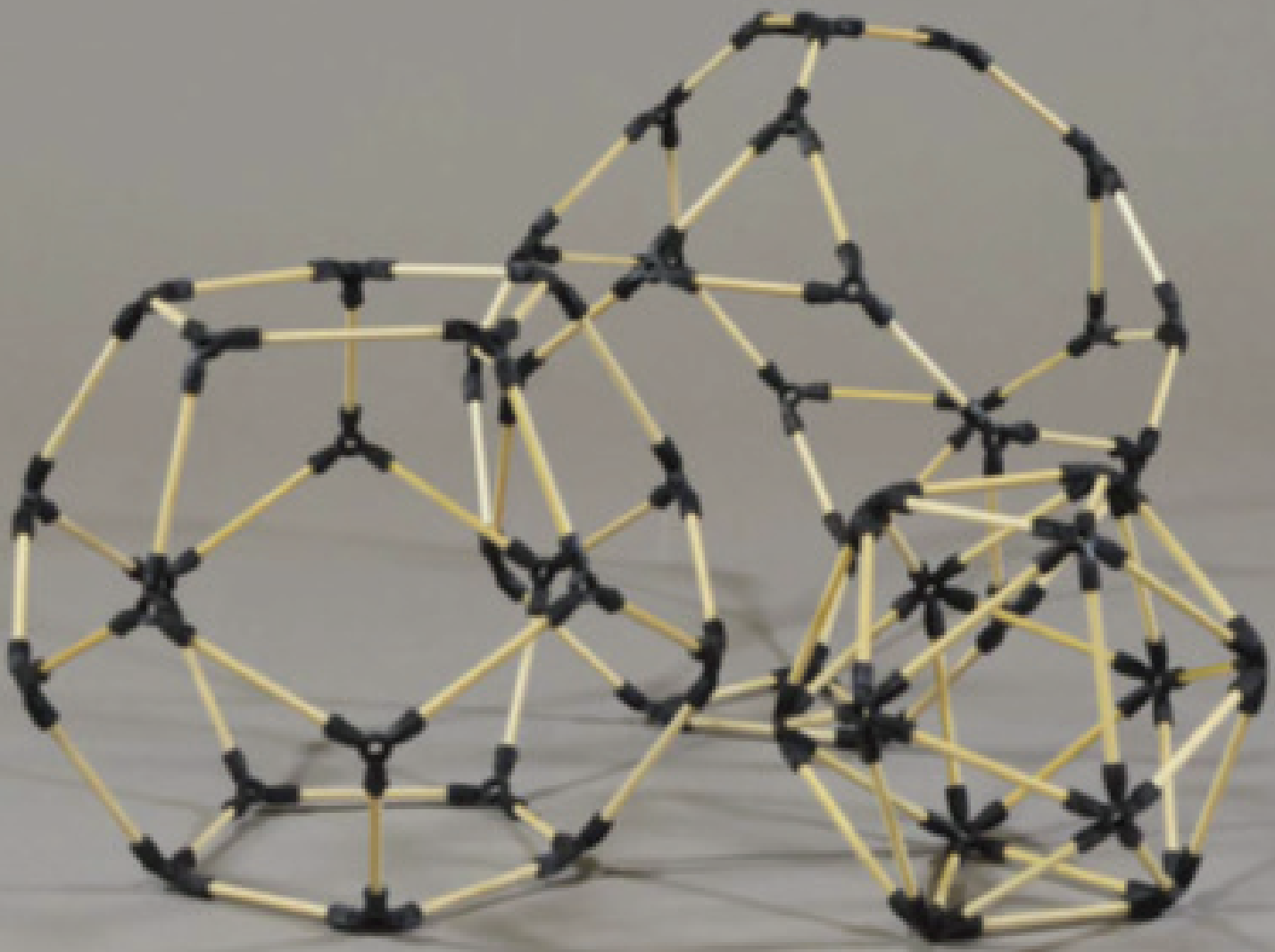
While both *Rapid Kinetic* and *Golem Kit* rely on a variety of different joints, Vera Parlac's *Pneu* reduces the number of parts in use in her soft architecture tectonic into only a small handful of laser-cut pieces with some silicon moulded inflatables. (Fig. 3.2) Each piece forms a 'pneu cell' and has four snap-fit joints.[55] A kerf pattern in the middle allows for bending motion. The ability of the structural pieces themselves to be inherently compliant results in an aggregate configuration resulting in multiple parallel structures of redundancy that make the resulting assembly stronger. This cellular framework of imagining an assembly as a singular unit helps with the conceptual jump from small objects to the design of larger architectural-compliant geotextiles.[56] In LASG's *Star Hub Kit*, the joints are 3D printed using Thermoplastic Elastomer (TPE) which is a plastic that can easily flex.[57] (Fig. 3.3) By using an inherently compliant material, the design of joints becomes simpler and requires less assembly. The inherent flexibility of TPE allows for the joints to bend in any direction in three-dimensional space, rather than the prescribed axle in more rigid assemblies.

55. Parlac, Vera. "Soft Architectural Assemblies: Soft Kinetics." *107th ACSA Annual Meeting Proceedings*, Black Box, 2019. https://doi.org/10.35483/acsa.am.107.69.

56. Kevan Cress and Timothy Boll, *Living Architecture Systems Description: Extensible Spatial Data System For Responsive Architectural Environments*, ed. Philip Beesley (Cambridge, Canada: Riverside Architectural Press, 2023). https://livingarchitecturesystems.com/publication/living-architecture-systems-description/

57. Philip Beesley, ed., *Star Hub Kit: Exploring Archimedean Polyhedra*

↳Fig. 3.3 Star Hub Kit 2.0, Note the flexing of the joints due to the flexible nature of TPE. Photo by LASG.



This sets up a very interesting question of what is the more accessible digital fabrication method as both typological tectonic are equivalent, only a change in method of fabrication. Laser cutting is very easy to design for and can potentially be made from more sustainable materials like cardboard, plywood or fibreboard. The machines have been around for decades, yet are expensive and difficult to own. The benefits of 3D printing are the increase in dimensional possibility and its general affordability. The cost and ease of use for decent 3D printers have dropped consistently in the last decade. Many schools, libraries and community centres now have a good number of 3D printers that can be used by locals at a low cost. Despite this, creating the actual component to be 3D printed can be a challenge, especially for those who are not from a technical field that requires knowledge of CAD and 3D Modeling. There are more accessible 3D modelling tools like TinkerCAD, but these lack the precision needed to model components like this. 3D printing is also marred by the inherent fact that plastic is bad for the environment, from microplastics to being sourced from fossil fuels. One could get Polylactic Acid (PLA)[58] which is derived from plant sugars and is technically recyclable. Unfortunately, recyclable in this context means you must pay for someone else to recycle.[59] The choice of digital fabrication allows for the ability of the kit to be expanded with a high degree of openness but begs the question of which tool is better suited for the task of empowering individuals to design. By evaluating these digital fabrication techniques based on the thesis framework, an FFF[60] 3D printer will likely be the best at balancing the factors of sustainability, accessibility, extensibility and affordability.

58. Polyhydroxyalkanoates (PHA) in filament form exists and is completely biodegradable without the need for industrial composters allegedly, but is generally a bit more expensive and not as widely available. There are also PLA filaments with bio-based filler like wood or algae which could lower its overall environmental footprint.

59. Regardless, please investigate how to recycling your 3D prints whether it is made from PETG, PLA or others and explore using recycled filaments.

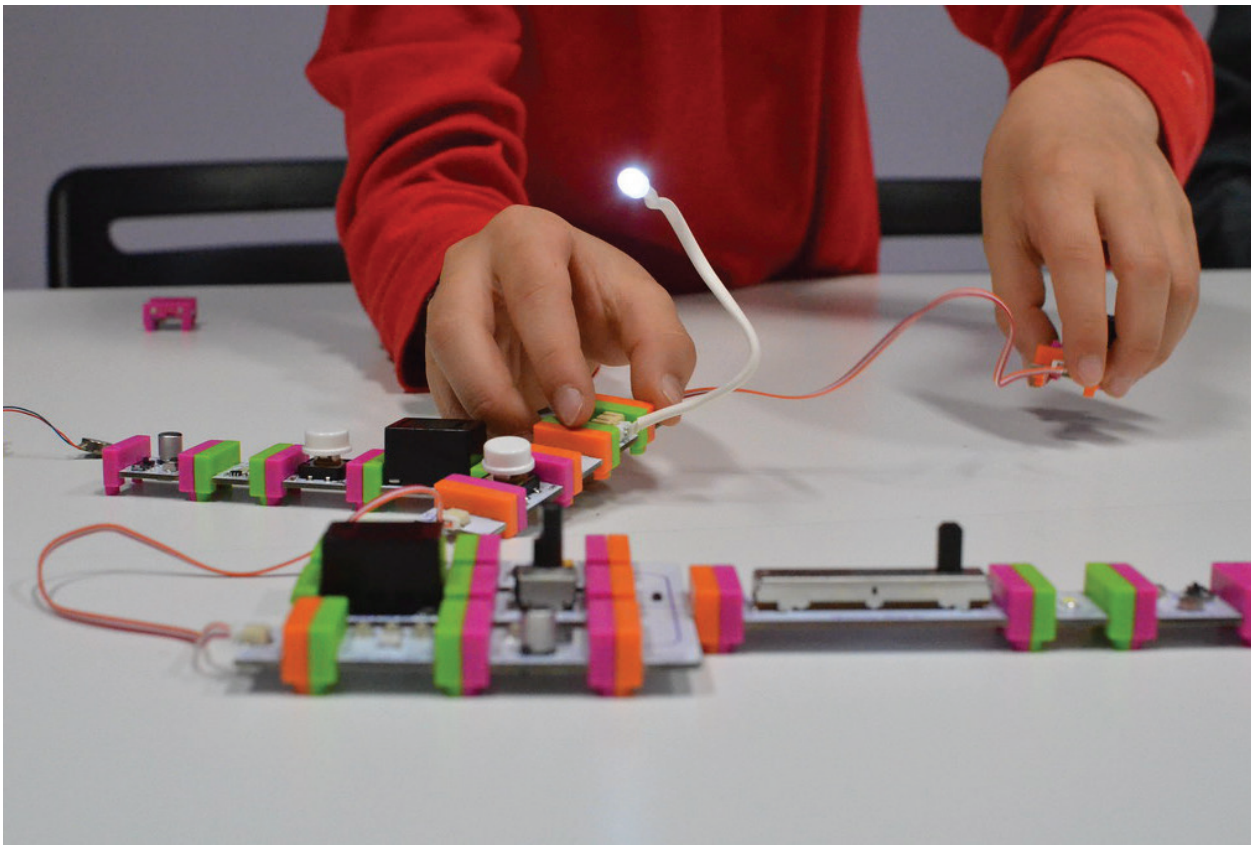
60. Fused filament fabrication, also known as fused deposition modeling or FDM

	SPIKE / Powered Up	***LittleBits***	***Elegoo Arduino Kit***	***Grove Pi Kit***	***Connected Interaction Kit***	***SmartCells Kit***
Owner	Lego	Sphero	Elegoo	Seeedstudio	TUDelft IEM / StudioLab	LASG
Age Range	4 to 16	8 to 14	12+	9+	20+	14+
License	Proprietary	Proprietary	Proprietary	Creative Commons	Creative Commons	Proprietary
Controller	Proprietary	Proprietary	Arduino Uno	Raspberry Pi + GrovePi Shield	ItsyBitsy + Custom Grove Expander Board	Node controller + Adafruit Wing Arduino
Components	Proprietary	Proprietary	Hobbyist electronics[62]	Grove	Grove	Hobbyist electronics
Cable Type	Proprietary	Proprietary	Dupont	Grove	Grove	Dupont
Addons	Yes, only through Lego	Yes, only through Sphero	Yes	Yes, via Grove ecosystem	Yes, via Grove ecosystem	Yes
Scaffold	Lego / Lego Technic	N/A	N/A	N/A	Typically PVC Tubing + acrylic hubs, could be anything	Skewers + PVC Tube connectors
Connectivity	Bluetooth to smartphone	Addons needed (Custom protocol, Wi-Fi, Bluetooth)	UART, I²C or SPI. IR, Variety of others (3rd party)	Wi-Fi, Bluetooth	ESP32 (Wi-Fi, Bluetooth)	MQTT over Wi-Fi
Programming	Block-based / python (3rd party)	Block-based	APL (C++ based)	Python, C, C#, Go, NodeJS	Circuit Python, APL	Web Interface, APL
Manual	Online	Online / Paper	Online / CD	Online / Paper	Online / Paper	Online / Paper
Approachability	✳✳✳	✳✳✳	✳	✳	✳	✳✳✳
Affordability	✳	✳	✳✳	✳✳	✳✳	✳✳
Accessibility	✳✳✳	✳✳	✳✳✳	✳✳✳	✳✳	✳
Extensibility	✳	X	✳✳✳	✳✳✳	✳✳✳	✳✳
Reconfigurability	✳✳✳	✳✳✳	✳✳✳	✳✳✳	✳✳✳	✳✳

↑Fig. 3.4 A comparison of components, features, attributes between different interactive / robotics kits. The last rows are an evaluation based on the framework established in Chapter 2.

Interactive Kits

While designing this kit, it is important to review existing kits that are being sold to hobbyist consumers and educators, and being developed by academia, and evaluate them based on the framework established to see what gaps exist in the realm of STEAM Kits that could be used for interactive architectural development. In this section, six products will be analyzed, four that are marketed for consumers and two that are being developed in academia.



↑Fig. 3.5 Note the ease of connecting via simple magnets, and the colours! Ultra-lab via Flickr CC BY-SA 2.0 DEED

Looking at the kits, a few general trends emerge: Kits that had more proprietary IP like connectors and coding programs had a slight lean toward marketing towards educators, resulting in an easier experience in learning and using but was much more 'closed,' as in less extensible and more expensive. Those that used an existing third-party microcontroller like Arduinos were generally marketed more towards hobbyists, and were more open and extensible but had a higher skillset barrier of entry. What target demographic that kits were more open to marketing for, is a huge factor in their design. Ayah Beir, the creator of LittleBits, wanted to make STEM attractive to girls, while not alienating boys, so opted for a more neutral but children-friendly design.[61] (Fig. 3.5)

61. Ayah Bdeir, "An Insider's Look at Why Women End up on the Cutting Room Floor," *Medium*, March 7, 2019, https://medium.com/@ayahbdeir/an-insiders-look-at-why-women-end-up-on-the-cutting-room-floor-71a4865a15b0.

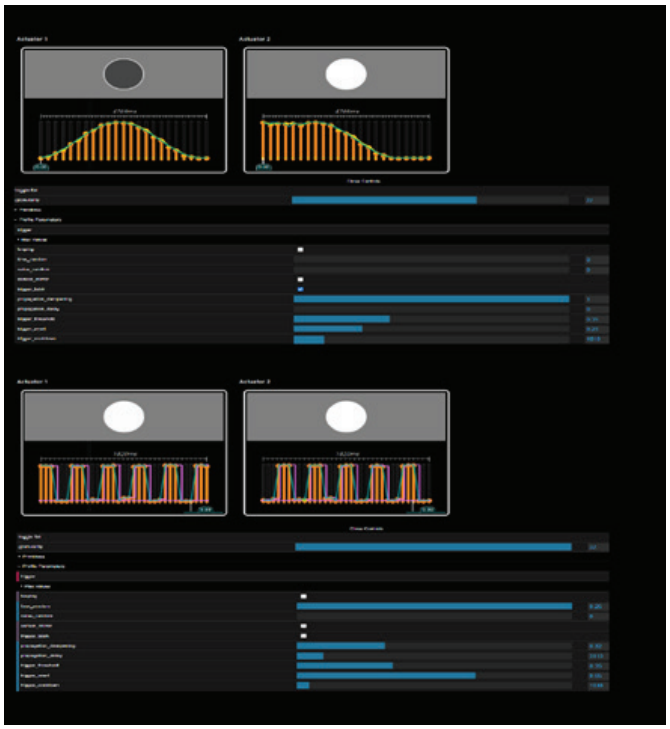
The focus on children and the classroom results in products that are very approachable, to ease the kids into STEM subjects. This forms a spectrum of trade-offs between approachability and extensibility.[62] What determines where certain things are placed on this spectrum is largely how it is designed for selective exposure. The more of the inner workings are exposed, the more fields of knowledge there are to explore and know, but also makes it more intimidating and "... much more time had to be spent on the technicalities of making things work—connecting breadboard, motors drivers, jumper wires, and resistors, as well as understanding the syntax of C code. These technicalities were exactly what the previous generations of designers attempted to hide from students, because they ended up being considerable barriers for novices."[63] This idea becomes a dilemma when designing kits because if you make it too easy to use, it may exclude potentially exciting capabilities since the goal of kits is to be creative, yet the opposite of that is having a very technically demanding toolkit that has a small demographic reach. Seymour Papert stated that for technology to be effective it must have 'low floors' and 'high ceilings;'[64] it must be easy to start with, and allow for a gradual road to sophistication over time. Mitchell Resnick adds an additional dimension of 'wide walls' - designed to support and suggest a variety of explorations that could take place on the road to sophistication.[65]

62. Bliksten uses the terms 'usability' and 'power' instead. Refer to Paulo Blikstein, "Computationally Enhanced Toolkits for Children: Historical Review and a Framework for Future Design," *Foundations and Trends in Human–Computer Interaction* 9, no. 1 (2015): 1–68, https://doi.org/10.1561/1100000057, 47.

63. Paulo Blikstein, "Gears of Our Childhood: Constructionist Toolkits, Robotics, and Physical Computing, Past and Future," *Proceedings of the 12th International Conference on Interaction Design and Children*, June 24, 2013, 173–82, https://doi.org/10.1145/2485760.2485786, 181.

64. Mitchel Resnick, *Lifelong Kindergarten: Cultivating Creativity through Projects, Passion, Peers, and Play* (Cambridge, Massachusetts: The MIT Press, 2018), 74.

65. Mitchel Resnick and Brian Silverman, "Some Reflections on Designing Construction Kits for Kids," *Proceedings of the 2005 Conference on Interaction Design and Children*, June 8, 2005, 117–22, https://doi.org/10.1145/1109540.1109556, 118.



↑Fig. 3.6 Web-based GUI for LASG's Smart Actuator Interface

The SmartCell kit by LASG is a great signifier of this spectrum, with its web-based UI for its SAI system being the most abstracted yet has the potential to be the easiest to work with.[66] Consisting of controlling things with mostly sliders and visual signifiers for actuation, really helps with making it easy to visualize how parameters affect actuation. (Fig. 3.6) On the other hand, its scaffolding system is very approachable, with a simple concept and does not shy away from a kitchen sink approach. Many other building materials included in the kit promote the use of other objects and DIY-ing solutions to extend the kit. The node controller that is attached to their Adafruit Arduino, also makes it great at being a plug-and-play situation, with the board dealing with all power regulation. Lights on the node controller also help show how each port is actuated, further increasing the connection between the physical and digital tools.[67]

66. Beesley, Philip et al., "Appendix: Notes on Software and Communication Protocols." *Poietic Veil: TU Delft Science Centre Prototype Testbed 2022* (Toronto, Ontario: Riverside Architectural Press, 2022). 68-73. https://livingarchitecturesystems.com/publication/poietic-veil/.; Beesley and Lancaster. Living Architecture Exploration Kits Component Catalogue.

67. Philip et al., "Appendix: Notes on Software and Communication Protocols."

Sets that were more geared towards hobbyists were more open-sourced, and had compatibility with a variety of existing products and systems but were harder to approach. The kit developed by TU Delft's IEM program also had many similarities to these products, due to their target audience being older, and being adjacent to TU Delft's Industrial Design Engineering program makes this appropriate.[68] Both IEM and Seeedstudio's kits use Seeedstudio's Grove modules[69] which all use the same type of connectors similar in purpose to the proprietary connectors of LittleBits and Lego SPIKE. Other connectors include Stemma and Qwiic[70] which use more available hardware connectors that are used in the electronic industries and could be a viable compromise between ease of use and extensibility[71], as they usually have an extensive ecosystem of sensors and other types of modules. It also seems to be a more resilient design choice to go with these standards that are not dependent on commercial companies since they have control over it. LEGO discontinued its iconic Mindstorms and replaced it with WeDo in 2009, and then upgraded that to WeDo 2.0 in 2016[72] and scrapped that to release its current STEAM suite known as SPIKE in 2019.[73] While the most approachable to children and educators, the constant changes the LEGO company makes to its STEAM suite and lack of backward compatibility creates anxiety over its longevity of building up a community and ecosystem. Looking at trends in this field, it seems that Arduinos and their derivative have become the standard in the Maker movement, and therefore have extensive documentation, products and resources online.[74] This makes using industry/commercial standards that are open source seem to be the best compromise between

68. "Connected Interaction Kit (2023 Edition)," *GitHub*, https://github.com/id-studiolab/Connected-Interaction-Kit?tab=readme-ov-file.

69. "Grove Base Kit for Raspberry Pi: Seeed Studio Wiki," *Seeed Studio Wiki*, https://wiki.seeedstudio.com/Grove_Base_Kit_for_Raspberry_Pi/.

70. Les Pounder, "Stemma, Qwiic and Grove Connectors: Which Is Right for You?" *Tom's Hardware*, April 24, 2021, https://www.tomshardware.com/features/stemma-vs-qwiic-vs-grove-connectors.

71. They can also be hacked to be compatible with other wire types with just some simple soldering knowledge.

72. Wayne Burnett, "Get Started with WeDo," *LEGO Engineering*, July 31, 2022, http://legoengineering.com/get-started-with-wedo/index.html.

73. Stefan Etienne, "Lego's Spike Prime Brings New Programmable Bricks to the Table," *The Verge*, April 2, 2019, https://www.theverge.com/2019/4/2/18292326/lego-spike-prime-programming-bricks-scratch-technic-robotics.

74. Blikstein, "Computationally Enhanced Toolkits," 37.

extensibility, approachability and affordability. Since most kits analyzed did not have a scaffold associated with them, the analysis presented here was also used to gauge and present options for what could be paired with the kit designed in this thesis as its 'control layer.' If paired with a more widely used and open-sourced system allows for the kit's design to be readily compatible with more devices, and open-source and FFF 3D printing allows for ease of future add-ons. Issues of accessibility in knowledge on coding and electronics really underpin how there are a variety of people with different skill sets and interests who prefer different configurations of hardware and software. There is also a variety of tools that help with making coding, or composing behaviour of microcontrollers to be more accessible to people with no to little coding knowledge. There have many attempts to try Scratch-like success but for Arduino, many have become defunct and controlled by companies and none have become the de facto standard. Many of them are block-based, meaning they are reminiscent of Scratch's interface of abstraction of code into puzzle-like pieces. Examples include Seeedstudio's Codecraft, Makebot's MakeBlock (based on Scratch 3.0), CodeKit, and Snap4Arduino. Some like CodeKit and MakeBlock are trying to add a new feature of interoperability between pure code and Block-based. Right now it is a one-time conversion into code, which could be very helpful in graduating people from graphical coding to real coding. Another type of visual coding is a node-based interface (i.e. Grasshopper's interface) has been popular for a variety of contexts, with some like XOD.io, Visuino and Node Red being popular, and having IoT capabilities. Unfortunately,

none of these tools have a mature way to add your own custom block to the extent that coding allows, nor have they penetrated the market to have very vibrant communities and standards of interoperability and doing things, as each tool is a walled garden that looks like another, but it not the same.

It seems that when evaluating these different kits, the kits geared towards hobbyists, particularly the GrovePi kit and the IEM's Connected Interaction Kit offer a promising model when comparing the electronic aspects. Using the Grove system really makes their respective microcontroller become a plug-and-play situation. Both Seeedstudio and IEM's Studiolab's commitment to open source opens it up further for extensibility. LASG's SmartCell Kit's ease of use for both constructing the scaffold, and managing its behaviour was unique in fitting many of the framework's criteria, but was lacking in extensibility and felt restrictive when creating environments.

CH.4

PROTOTYPING A SOFT ARCHITECTURE

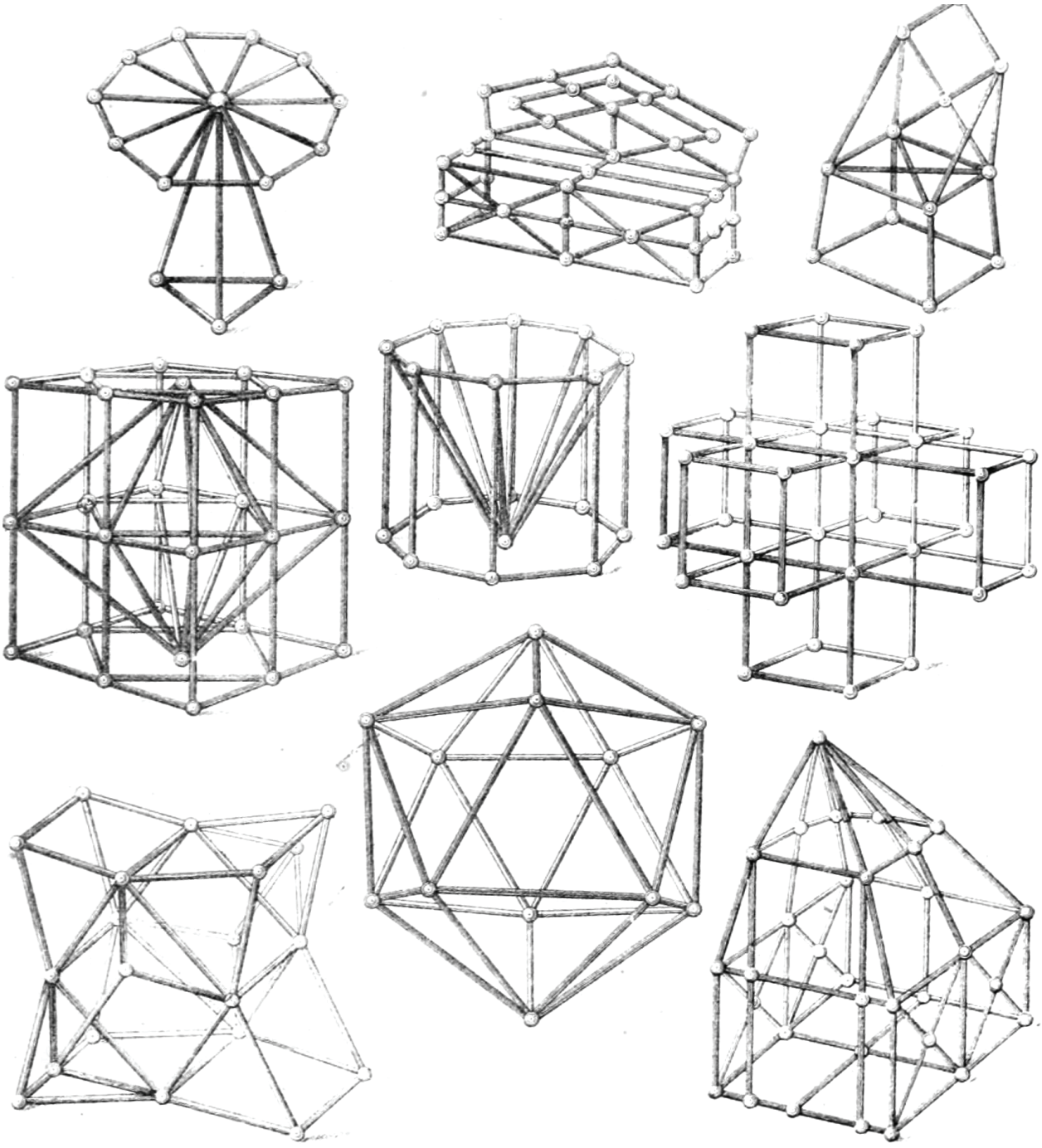
"Not having learned it is not as good as having learned it;
having learned it is not as good as having seen it carried out;
having seen it is not as good as understanding it;
understanding it is not as good as doing it."

Xunzi, "The Merit of the Confucian," *Xunzi*, c. 200s BCE. Translated by Homer Hasenpflug Dubs, 1928.

The objective of this thesis is to create a kit-of-parts that embody the principles of the Framework while also distilling the main essence of a new decentralised soft architecture. It takes an exploratory design approach by experimenting with digital fabrication and technology to create open-source easy-to-make components and assemblies. As a counter-statement to 'hard' architecture, the thesis will investigate redesigning scaffolds that are compliant as a means of limiting the scope of this thesis and expressing a soft architecture. Previous research has identified that the intersection of digital fabrication and embedded technology has a high potential as drivers of interdisciplinary innovation and experiential education.[75] As this kit is meant to be an educational tool for the exploration of responsive environments it relies heavily on ideas gleaned from fields of pedagogy to promote STEAM fields.[76] As stated previously, interactive architecture can be conceptualized into three layers: the scaffold, the actuation and communication. The Sphere Garland Kit is a geometric scaffold kit that distills ideas from the larger body of work that forms LASG's interactive installations and makes it into an approachable yet extensible tool for education and rapid prototyping.

75. Vincent Hui et al., "Collaborative Making: An Exercise in Vertical Learning in the Maker Age," *ICERI2017 Proceedings,* November 2017, https://doi.org/10.21125/iceri.2017.1785.

76. STEM fields and Art: Science, Technology, Engineering, Art, Mathematics



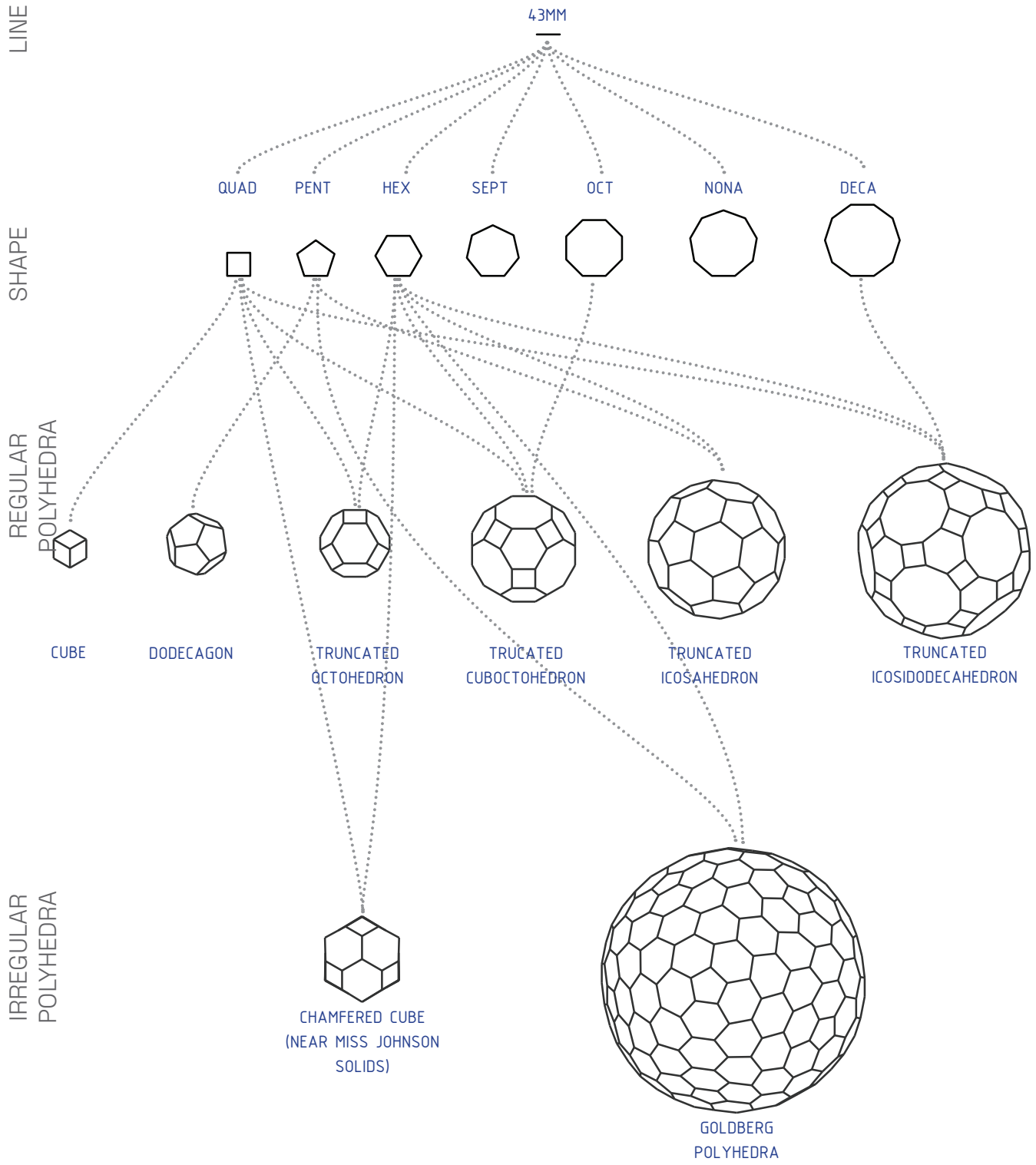
Open Rings

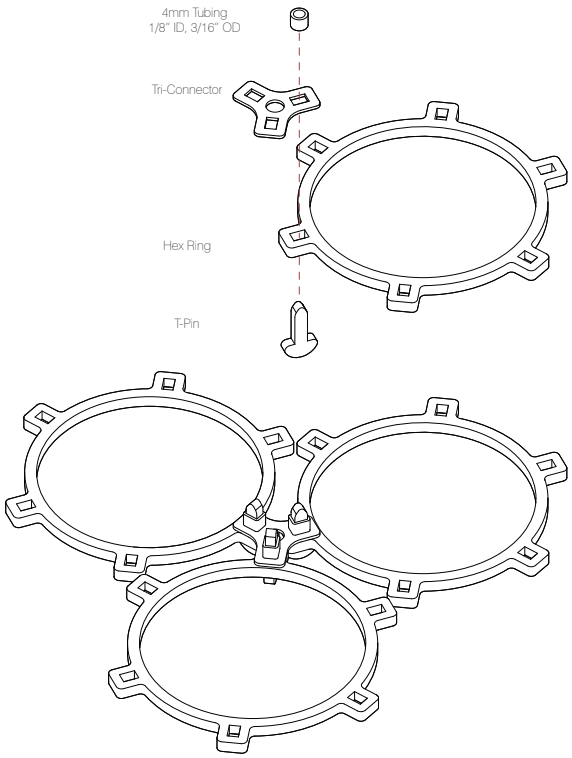
The seed of the entire scaffold system is a singular line with a fixed length – in this case, 43 millimetres. By adding more identical line segments, one can make regular closed polygons. These regular shapes serve as the basis of forms found in the Sphere Garland kit. These polygons can then be assembled in specific configurations that result in a series of uniform polyhedra. The process of assembly from simple components into larger configurations was inspired by the set of educational toys created by Friedrich Froebel in the mid-1800s. Froebel's Gifts was a series of toys that were aimed at helping children learn about the world, starting with simple things like a toy ball to large kits that could be assembled in a variety of different forms. (Fig. 4.0) These Gifts, along with Friedrich Froebel's development of kindergarten programs, were tools to make children think abstractly about the world, and relate them to symbols, forms, and colour. Froebel's gifts were instrumental to the early development of many artists, designers as well as prominent figures in Modernist architecture like Le Corbusier, Buckminster Fuller and Frank Lloyd Wright.[77] In a similar vein, interest in uniform polyhedra like the Platonic and Archimedean solids played a similar role during the Renaissance period, as artists', mathematicians' and philosophers' curiosity of form-making and perspectival illustration of the polyhedral led to intense experimentation and development in the mathematics, arts and sciences.[78]

↲Fig. 4.0 A variety of objects that could be created from one of Froebel's Gift known as "Peas Work". Ronge, Johannes. *A Practical Guide to the English Kindergarten*. 1858.

77. Norman Brosterman and Kiyoshi Togashi, *Inventing Kindergarten* (New York, NY: Kaleidograph Design, 2014), 134-153.

78. Noam Andrews, *The Polyhedrists: Art and Geometry in the Long Sixteenth Century* (Cambridge, MA: The MIT Press, 2022). 10-28.


LINE
43MM
SHAPE
QUAD
PENT
HEX
SEPT
OCT
NONA
DECA
REGULAR POLYHEDRA
CUBE
DODECAGON
TRUNCATED OCTOHEDRON
TRUCATED CUBOCTOHEDRON
TRUNCATED ICOSAHEDRON
TRUNCATED ICOSIDODECAHEDRON
IRREGULAR POLYHEDRA
CHAMFERED CUBE (NEAR MISS JOHNSON SOLIDS)
GOLDBERG POLYHEDRA

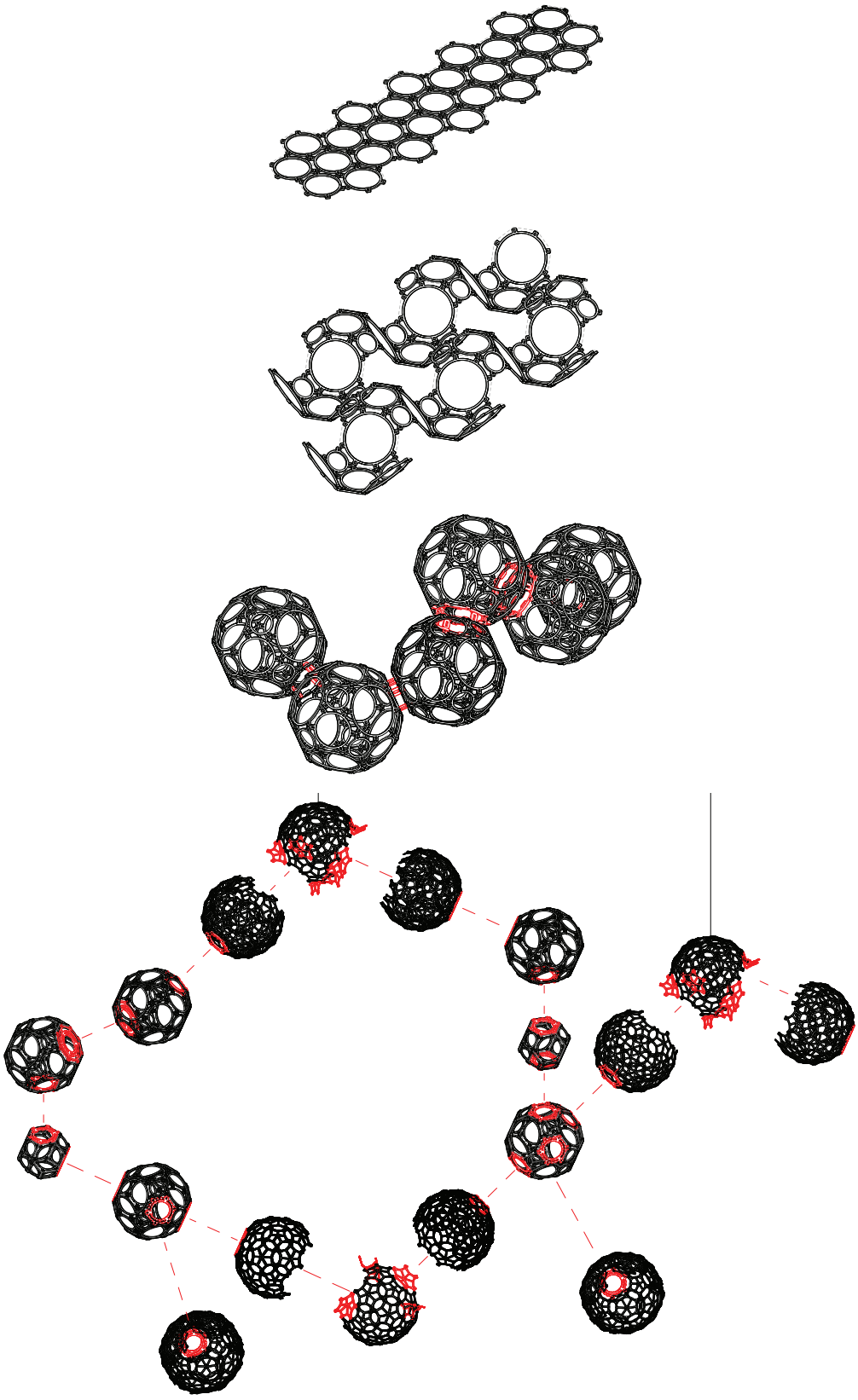


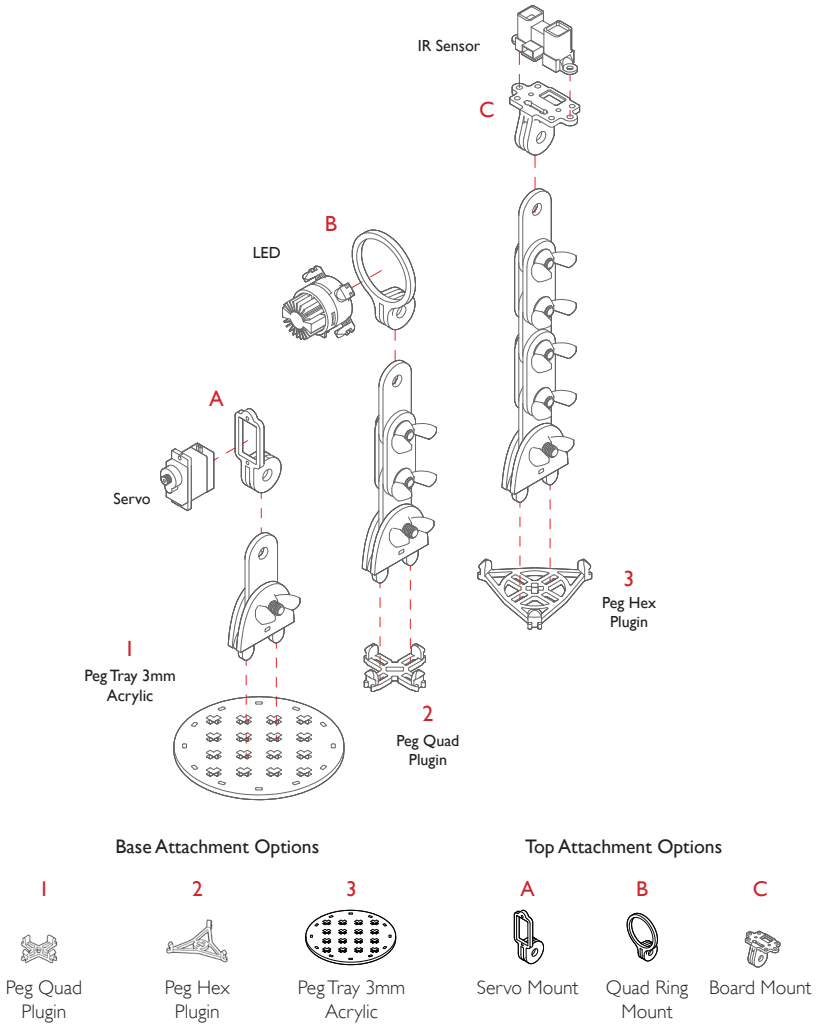
The Sphere Garland scaffold uses 3D printing to reify these abstract forms into a tangible series of components that can create a scaffold. The scaffold mainly consists of a ring that is based on a regular polygon, with a hole located at the 'vertices' to accept pins. (Fig. 4.2) It was important that the regular polygons all had the same side length so that the rings could join at the correct places. Using pins, tubing and connector pieces, the kit allows for the construction of various forms, starting from basic tiling patterns, and undulating waffles to partial and complete polyhedra like the Platonic solids, Archimedean and Goldberg polyhedra.[79] This allows for the kit to accommodate the design of something intimate like a small fixture to a large-scale installation that can evoke a more architectural structure.

↲Fig. 4.1 Generation of forms from a line of fixed length. Diagram by author.

←Fig. 4.2 Open Ring Tiles assembly instruction. Diagram by author.

79. Along with a small number of Near-miss Johnson solids





↲Fig. 4.3 Various configurations and geometries of kit. Diagram by author.

←Fig. 4.4 Device Attachment System using laser-cut MDF and Wingnuts. Diagram by author.

The usage of a plastic material allows for the scaffold to have a compliant tectonic while also giving the components the ability to be easily handled by users, and being secure. The open nature (both physically and conceptually) allows for them to be the genesis of 'totipotency.'[80] Snap-fit plugins that go inside the rings allow for a variety of different devices to be mounted with the freedom of rotational movement. These plugins allow for easy prototyping in real-time through reconfigurability, evoking Haque's *Reconfigurable House*. Using 3D printing as the main means of fabricating allows it to be extended by users for their

80. "The construction kit, as described by Gropius, also features the characteristics of precision and interchangeability, which constitute a property called *totipotency*. In the field of history of technology, this term describes the ability of individual elements to form a larger unity, i.e., the flexible assembly and configuration of elements into a whole."
Atli Magnus Seelow, "The Construction Kit and the Assembly Line—Walter Gropius' Concepts for Rationalizing Architecture," *Arts* 7, no. 4 (November 29, 2018): 95, https://doi.org/10.3390/arts7040095.

expression or to adapt to a variety of other technologies or items. Adding more movement, certain plugins could also receive extendable arms that are made of a series of laser-cut pieces attached together using wingnuts. This compounds the existing rotational capabilities by adding another plane of rotation. The ability to plug in and out while allowing for rotation in 2-axes combined with its extensive form-making possibilities and compliant nature, the scaffold of the Sphere Garland kit was designed to be a soft tectonic that seeks to meet the requirements of extensibility while still allowing for an intuitive design and rapid reconfigurability.

With all these features and possibilities baked into the kit, it is very important that they are presented in a manner that ensures that they are intuitively learned. If this were to be used in a proper educational setting, how would people be instructed and learn the features and possibilities of the kit?

Manual

In 1525, the German artist Albrecht Dürer published *Instructions for Measuring*,[81] a geometry treatise that emphasizes the importance of accurate drawing to artisans who worked to form various materials. The book is a comprehensive guide that combines artistic theory with practical instruction, reflecting Dürer's efforts to elevate the status of artists as a skilled practitioner and thinkers. He thought it was important for artisans to understand geometry through accurate drawing to help them mentally visualize forms thus strengthening the relationship between the physical

81. *Underweysung der Messung mit dem Zirckel und Richtscheyt*. Also known as *Four Books on Measurement*

forms and their representation in virtual space.[82] The book opens with a description of what a point actually is, and then proceeds to describe how to create various polygons and other forms with increasing complexity through the use of lines that connect between these points, requiring the use of only a compass and a straight edge.[83] In the final chapter of *Instructions for Measurement*, Dürer begins with a series of illustrations documenting uniform polyhedra like the platonic solids. Instead of presenting perspective drawings that showed the solids in 3D space as experienced by humans, each solid was given a brief description followed by primary orthographics, and one of the world's first representations of a 3D form as a flat unfolded surface - a net. By not including a perspective of the final form, Dürer was encouraging readers to follow the instructions he sets out in his book to create their own solids from paper nets.[84] As architect and historian Noam Andrews notes:

> Disdaining three-dimensional images of polyhedra for illustrating techniques of making polyhedra, Dürer had reconceptualized geometry as something disposable that could be traced, cut out, and folded together. By proxy the nature of geometrical knowledge had become intimate and approachable, capable of being touched, handled, manipulated, and experimented with.[85]

82. Andrews, 80.

83. Andrews, 79.

84. Andrews, 86.

85. Andrews, 94.

This new graphic representation of platonic forms created a novel understanding that stripped them of their cosmological connotations of a transcendent perfect form to become a hollow construct of paper, filled with mutable possibilities.[86] By including technical instructions in his treatise on geometry, Dürer elicits the reader to engage with his thinking and empirically prove to themselves the substance of his concepts. He reconceptualizes mathematical descriptions of solids while deconstructing their philosophical pretensions prevalent during his times to become approachable tools in making.

86. Andrews, 98.

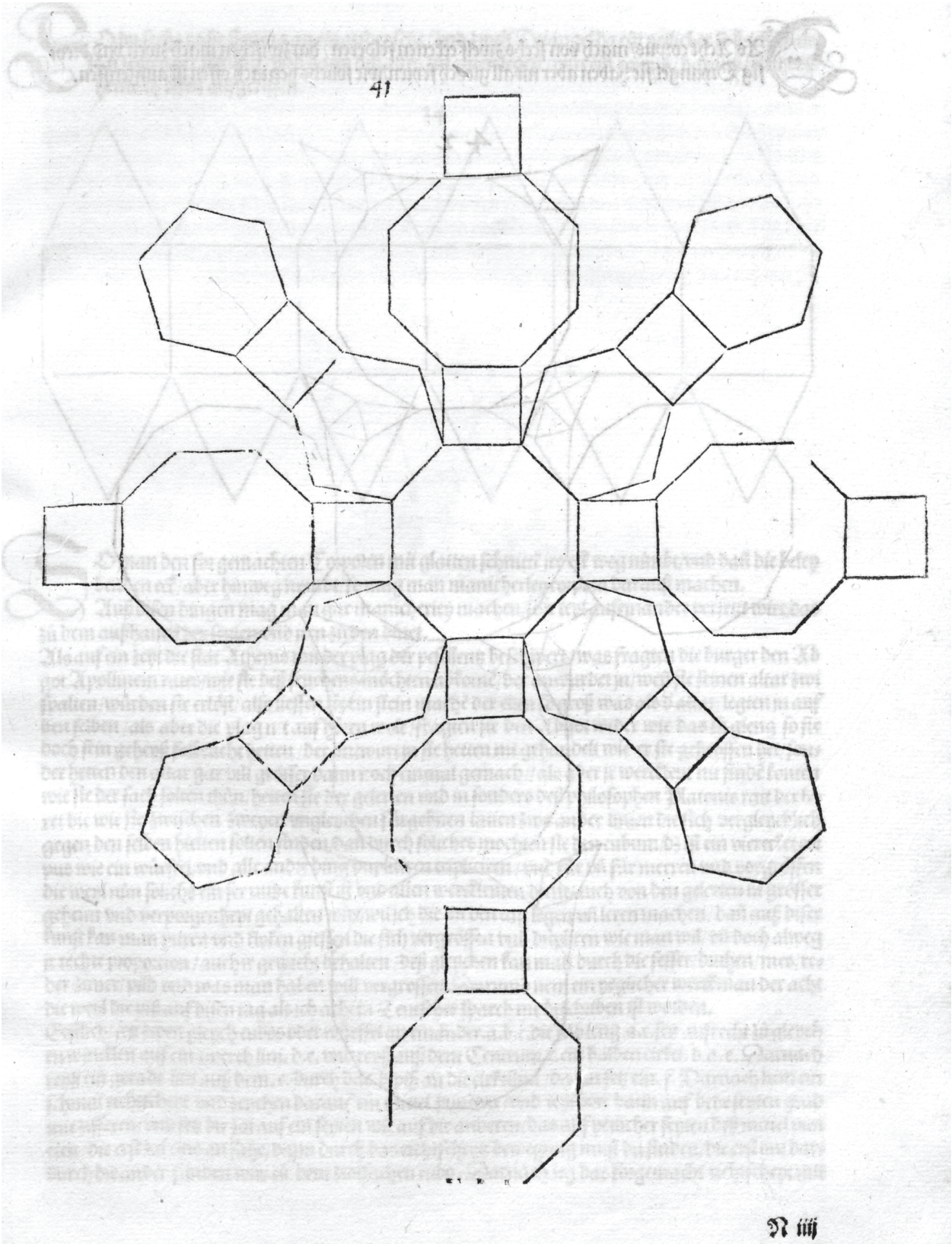
In *Instructions for Measuring*, Dürer uses technical instructions to make his ideas on geometry tangible and approachable, similarly, it is through the supplementation of the Sphere Garland kit with a manual which its conceptual ideas can engage with people's hands and minds to be manifested in the real world. Throughout *Instructions for Measuring*, there is a progressive theme of 'assemblage,' as Dürer starts by defining what a point is, connecting those points with lines, to form polygons, that later are assembled into nets that create polyhedral. Conceptually, things begin as disparate simpler components, and aggregate into specific larger and more complex assemblies, a logic that is consistent within the conception of the manual for the kit which helps readers orient themselves. This concept of 'assemblage' is also present in the typical layout of the manual, with the lexicon of required pieces at the top, then a drawing with assembly instructions, and then a representation of the final assembly. The manual starts with a point, in this case, a junction where the rings meet, which are repeated

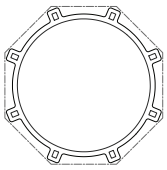
to form tessellations. Specific configurations then could create the flattened forms of specific undulating waffles, cowls and spheres which can be joined together to form lattices. Thus the earlier sections detail the construction of simple assemblies, which Later sections rely on as components for larger complex assemblies.

With a design for the scaffold, and a means of how to attach devices to it, the kit was still just a proof of concept and an assortment of plastic pieces. When the kit is coupled with a manual, it begins to convey something beyond its materiality, and shows the concepts behind it and the possibilities of the kit beyond. the kit was still a proof of concept that needed to be used by actual people in a real setting.

↪Fig. 4.5 Diagram of Truncated Cuboctahedron in Durer's Instruction for Measurement

↪→Fig. 4.6 Contrast with Manual Page for Truncated cuboctahedron. Diagram by author.


41
N iiij



Oct Open Ring Tile x6



Hex Open Ring Tile x8



Quad Open Ring Tile x12

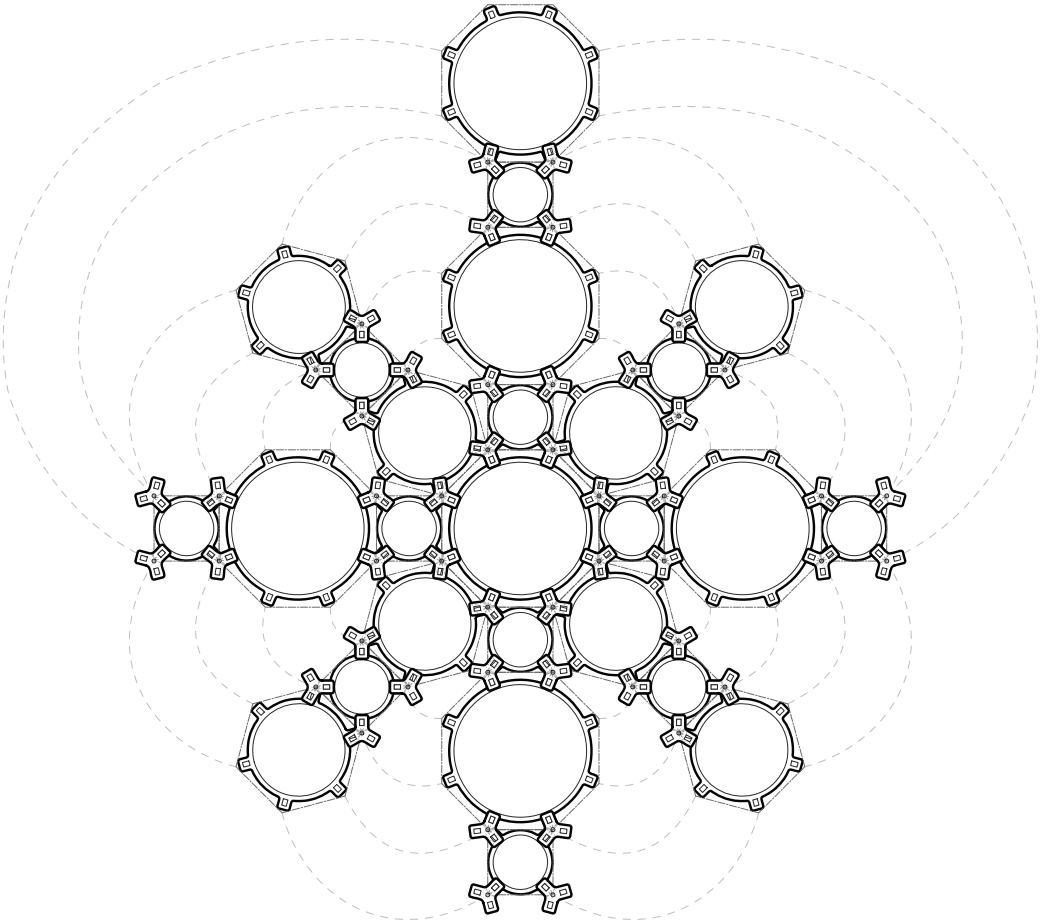


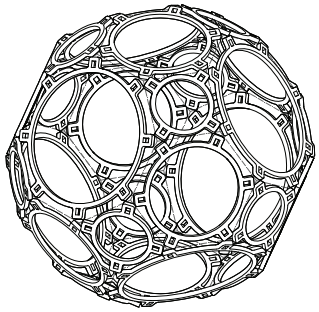
Tri-Connector x48



T-Pin x144

4mm Tubing x144







↑Fig 4.7 Students interacting with main canopy of the workshop. Photo by Izzy Zalat.

Case Study: Robotic Speculations Workshop

In November of 2023, LASG hosted a 5-day workshop at TU Delft for students in their Interactive Environments Minor (IEM). This is the fourth time LASG has run a workshop with IEM and was a collaboration with a variety of different groups at TU Delft. The goal of the workshop was to explore the question of how can we use interactive environments to spark thinking in transdisciplinary design and to reimagine the robotic possibilities of the future.[87] LASG's main role in the workshop was to bring the group's expertise in creating interactive environments through software, hardware and physical components. The workshop was a massive collaboration with many groups:[88]

87. "Robotic Speculations Workshop: TU Delft Interactive Environments Minor." Living Architecture Systems Group, December 26, 2023. https://livingarchitecturesystems.com/project/robotic-speculations-workshop-tu-delft-interactive-environments-minor-2023/.

88. Dave Murray-Rust et al., "Spatial Robotic Experiences as a Ground for Future HRI Speculations," *Companion of the 2024 ACM/IEEE International Conference on Human-Robot Interaction*, March 11, 2024, 57–70, https://doi.org/10.1145/3610978.3640793.

- TU Delft Interactive Environment Minor: Lead by Professor Aadjan van der Meer. The students of the workshop were from this minor and staff from IEM helped plan and run the workshop while also assisting with fabrication.
- TU Delft Department of Human-Centred Design: A group of researchers that are part of TU Delft's FRAIM project[89], focusing on Human-Robotic Interaction (HRI) speculations created the design brief and provided critique to gain insight from students for their research.
- Living Architecture Systems Group: Lead by Professor Philip Beesley, with the workshop being instructed by Matthew Gorbet and Adrian Chiu (author). Responsible for bringing physical components and software suite, and instructing students on how to use these tools.
- KLM Royal Dutch Airlines: A Transdisciplinary Taskforce was created in partnership with Amsterdam Schiphol Airport to investigate how robots could be used to further enhance baggage handling. Using a synthesis of their research and observation, they helped craft the design brief for the students.

89. "Interactive Environments Minor – 'IDE Airport,'" TU Delft, https://www.tudelft.nl/en/2023/io/november/interactive-environments-minor-ide-airport.

For LASG, this workshop was an opportunity to test and further develop a variety of STEAM tools that the LASG has been working on, in line with their STEAM stream.[90] LASG was represented by the author along with long-time LASG consultant Matthew Gorbet, who oversaw the software and electronic side of the tools we were bringing to Delft. Other project leads from the LASG side were Professor Philip Beesley and LASG's Design Director Timothy Boll who helped with the planning and

90. Lucinda Presley, Becky Carroll, and Rob Gorbet, "It Lives! A Steam-Based in-Class Workshop for Promotion of Creative and Innovation Thinking," *2016 IEEE Integrated STEM Education Conference (ISEC)*, March 2016, https://doi.org/10.1109/isecon.2016.7457546.

conception of the workshop and technical assistance. There were two key goals of the workshop from LASG's technical perspective: (1) seeing how well Matthew Gorbet's Influence Engines[91] could interface to TU Delft's Connected Interaction Kit that uses a completely different microprocessor (ItsyBitsy) through wireless protocols.[92] (2) Testing the Sphere Garland Kit as a pedagogical STEAM tool for workshops. LASG wanted to see how these tools were being used by students in a workshop environment and see what needed to be refined, hopefully as a foundation for future workshops at TU Delft and beyond.

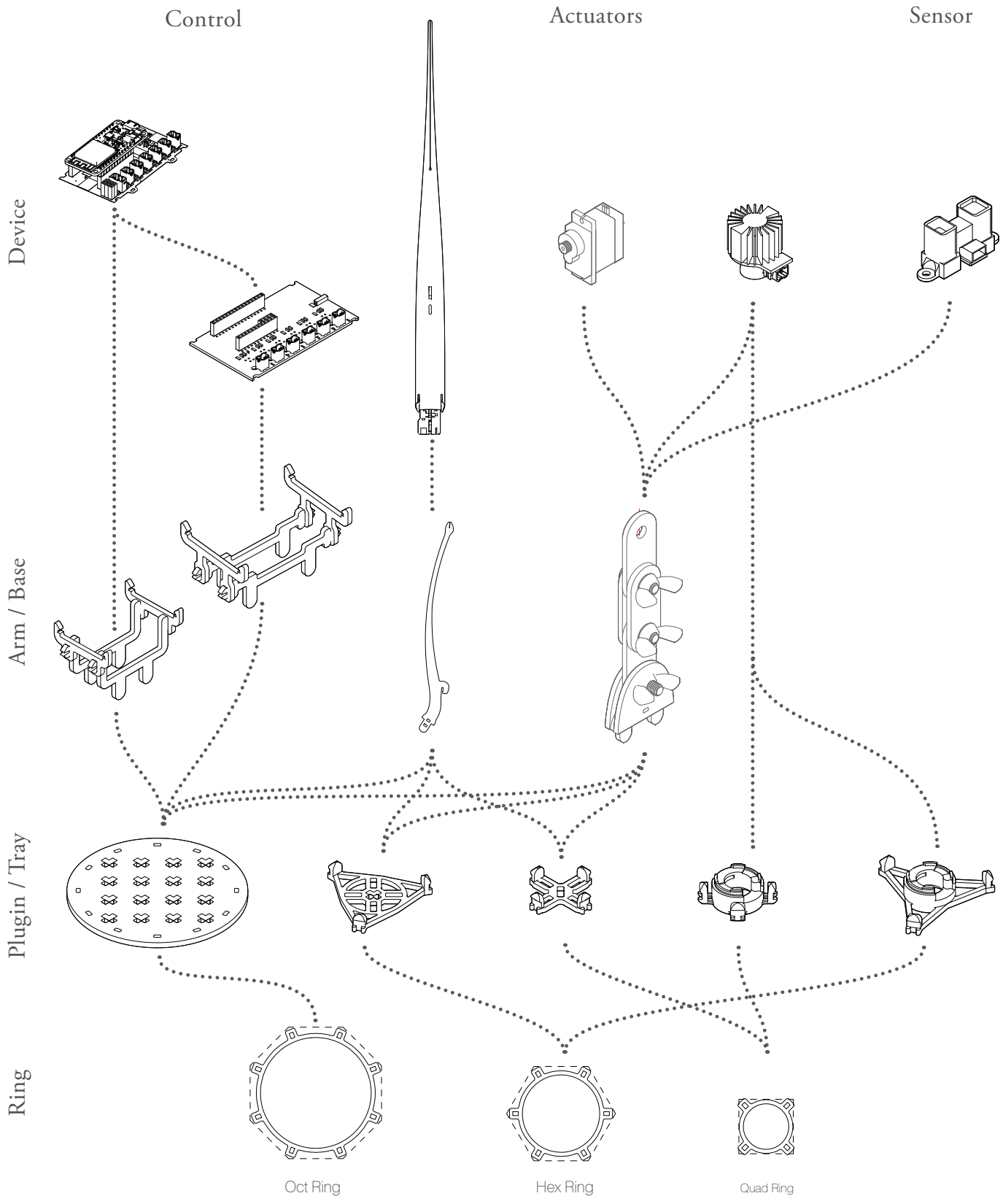
91. Gorbet, 56.

92. Beesley et al., "Appendix." *Poietic Veil*. 68-73.

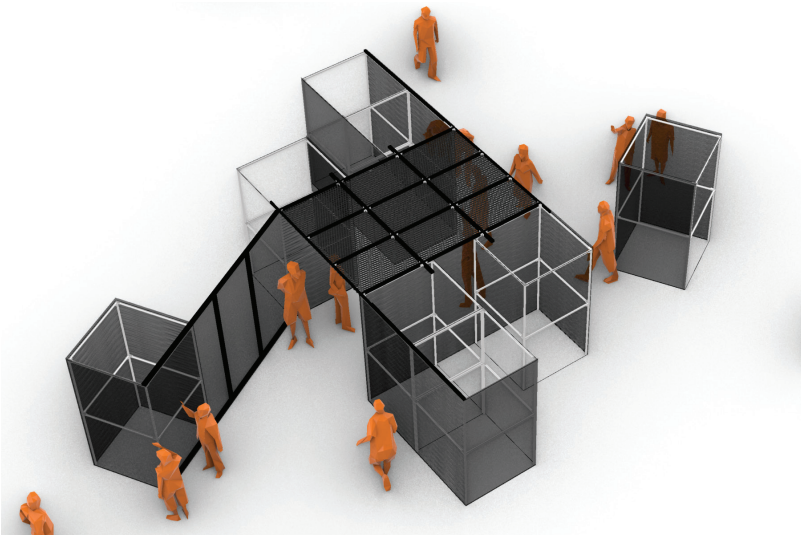
The kit presented at the workshop was used to test the Ring scaffold kit, and its attachment system. Only a few actuators were brought to help narrow the scope of the 5-day workshop so concepts and expression could be conveyed in an abstract manner and not rely on symbolism. Some actuators were some of LASG's own specialized hardware to see if the custom electronic components used in LASG's larger installation work could be made more approachable in the context of a shorter educational workshop.

Students were put into teams of 7 and were given a brief that was designed by the group of HRI Researchers from TU Delft's Department of Human Centre Design in collaboration with KLM's Transdisciplinary Taskforce. A larger structure created by IEM Staff was erected to serve as the 'site' of the workshop creations. Each team was assigned a location in the 'site' and a meta-behaviour that served as inspiration for what their fixture was supposed to do. The workshop began with various lectures by TU Delft,

↳Fig. 4.8 Sphere Garland Kit attachment system that was presented at the workshop. Diagram by author

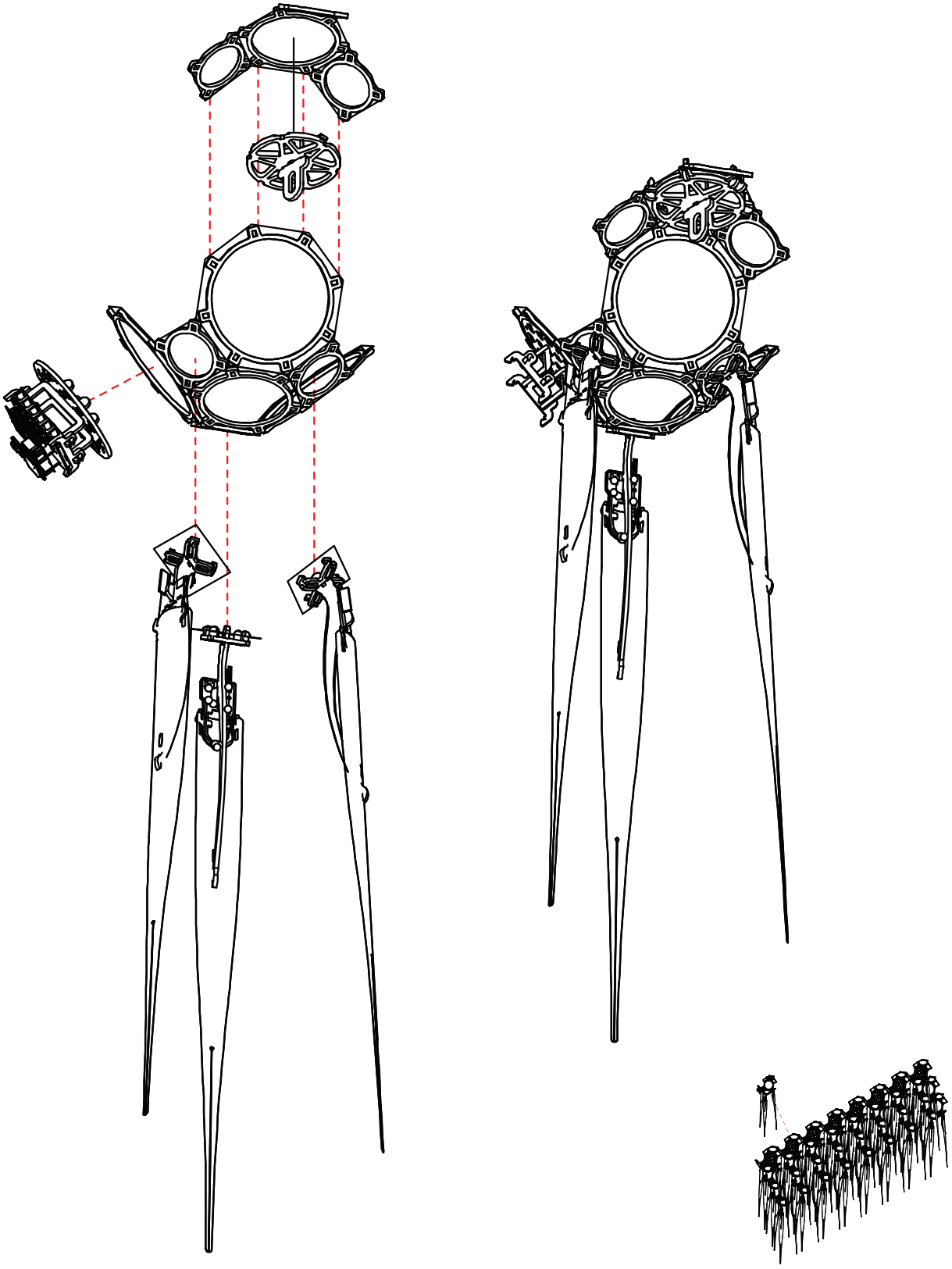

Control
Actuators
Sensor
Device
Arm / Base
Plugin / Tray
Ring
Oct Ring
Hex Ring
Quad Ring

KLM and LASG introducing a brief of the workshop, main concepts and tools to be used respectively. LASG Workshop leaders then gave a tutorial on how to use the physical kit components via example instructions to create a demo fixture. The goal was for each team to complete their demo fixture, which would link up with each other to create a larger 'canopy' testbed to serve as an example piece for the workshop. Throughout the week students split their time between brainstorming and prototyping how they could express their assigned concept at the location they received in the structure while using software and hardware tools provided by LASG. There were informal critiques throughout the week by various TU Delft educators and LASG workshop leaders. In the end, students presented their final project, and KLM researchers opened the entire structure with active student projects to select groups of the public to conduct their own research on their insights and observations. The outcome of the workshop was that each team had a fixture that utilized the Sphere Garland kit, LASG electronics coupled with hardware from TU Delft's own kit, that interacted with Gorbet's Influence Engines.



→Fig. 4.9 Rendering of the structure built for the workshop, that the students could attach their creations on. Diagram by Chris Kievid.

↳Fig. 4.10 Sphere Garland Kit attachment system that was presented at the workshop. Diagram by author









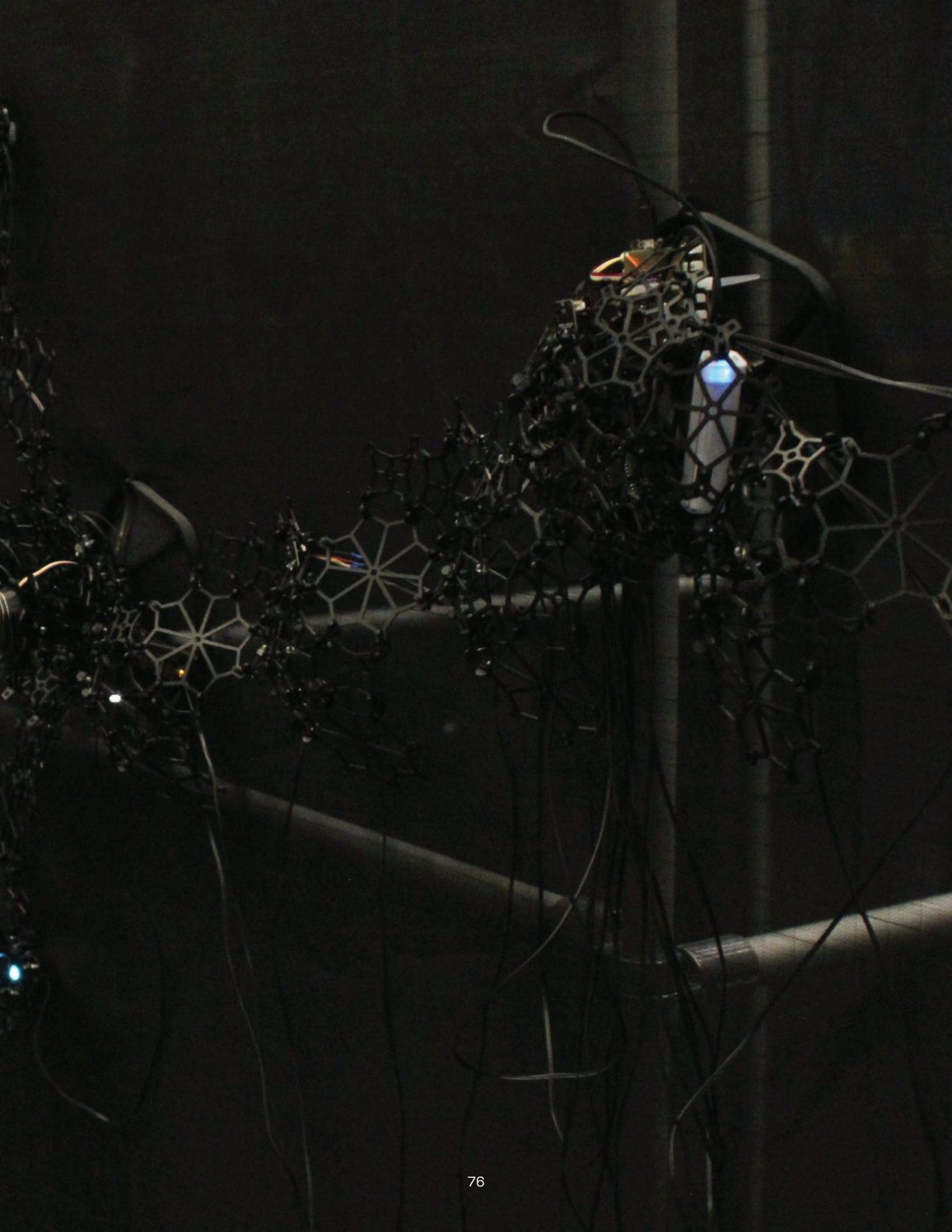
↲Fig. 4.11 Students interacting with the canopy and workshop creations. Photo by Izzy Zalat

↑Fig. 4.12 Teams of students collaborate to create peices of the demo canopy. Photo by author.

←Fig. 4.13 Students presenting their ideas to peers, workshop leaders and guest critics. Photo by Rubin Philipart.

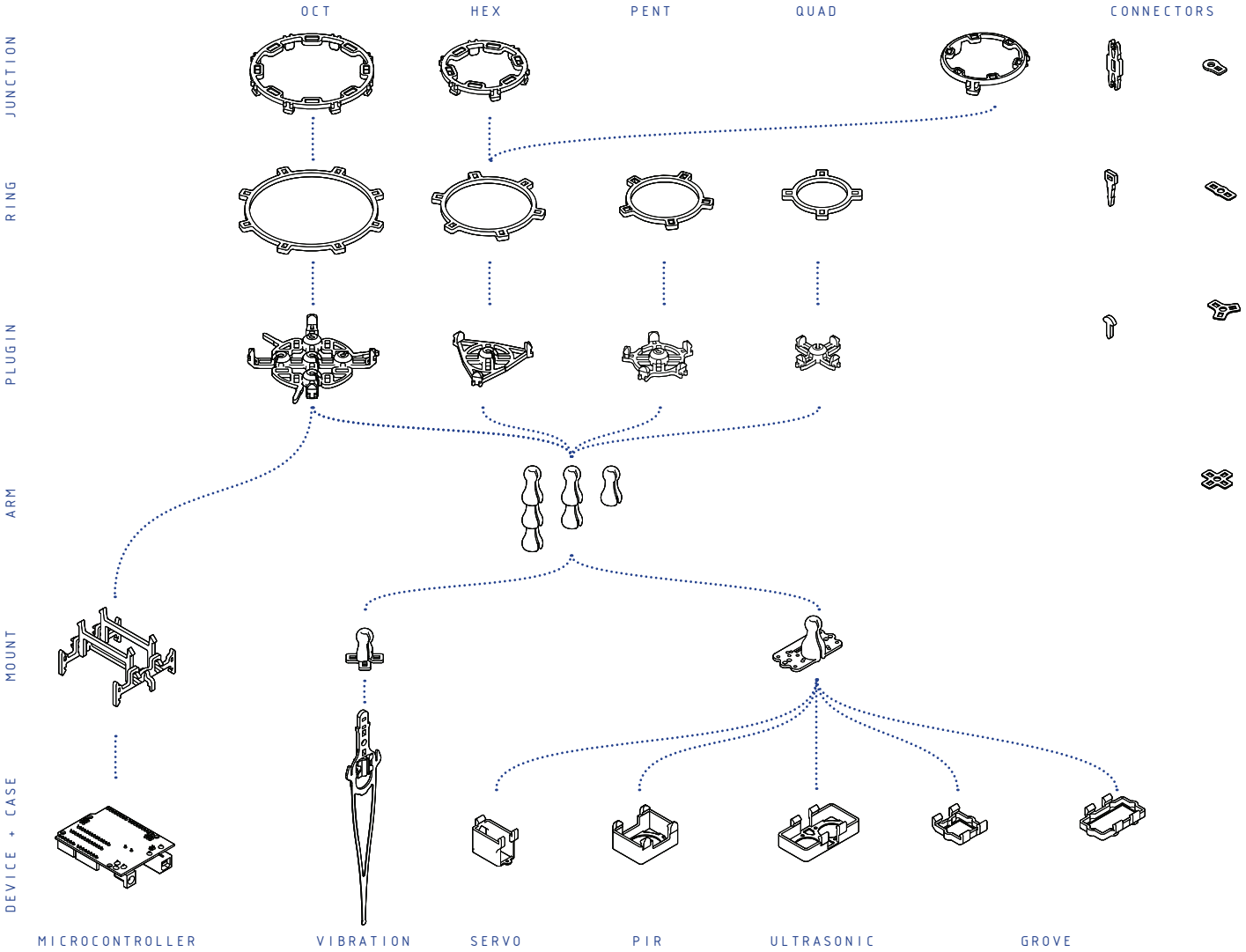
↪Fig. 4.14 Guests interacting with workshop creations. Photo by Izzy Zalat.





Results and Revisions

One of the key objectives for LASG in participating in this workshop was to see how its tools that were derived from LASG's interactive testbed development and conceptual frameworks would perform in an educational setting. Observations of students using the kit allowed for a more intimate look into areas of the kit that could use more improvement. Another goal was to test a new logistical model LASG is hoping to use moving forward for its workshop and sculpture, in which local partners would assist in some production or manage the majority of it depending on the scale and circumstances. During preparation for the workshop, 3D Print production was split between TU Delft and LASG, to see if this was a viable model in future workshops. The idea would be that LASG would act as more of an instructional and managing role so that it could focus on design and execution while relaying fabrication files and instructions to their partners akin to releasing construction drawings to contractors. Partners could then fabricate and source locally without having to rely on LASG shipping all materials across the border. As this was a new process, a few issues arose during the workshop due to a lack of quality control on the prints. This led to a sizable quantity of very poorly printed pieces that were unusable or very difficult to use since a lot of pieces were designed to be snap-fitted or were meant to fit snuggly into each other. This caused occasional frustrations with the students throughout the workshop and affected their experience with the kit. Future work could be to look into standards



↑Fig. 4.15 Revised attachment system for Sphere Garland System. Diagram by author.

for transmitting 3D print files and ensuring clear communication to partners about the importance of print quality.

Another issue that arose from remote communications on a project that is inherently physical, was the difficulty in specifying certain materials that were not available locally at the host location. The version of the kit at the workshop used a variety of materials beyond just 3D prints. It included a specific semi-flexible

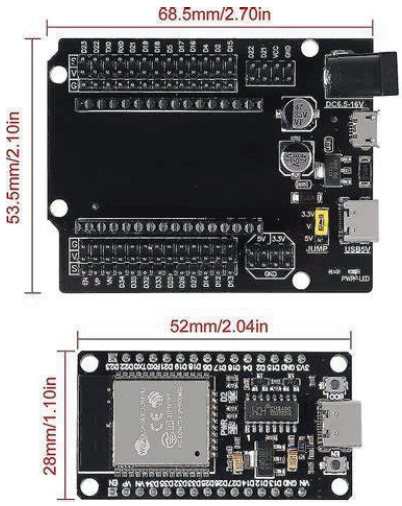
93. ACRYLITE® Resist™ 65. An impact resistant acrylic that has a slight flex as to not be brittle.

acrylic,[93] Medium medium-density fibreboard (MDF) and cardboard for various other pieces and tools, which ultimately were not fabricated due to a lack of access to tools, or were redesigned last minute to be 3D printed. Replacing pieces with a 3D counterpart also had the added benefit of better usability as the 3D printed version of objects that were originally made from acrylic were more flexible and therefore easier on the user's hands while still maintaining a tight snap-fit.

Another piece that was not used was the MDF arms that were secured together with zip ties and wingnuts. The arm was a multi-piece assembly that could be extended with additional wingnuts and MDF pieces to give devices a longer and adjustable reach from the scaffold. it's material and weight incongruency compared to plastic along with its non-intuitive assembly made it an awkward fit when compared to the other pieces. Due to this piece's material, conceptual and aesthetic disconnect from the rest of the system made students unable to intuit and understand its use and assembly. A new arm system only using 3D printing was conceptualized using a ball and socket joint, allowing for a greater degree of movement. New plugins and mounts were designed for this system to attach a variety of different actuators including ones used in TU Delft's interactive kit (i.e. the Grove system). In this version of the kit, there are only 4 ways components can be joined together, thus making it intuitive and simple to learn. By using only one material and method (3D printing and plastic filament), there would be a more streamlined approach to the design, representation and communication of the kit, cutting

down the number of inquiries between parties and creating a more cohesive system.

During the workshop, the TU Delft students used their own microcontroller, which was connected with LASG's microcontroller in order to engage with the Influence engine aspect of the workshop. This presents two ideas about how the kit should be used: (1) purely a scaffold system that could be paired with other people's electronics regardless of what system (grove, hobbyist electronic, even LittleBits) they are used or (2) a standalone kit that is bundled with electronics. The first idea leverages the 3D print aspect of the kit, where slight tweaks are needed for the mount pieces to fit the preferred electronics. As a standalone kit, that is not geared toward that particular workshop, there would not be a need for having two different types of microcontrollers. Replacements for the custom proprietary hardware used by LASG and TU Delft could be common microcontroller models that are popular amongst makers. As we want the ability to create distributed networks, these microcontrollers need to have a wireless module built-in. For these options, all of them have an ESP-32 wireless module by Espressif systems[94] due to rampant popularity with DIY Makers; the ability to use wi-fi, Bluetooth and its own communication protocol like ESP-MESH and ESP-NOW; and it being officially adopted as the wireless module for the Arduino R4 Wifi. ESP-NOW is of particular interest as it creates distributed networks without the need to connect to the internet. Adafruit,



↑Fig. 4.16 Image of inexpensive ESP-32 Development Board and associated breakout board. The breakout board has the same dimensions as the arduino.

94. "ESP-NOW Wireless Communication Protocol," Espressif, https://www.espressif.com/en/solutions/low-power-solutions/esp-now.

Aliexpress and Arduino all present a few inexpensive options for ESP-32-equipped microcontrollers paired with the appropriate breakout board to make them easier to work with. With the addition of these common microcontrollers and the manual, the kit can be independently distributed online as a standalone system.

Evaluation

The main goal of this thesis was to leverage digital fabrication, DIY principles and open source to critically analyze interactive architecture through the creation of a kit-of-parts to make it more accessible while also expressing a new soft tectonic that is compliant and decentralized. Through the workshop, there was a chance to see how the kit would be used by people outside of the designers, allowing for it to be evaluated on what could work and what didn't and what could be improved. In this section, an evaluation of the kit informed by observations and insights gained from the workshop will be presented following the five principles established in previous sections (ch.2) This section will also detail limitations and future research directions.

***Accessibility

It must be based on open-source principles to allow for easy access to learning resources and assets to prevent obsolescence. Do people have easy access to the resources needed to use this.

An end goal of this project would be to release it online along with supplemental assets. The manual would also be posted in a printable PDF so that it could be viewed digitally and printed. If one were to go with a standalone kit with an Arduino-based microcontroller, there are plenty of resources online on how to code for Arduino. The only potential barrier to entry for most people who just want to use the kit would be access to a 3D printer. The accessibility and cost of 3D printers these days are much better than it was a decade ago due to the growth of the maker movement and the rise of fab labs. Likewise, many libraries, schools, community centres and businesses have services providing 3D printing as the cost of acquiring one has gone down. Future research could be the integration of digital media like 3D model viewers.

**Affordability

It must be inexpensive and accessible to acquire materials and components, this could include reusing existing objects, but an option to buy will be presented if it is within acceptable prices.

The most expensive aspect of this kit is the 3D printer, but as stated in the previous section access via institutions has made it relatively accessible, while its cost has kept on going down. Besides that, the next most expensive are the microcontrollers, there are ways to make this aspect extremely cheap using inexpensive clones bought online, though this requires one to not use the Grove system, and therefore might require a bit of extra knowledge on circuitry.[95] If one

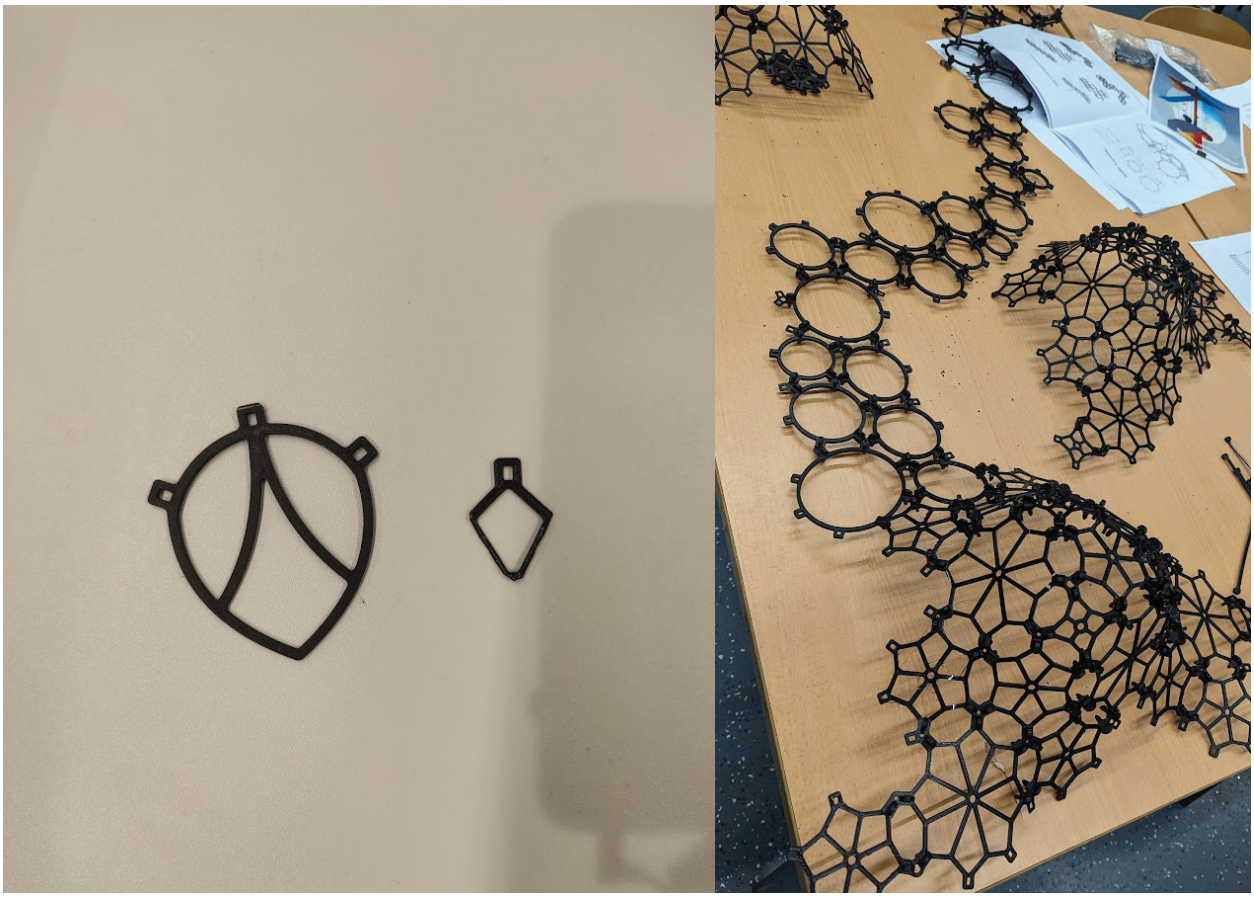
95. The ESP-32 breakout board is essentially a poor man's grove system in a certain sense. Moving away from the grove system also reduces costs as well.

were to use the break-out board option as opposed to the grove system, costs for sensors and actuators also drop a bit.

***Extensibility

The methods and modules presented must allow for high customizability to allow for the extension of the kit and a limitless form of expression.

By making this kit entirely from a 3D printer, users can create their own extensions and models, giving the kit a high degree of extensibility. (Fig. 4.13) This aspect of the kit requires knowledge of 3D modelling, and even the easiest-to-use modelling software (like TinkerCAD) would not be able to give users the amount of control over the measurements for snug fits and snap fits. Potential future research could explore a way in which certain parts of the models that have these more precise measurements are provided as a drag-and-drop fragment in TinkerCAD, which users attach to their own creation. Not only can they make new pieces, but they can adapt and remix existing pieces to accommodate new devices that did not originally exist in the kit. Some attachments were designed to accept multiple electornic attachments (both Grove mounts accept most Grove sensors) and were also designed to be easily modified to accept new electronic components. Future research would be expanding the lexicon of parts to accept more types of devices.

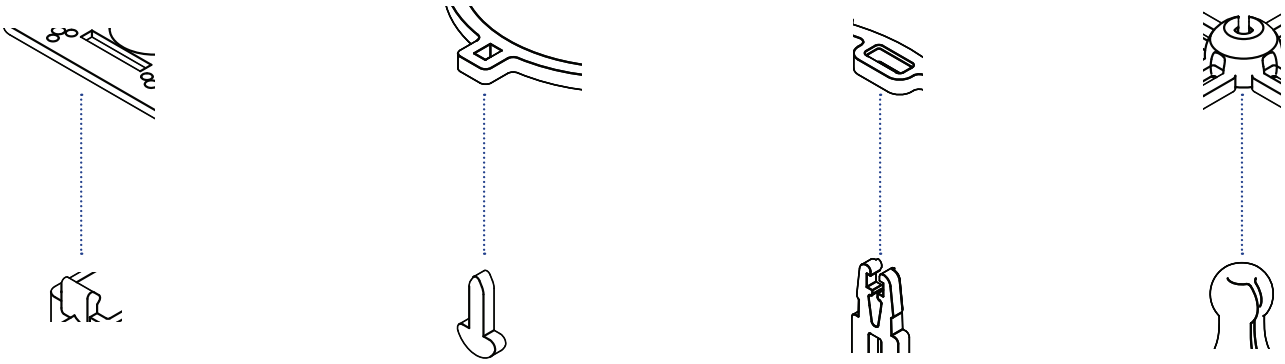


↑Fig. 4.17 Images of student explorations. Left shows students wn custom pieces. Right show form making explorations. Photos by author.

**Approachability

It must be approachable so that most people can learn how to do it quickly and intuitively. Novices can understand how things come together and work.

The latest iteration only has four types of connections with their design was meant to be intuitive and easy on the hands. (Fig. 4.14) The design of the manual also increases its approachability providing visual aids on how things assembled. The biggest barrier of entry, is for the features of the kit that are most extensible, modelling and coding. Future research should investigate what software for coding and modelling could help in this regard.



↑Fig. 4.18 The four connections used in the latest version of the kit. Diagram by author.

***Reconfigurability

It must consist of pieces that can be rearranged and reusable. Pieces should never have a one-time use lifespan. Therefore, connections must be designed in a way that is secure yet enables ease of disassembly
All pieces and their joints were designed to be reusable and easy to disassemble. The ring system, with the plugins along with the ball and joint arms and mount attachments are all meant to be reconfigurable and mutually interchangeable on-site to allow for rapid prototyping.

When evaluating this kit, it seems evident that it falls into the same pitfalls as many others like it. The more inexpensive and or extensible the kit is, the more knowledge users are required to be able to use it. The more intuitive and approachable the kit is, the more expensive and closed off it becomes. The key defining feature of this kit is that it had a scaffolding system that was extensible via 3D printing, which was identified as a gap in the research and market in previous sections.

Other kits did not have this at all or were very expensive and were a closed system. This shows that further research in this area would be useful in the field of interactive architecture as it is not well researched nd has a lot of potential new application, especially when overlapping with STEAM education. Future research would be the continued development and refinement of the kit through new material research or exploring new ways of disseminating the kit via efficient discrete kit packages and via new digital media.

	Sphere Garland Kit	***SPIKE / Powered Up***	***LittleBits***	***Elegoo Arduino Kit***	***Grove Pi Kit***	***Connected Interaction Kit***	***SmartCells Kit***
Approachability	**	***	***	*	*	*	***
Affordability	**	*	*	**	**	**	**
Accessibility	***	***	**	***	***	**	*
Extensibility	***	*	X	***	***	***	**
Reconfigurability	***	***	***	***	***	***	**

↑Fig. 4.19 Comparison of the Sphere Garland Kit with precedents based on the framework established in Chapter 2.

Sifting through this mound of stuff won't help in finding that piece.
Maybe just get a new one from large open shelves filled with little bins of doodads of mechanical hardware and electronics?
Behind the open shelves, a group of teenagers have made this wobbly tower of wood dowels strung with cables that wobble and lights up but fall to the ground, scattered
i n t o b i t s
a n d p i e c e s.

They begin to pick them up from the floor and reassemble them;
Reconfigure?
or were they redesigning their creation?
There is a hum of activity as people are working throughout the space and chatting with each other on how to do something or silently admiring people's little work in progress as they briskly walk by to grab something.

People are working on their own projects,
some a personal hobby,
some to fix something from home,
some for a school project due on Monday
or maybe something for work?

But probably not.

Away in the distance, the tree-like lattice structure of the room begins to shift and respond to something,
and the many little creations that have been added and connected to the framework over the years all begin to whirr and wiggle.

Something new has joined the matrix.
Looking back at the teenagers, it seems like they manage to hang their fixture from the mesh of branches that form the ceiling as if it were a bauble.
The room dims as petals that allow light in close,
their creation bobs up and down, adding a slight bounce to the scaffold of the room, while little lights of orange fade in and out.

And in this twilight, people pause from their tinkering briefly to look around,
as small lights interspersed throughout the room's structure also pulse,
seemingly in a syncopated response.

CH.5

CONCLUSION

"It has been the risk-takers, the doers, the makers of things—some celebrated, but more often men and women obscure in their labour—who have carried us up the long, rugged path towards prosperity and freedom."

President Barack Hussein Obama. "What is Required: The Price and the Promise of Citizenship." First Presidential Inaugural Address at United States Capitol, Washington, D.C, USA, January 20, 2009.

Prototyping interactive architecture has high barriers due to the costs and expertise required and remains inaccessible to most people despite how democratized electronic components and knowledge have become. The creation of the approachable framework in this thesis helps build upon an existing foundation and extends it so that it allows for a ready exploration and rapid prototyping of an emerging soft tectonic in interactive architecture. From the review of current scaffolds, actuators and controls, there is a gap in finding a system that encompasses all three while still being accessible yet extensible by users. The combining of 3D printing and embedded technologies in such a kit could serve as a new paradigm of softness that one day could be extended to soft scaffolds and even sensors. Applying ideas of DIY and Open source in the creation of a kit of parts for actuated ‘soft’ interactive architecture hopefully allows for a more approachable future exploration of compliant scaffolds and decentralized control towards a new architecture.

By making these kits become more approachable by encouraging a DIY approach and open-source principles of sharing, the barrier of entry becomes lower

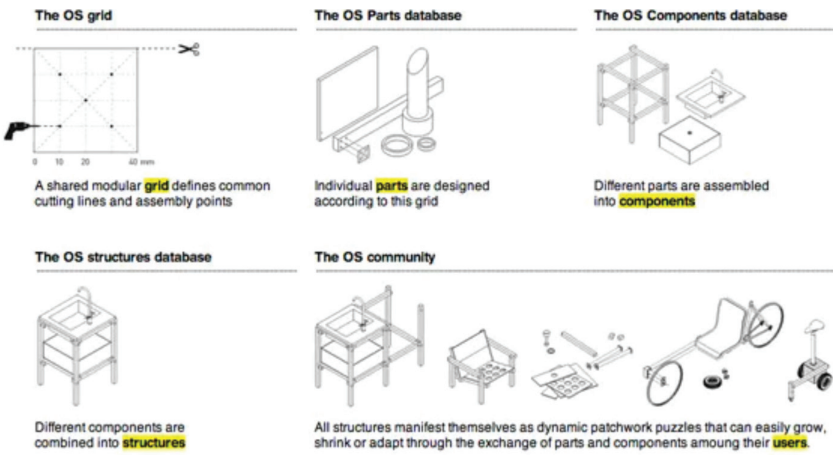
and interest in responsive environments in everyday life both as a user and maker becomes normalized and even more valued as a craft rather than an act of technical production. When related to architecture, craft traditionally would beget a vernacular tectonic; how does the tinkering of gadgets and gizmos generate a new interactive tectonic?

If the proposals offered within this thesis were taken up as general policy, and practiced by many members of a community, we might see an increase of interest in the making of interactive architecture and STEAM fields in general. One could imagine students using this kit and having them attach their own creations to a larger interactive testbed, creating a true ecosystem of exploration. If one were to extrapolate the conceptual idea of 'softness' established in this thesis and apply it to a broader scale, one could imagine a whole online community that is in service to a global system of open-source components that are designed and fabricated within the community. This global community of makers would design physically and electronically interchangeable modules similar to Open Structures[96] and Archigram's *Plug-in City*[97] and *Capsule Homes.*[98]

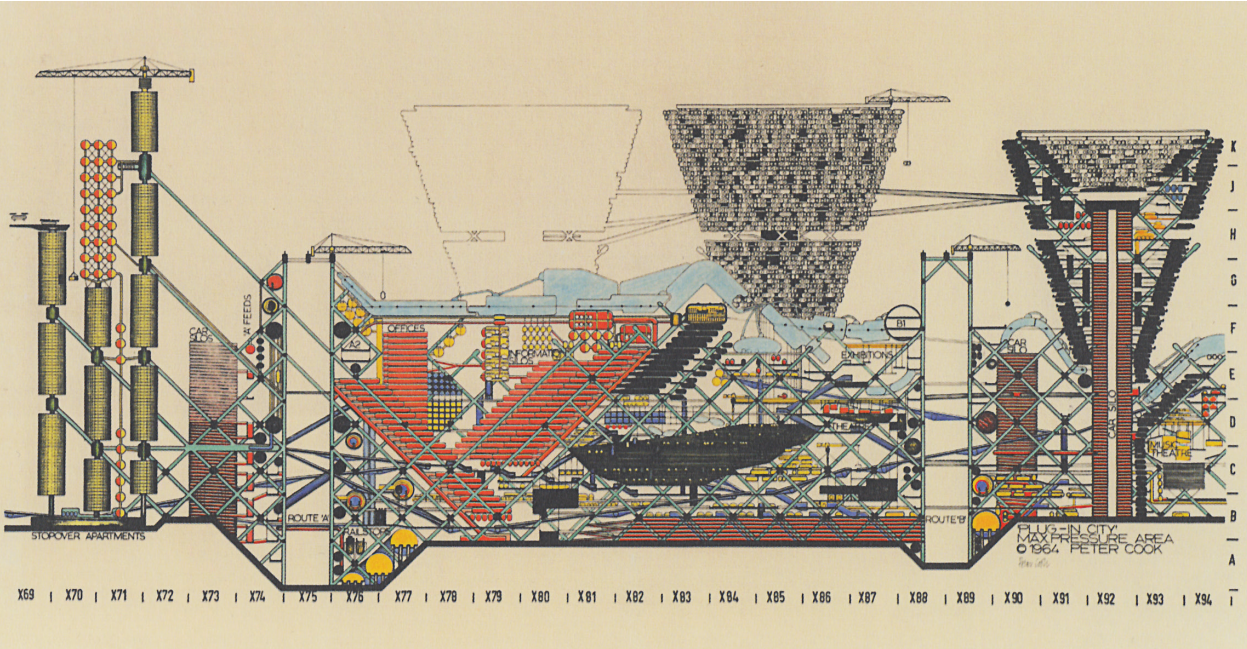
96. OpenStructures, https://www.openstructures.net/.

97. Peter Cook. *Plug-in City.* (1964)

98. Warren Chalk. *Capsule Homes.* (1964)



→Fig. 5.1 Open Structures System. From openstructures.net



↑Fig. 5.2 Plugin City by Archigram.

Difficult problems revealed while studying this topic are the difficulties of addressing the issues of accessibility and sustainability. Talk about how it is the most pertinent problem. The contribution of this thesis lies in the documentation and creation of various methods with a kitchen-sink mentality that allows for rapid making and prototyping using technology in creating responsive environments in the hopes that this thesis can serve as a framework in the creation of responsive environments more approachable. As noted previously sustainability was also an important factor that I wanted to consider but could not address in a meaningful way. The usage of smart material or bio-composite that can be actuated could be a way of addressing this, but I found the production of this material and components to be too technical facing and hard to acquire. Even Michael Fox, whose book *Interactive Architecture* is cited heavily in this thesis and in interactive architecture research, states that he believes that the



> "idea of a composition of discrete kinetic structural systems and devices is outdated and should rather be replaced by an idea pertinent to the potential of smart materials behaviour. [...] Such materials would incorporate sensing and control capacities, operating biomimetically at a very small scale."[99]

Manuel Kretzer's *Actuated Matter Workshop* embodies these ideas while using the same principles of this thesis but with a more bio-based material perspective,[100] while his Materiality platform serves as a foundation on how to disseminate methods found in more technical scientific literature for designers and artists to use.[101] With this in mind, it could also be possible that there will not be another machine age to come, but perhaps a more organic one, that is even softer than the 'soft architecture' defined at the beginning of this thesis.

↩Fig. 5.3 Capsule Home had plug-in modules that users could swap out for repairs or to exchange with other types of modules for new configurations. Drawing by Warren Chalk, 1964.

99. Fox, "Catching up with the Past." 8.

100. "Actuated Matter – Materiability," https://materiability.com/portfolio/actuated-matter/.

101. Manuel Kretzer, *Information Materials Smart Materials for Adaptive Architecture* (Bern, Switzerland: Springer International Publishing, 2016). Also see his website: https://materiability.com/

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Appendices

Appendix A: Sphere Garland System Folio

Philip Beesley (ed.), Adrian Chiu (ed.)

Drawings by Adrian Chiu

Appendix B: Interactive Environments Minor Workshop 2023 Manual (Scaffold Section only)

LASG

Drawings by Adrian Chiu

Sphere Garland System

Living Architecture Systems Group



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Social Sciences and Humanities
Research Council of Canada

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Introduction

This manual is presented by the Living Architecture Systems Group (LASG) in collaboration with Science Centre Delft and the Interactive Environments Minor of TU Delft on the occasion of the 2023 Living Architecture Interactive Environments Workshop, Oct. 30-Nov.30, 2023. The manual provides download links that provide access to multiple components for fabrication, software and behaviour control systems developed by members of the Living Architecture Systems Group. The compressed print version of this manual supports introductory material. The digital version of the manual is expanded and includes extensive additional resources.

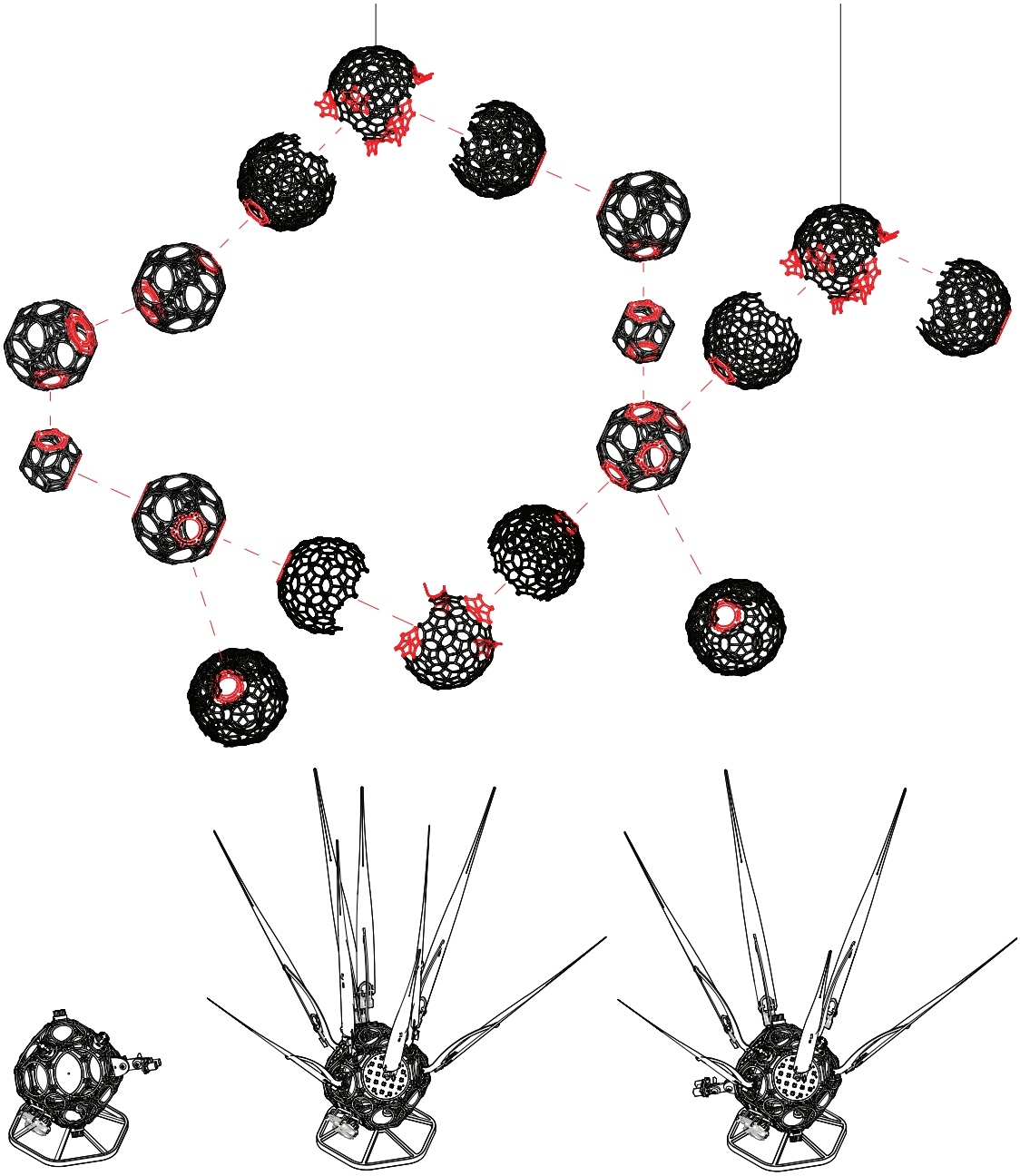
The web-based software and the physical kit components that have been included within this set are part of an evolving collection of tools and component designs that have been developed by the Living Architecture Systems Group under Creative Commons licensing. Large-scale interconnected arrays in both virtual and physical forms can be easily constructed by extending the system components that are provided in these kits. These patterns can be duplicated for personal non-commercial use, conditional on preserving credit for authorship and on preserving the original license within material that you copy or adapt.

The component designs have been developed as part of a research and creation initiative that is seeking to develop architecture that approaches the qualities of living systems. Qualities within the kit scaffold designs support minimal material use and compliant structures that are capable of accommodating multiple components and evolving functions. The structures that are documented here include filamentary triangulated skeletal frameworks for highly efficient waffle, shell and spherical envelopes.

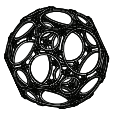
This manual describes the electronic components and software used in this kit. It demonstrates recommended connections between the “control” boards, and the actuators (motors, lights) and sensors. By following the recommended connections, the electronic components can be flexibly arranged in a wide variety of different configurations.

This flexible mounting system can support development of composite mechanisms, creating a diverse range of actuator and sensor components. This mount system includes cable-tie attachments that support precisely angled locations within the skeletal scaffold. A slotted tray design is included that accommodates a range of component mounts employing simple pegs, securable with locking washers.

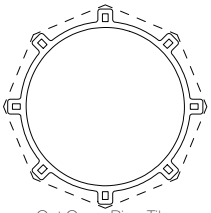
Descriptions of software include the “profile” configurations used to customize how the physical electronics behave. This software will allow you to finely tune the output of individual mechanisms, how they respond to external stimuli, and how they propagate through a system. It will also allow you to then plan out physical configurations and simulate larger systems on a virtual canvas.



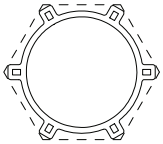
Ecosystem of Exploration



Open Ring Tile Truncated Cuboctohedron



Oct Open Ring Tile



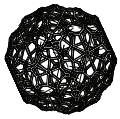
Hex Open Ring Tile



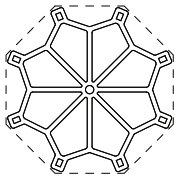
Pent Open Ring Tile x6



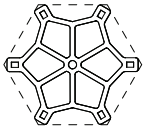
Quad Open Ring Tile



Stellated Skeleton Tile Truncated Cuboctohedron



Oct Stellated Skeleton Tile



Hex Stellated Skeleton Tile



Quad Stellated Skeleton Tile

Connectors



Tri-Connector



Bi-Connector



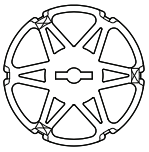
T-Pin



4mm Acrylic Tube



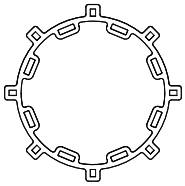
Hanging Eye



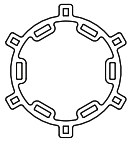
Hanging Plugin



Hanging Eye



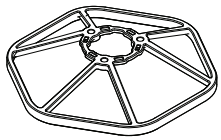
Oct Junction Connector



Hex Junction Connector

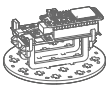


Connector Peg

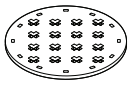


Base Stand

Scaffold Components



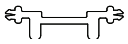
Node Controller Tray



Oct Peg Tray

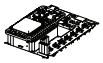


Node Controller Sled

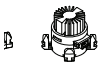


Node Controller Base

Tray Locking Plate



Node Controller



LED Case



Quad LED Base



Hex LED Base



LED Cover



LED PCB



Vibrating Lash



Lash Reflective Mylar



Lash Stalk 3mm Acrylic

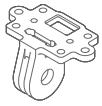


Vibration Motor Holder Resin

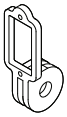


Lash PCB

Mounts and Devices



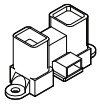
Board Mount for IR and Grove



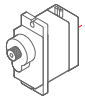
Servo Mount



Quad Ring Mount



IR Sensor



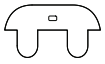
Servo Motor



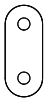
Arm



Arm Base Plate



Arm Mounting Peg



Arm Mounting Plate



Pan Head Screw

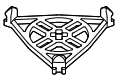


Wing Nut

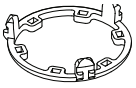
Plugins



Peg Quad Plugin



Peg Hex Plugin



Dressing Plugin

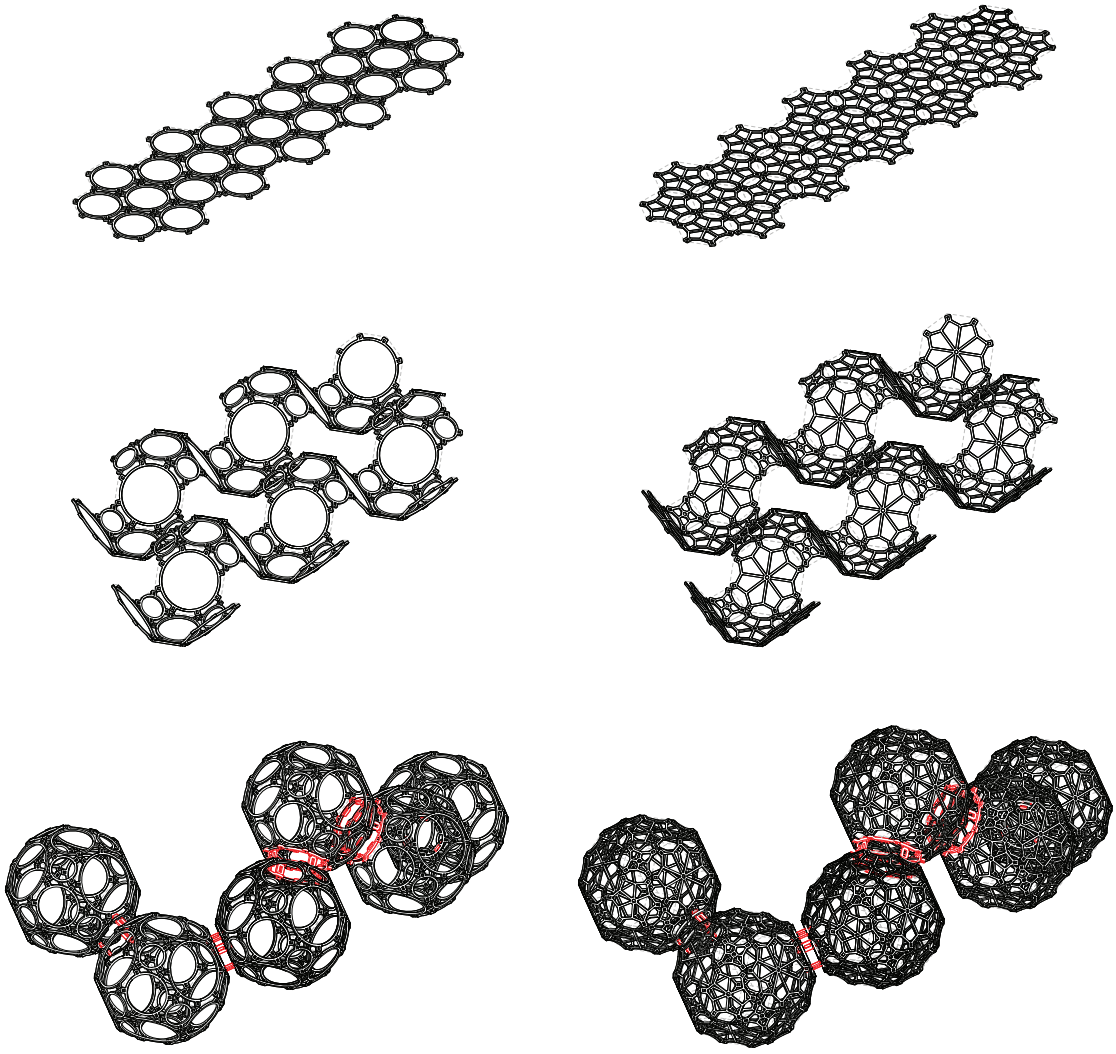


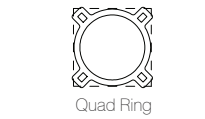
Cable Pin

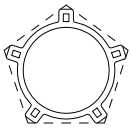
Actuator and Sensor Components

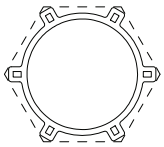
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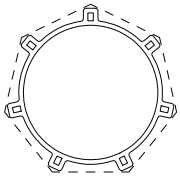
Scaffolds

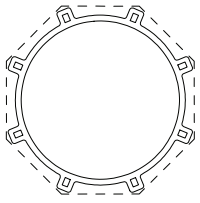



Quad Ring


Pent Ring


Hex Ring

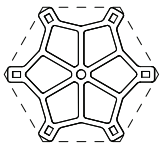

Hept Ring

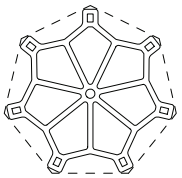

Oct Ring

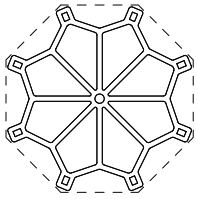
Open Ring Tile


Quad Ring


Pent Ring


Hex Ring


Hept Ring


Oct Ring

Stellated Tile


Bi-Connector


Tri-Connector

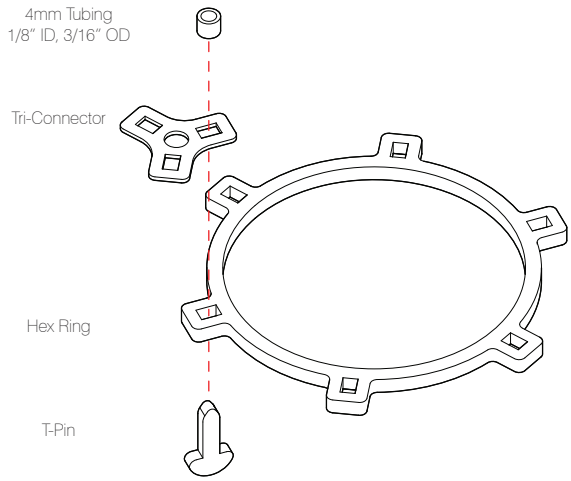

Quad-Connector

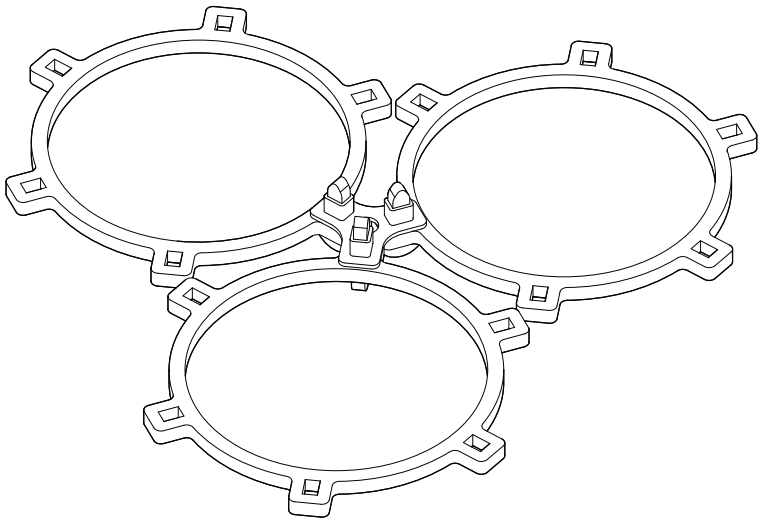

Uni-Connector


Straight Connector

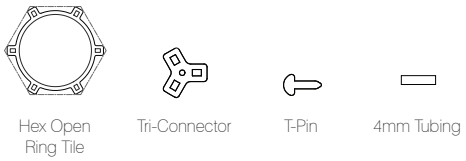

Cross Connector

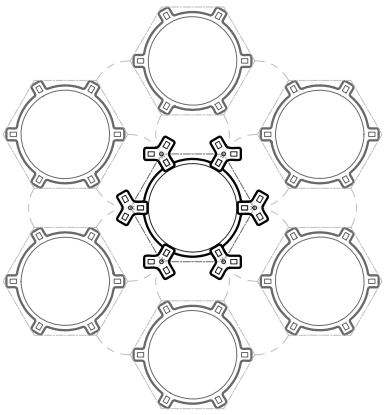
Scaffold Lexicon

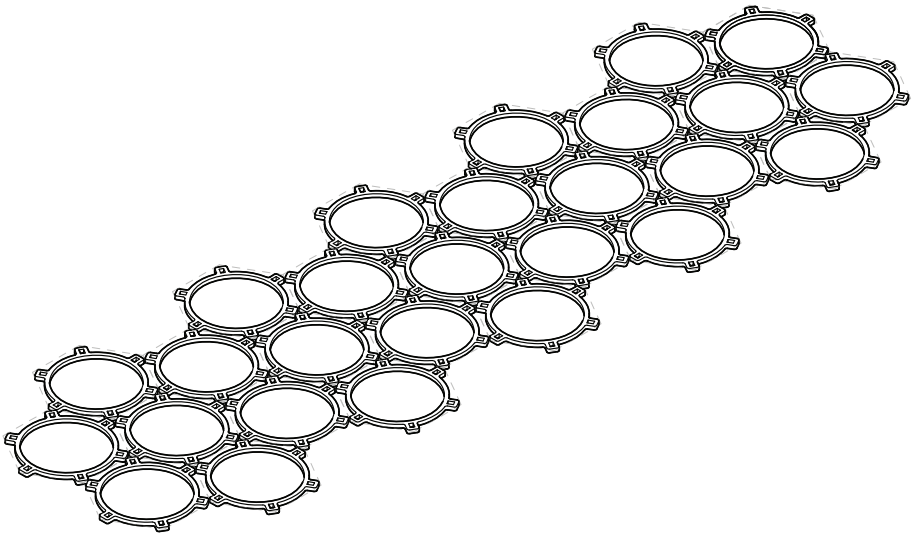




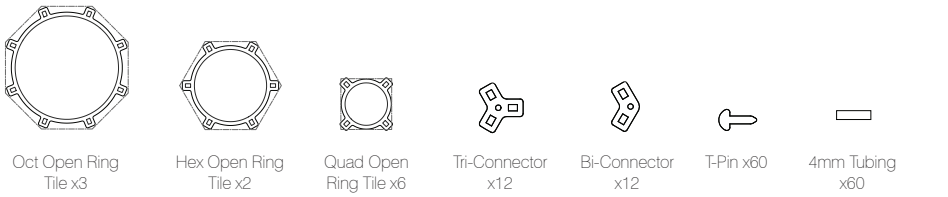
Connector Assembly

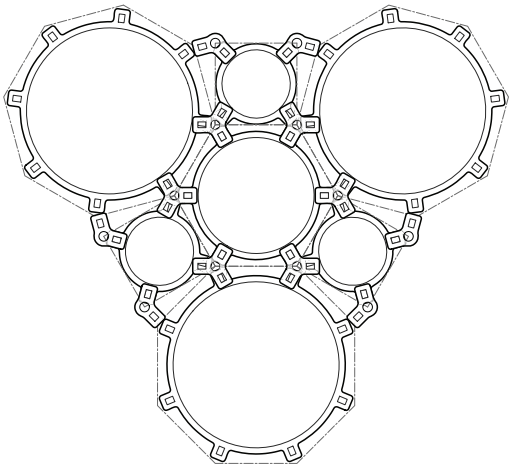


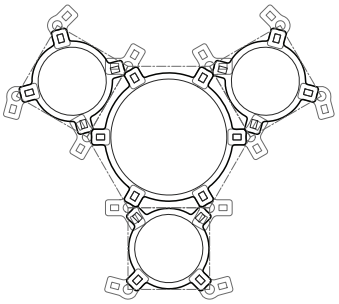


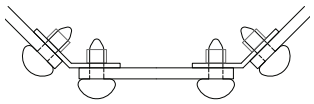


Hexagon Tiling



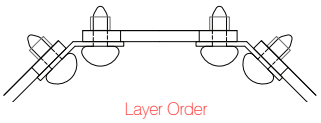




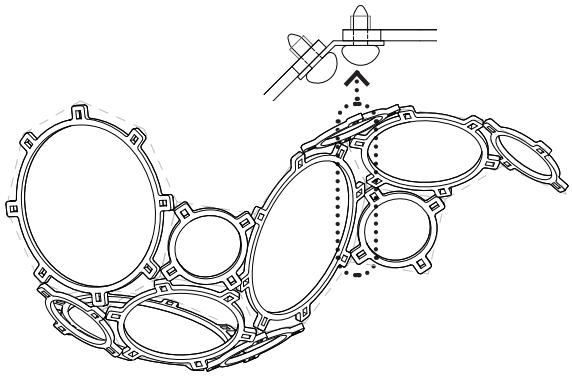


Layer Order
(Top to Bottom):
Tubing
Tri/Bi Connector
Ring
T-Pin

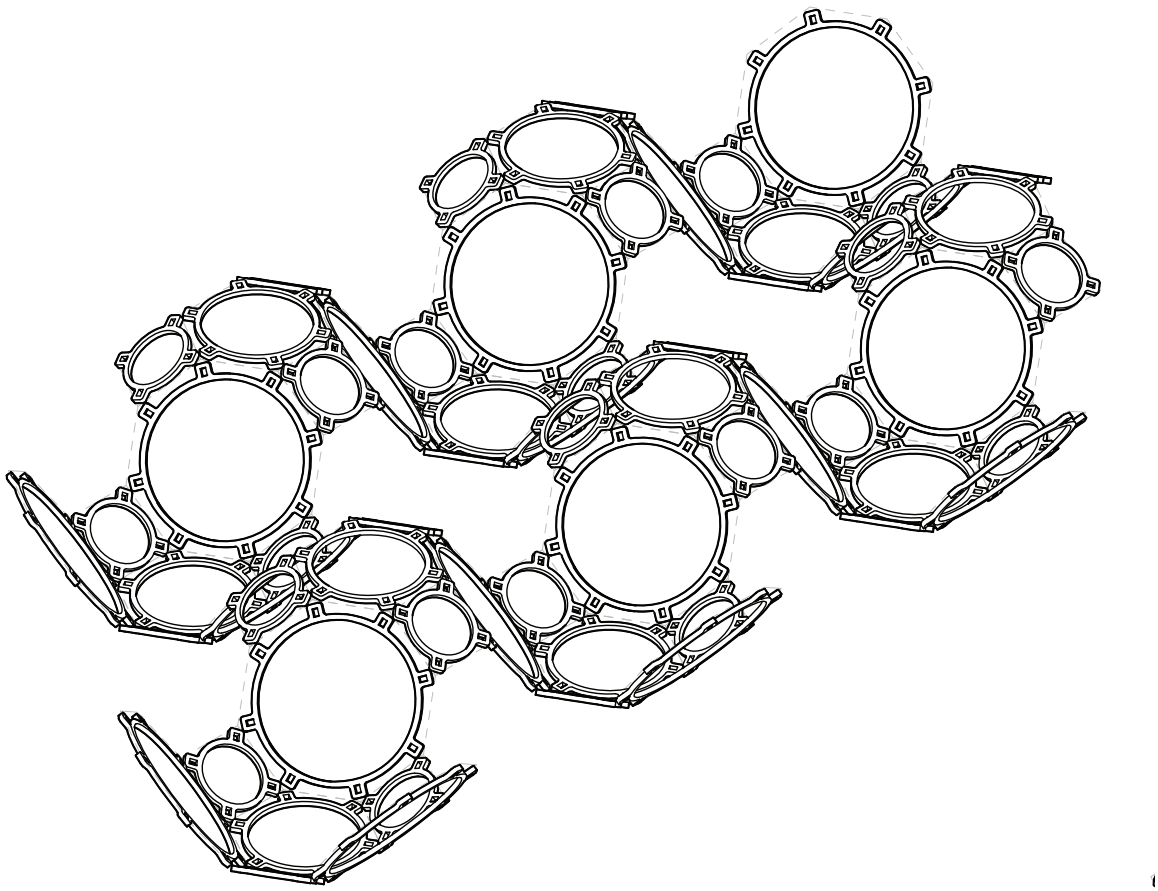
Layer Order
(Top to Bottom):
Tubing
Ring
Tri/Bi Connector
T-Pin



Layer Order
(Top to Bottom):
Tubing
Ring
Tri/Bi Connector
T-Pin

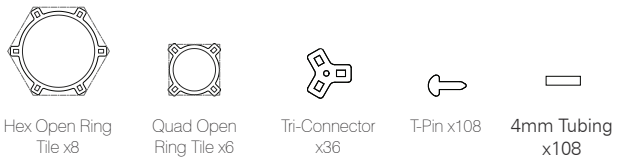


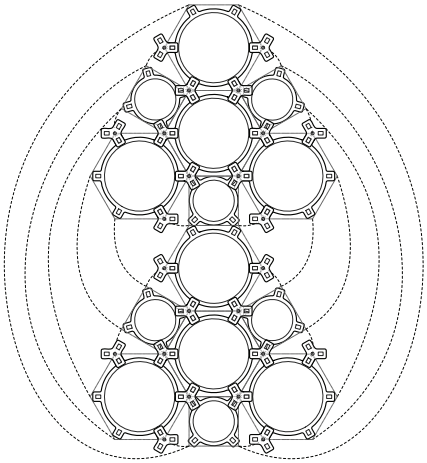
Truncated Cuboctohedron Waffle Unit

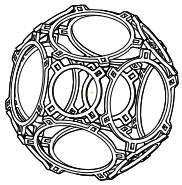


Truncated Cuboctohedron Waffle

SPHERE GARLAND SYSTEM 12







Truncated Octohedron



Oct Open Ring Tile x6



Hex Open Ring Tile x8



Quad Open Ring Tile x12

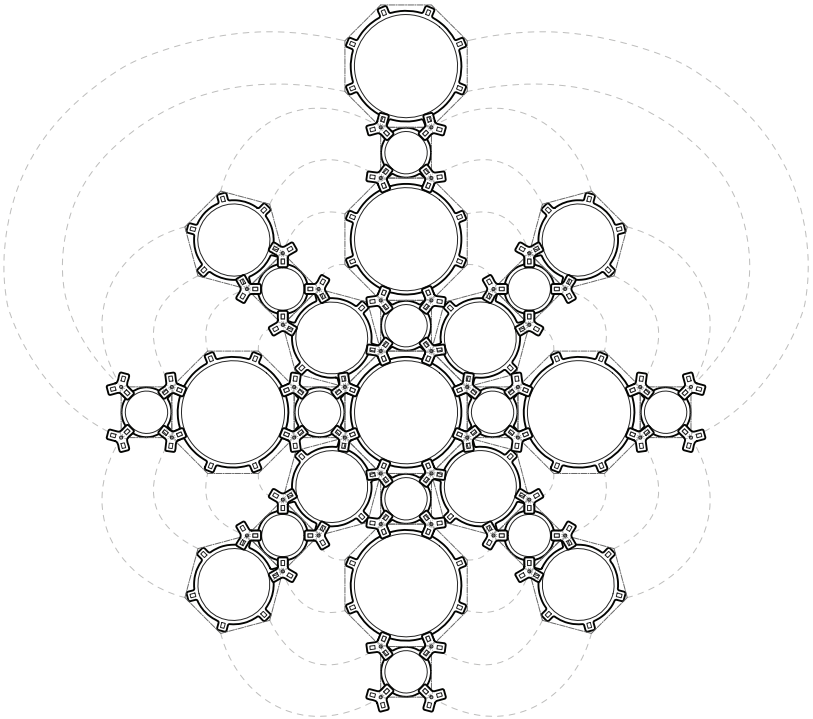


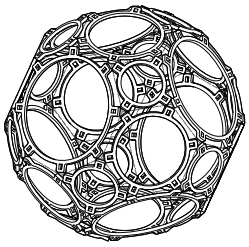
Tri-Connector x48



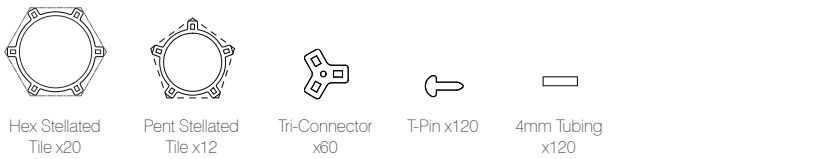
T-Pin x144

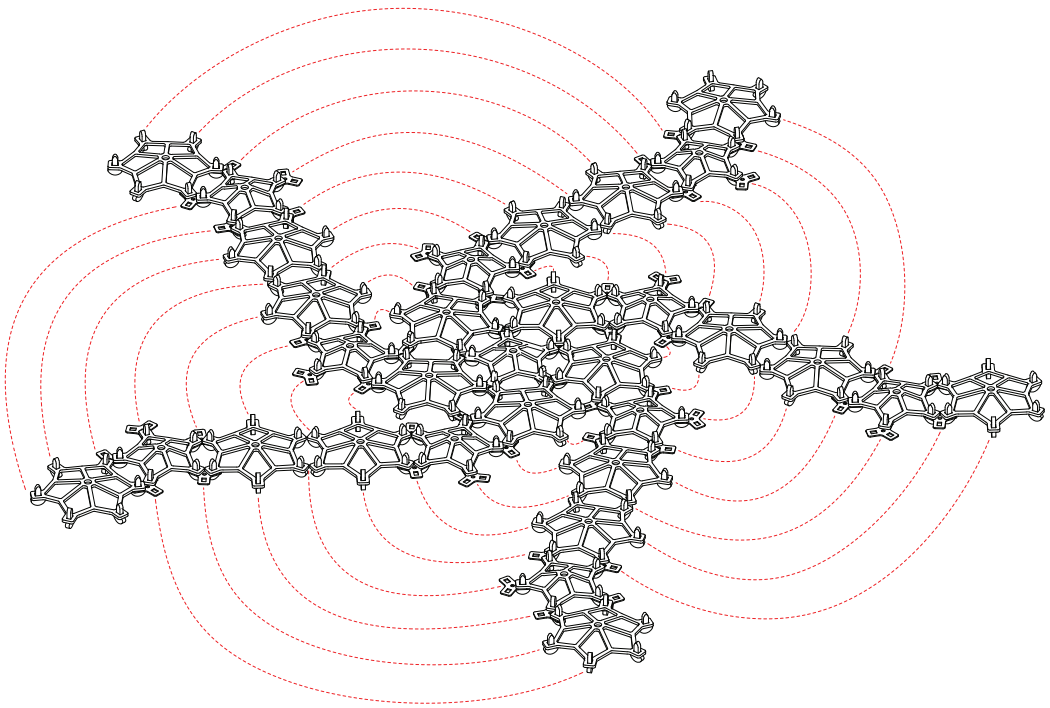
4mm Tubing x144

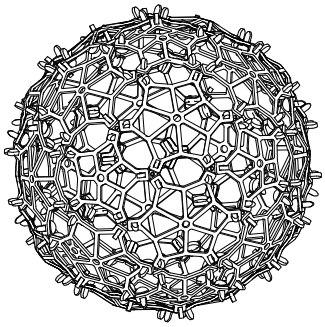




Truncated Cuboctohedron







Truncated Icosahedron



Hex Junction Ring x2



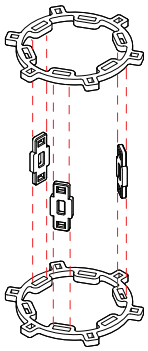
Junction Peg x3



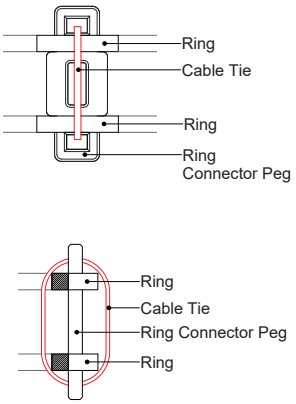
Oct Junction Ring x2

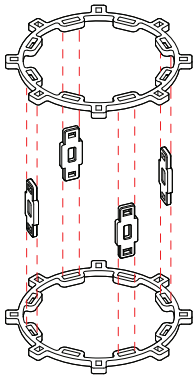


Long Junction Peg x4

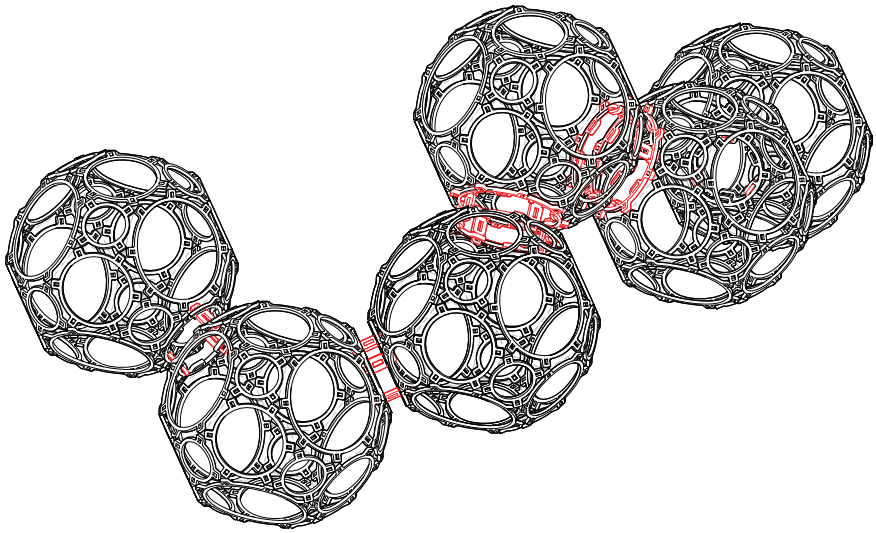


Hex-Hex Junction

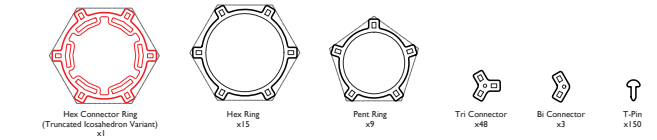


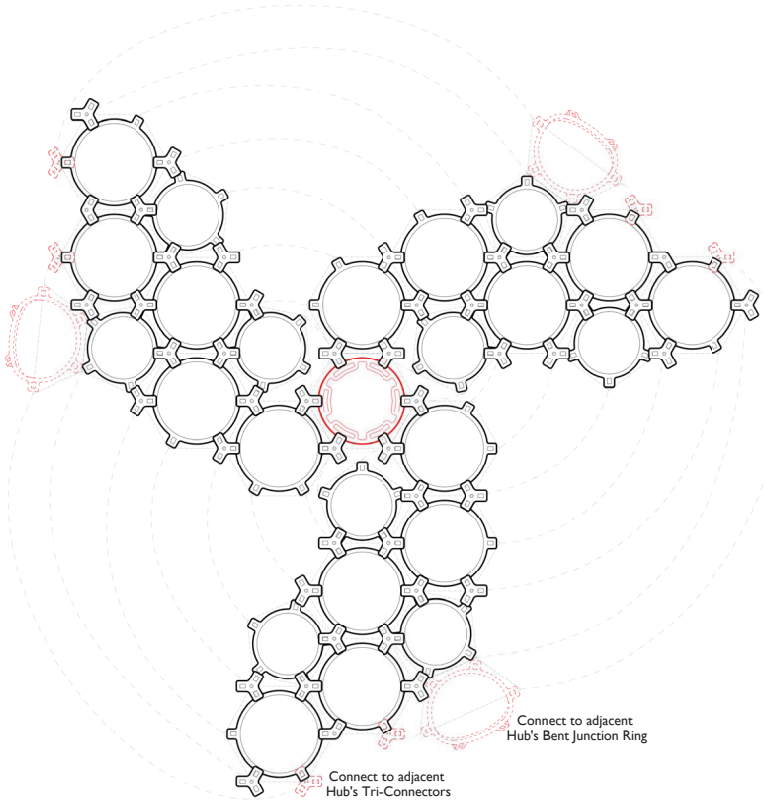


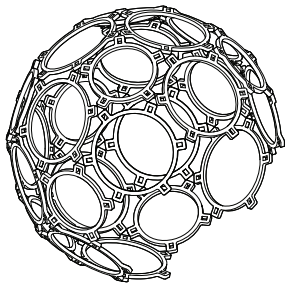
Oct-Oct Junction



Sphere Junction Rings

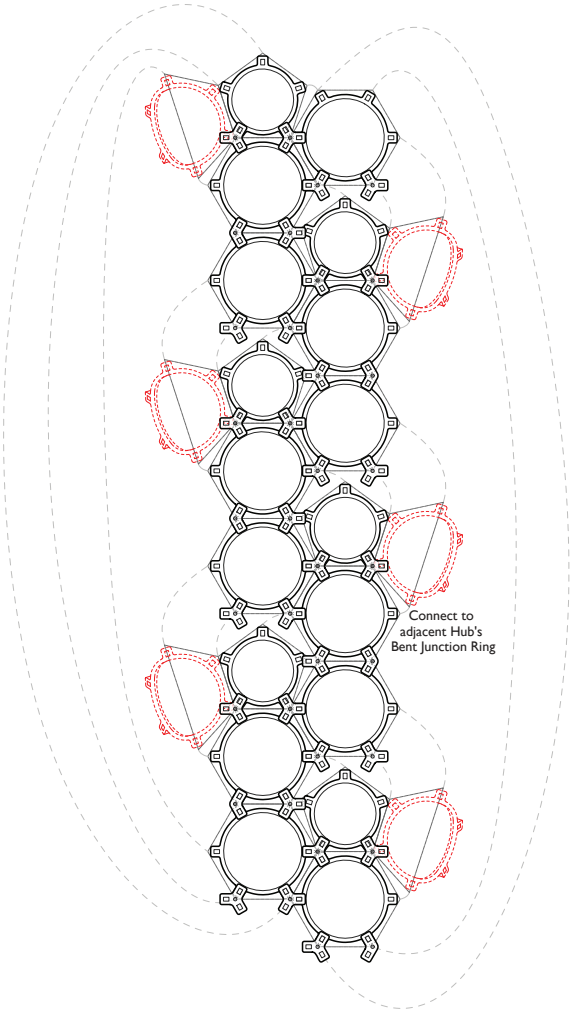


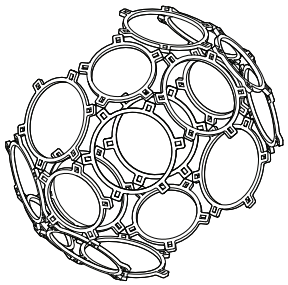




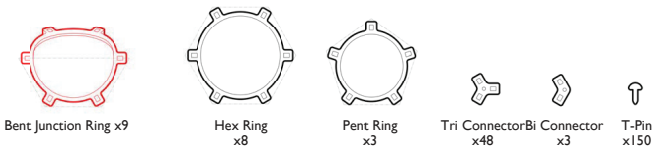
Truncated Icosahedron Terminal Scaffold

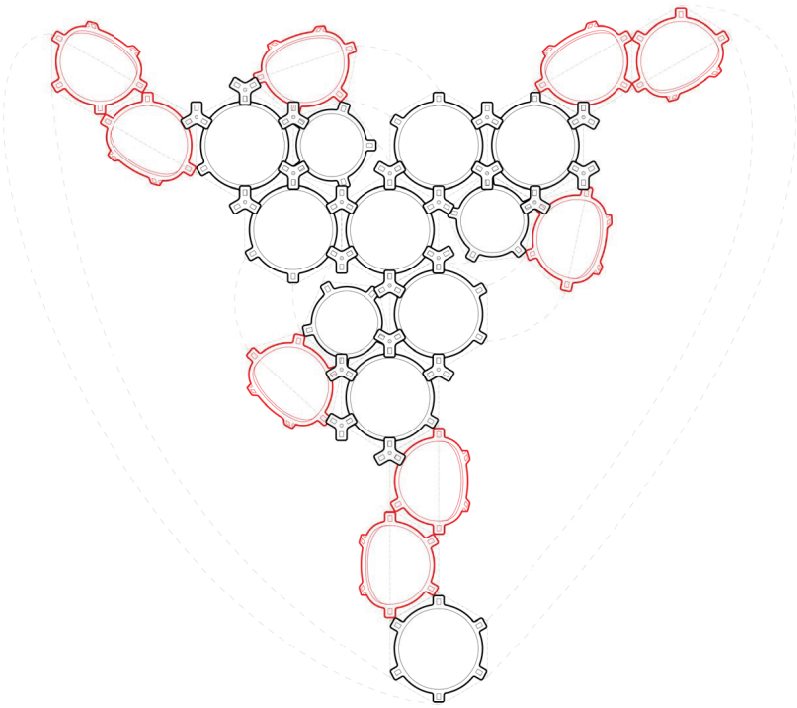


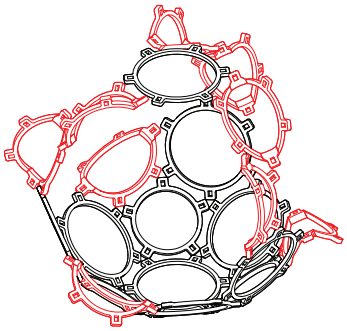




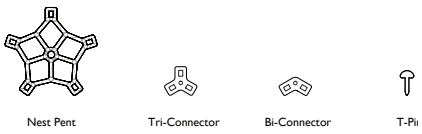
Truncated Icosahedron Spoke Scaffold

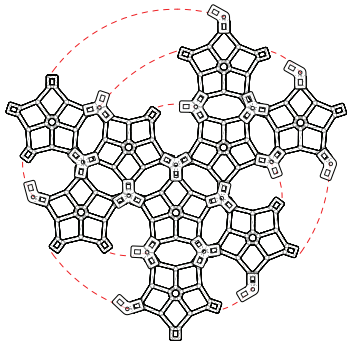


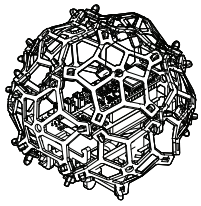




Truncated Icosahedron 3-way Hub Scaffold







Dodecahedron Nest Scaffold

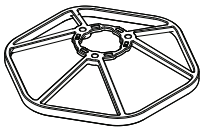
SPHERE GARLAND SYSTEM 20



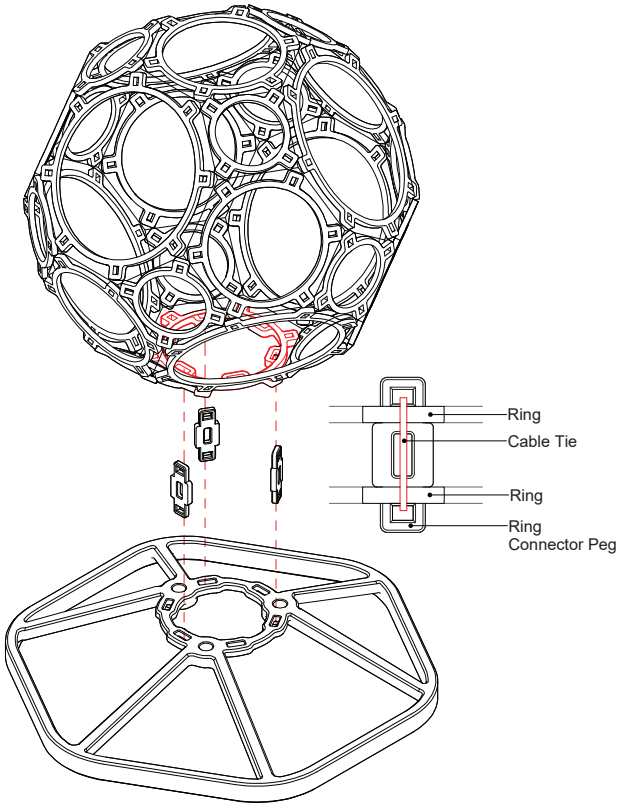
Hex Junction Ring x1

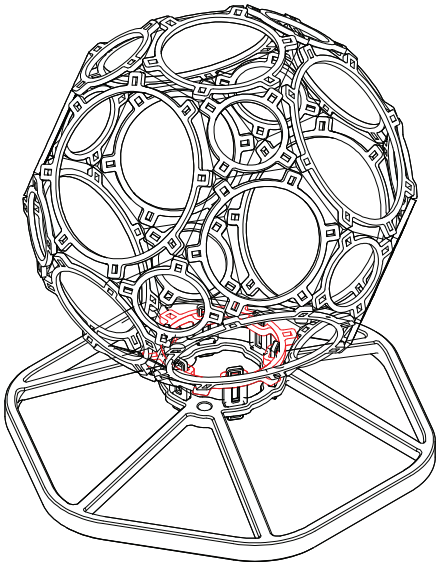


Connector Peg x3

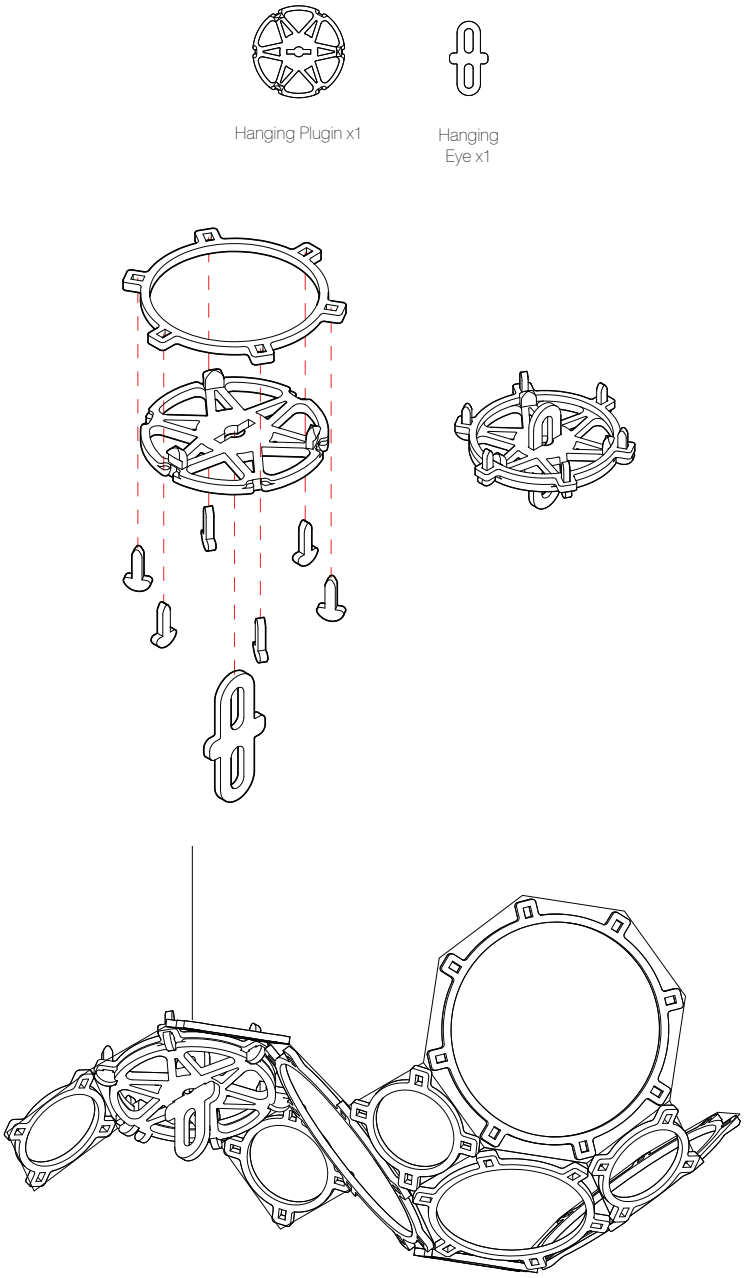


Hex Base x1





Base Stand



Hanging Point

Thermal Forming Instructions (Localized Heating)

Thermal Forming is the process of using heat to reshape a material. It is commonly used to give an object a more 3 dimensional shape when its manufacturing process would otherwise struggle to produce that shape.

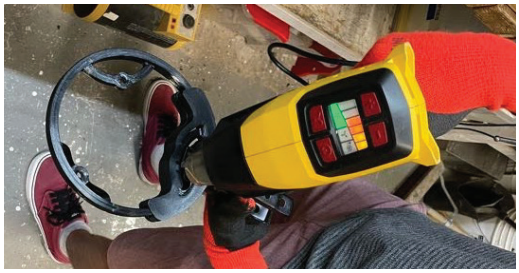
Step 1

Place the Base Ring into a containment jig made of less malleable material. Keep the 'flat and smooth' side up (for more detailed process description: see step 1 of Thermal Forming Instructions - Uniform Heating)



Step 2

Apply heat to the area that will be stretched using a heat gun. Make sure the heat gun is at least 10cm away from the object at all times to avoid overheating the jig. Heat until the Base Ring has a rubber-like consistency.



Step 3

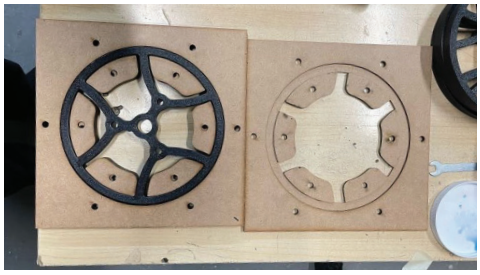
Remove the Base Ring from the jig, and use the center screw to guide the alignment of the object to the base jig. Slowly and uniformly press down on the sides. Use clamps to keep the jigs aligned while the object cools.

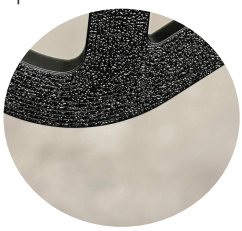


Thermal Forming Instructions (Uniform Heating)

Step 1

Place the object to be formed (in this case a base ring) into a containment jig made of less malleable material. This helps to localize the heat to areas that need to be stretched, while protecting the areas that need to remain flat. Each 3d printed face usually has a unique texture, a 'flat and smooth' side, and a side with more visible extrusions. For consistency, keep the 'flat & smooth' side facing up





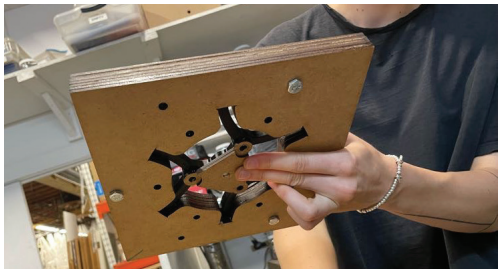
Flat & Smooth



Visible Extrusions

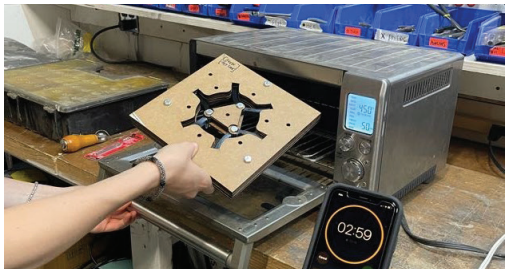
Step 2

Attach the top pieces of the jig using screws and nuts in a triangle formation to ensure its stability.



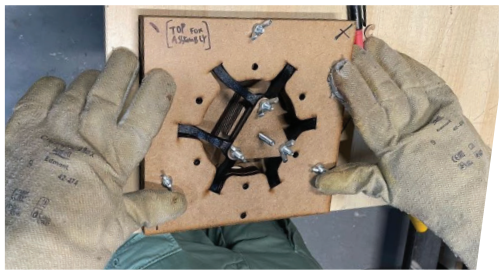
Step 3

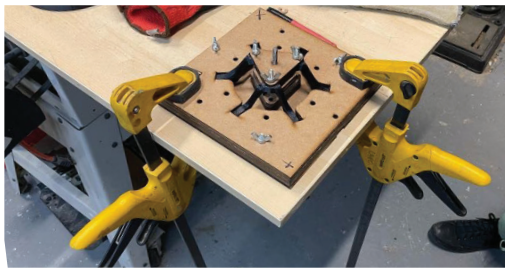
Have oven set at 450 - place jig into the oven for 3 minutes (heat and time may vary based on material size and required malleability)



Step 4

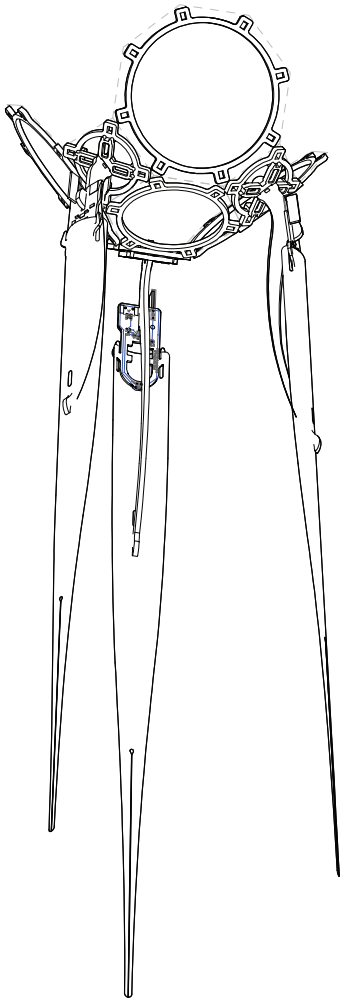
Remove the jig from the oven, and keeping the 'Flat & Smooth' side up, align the containment jig with the base jig, slowly and uniformly press down on the sides. Use center screw to guide the alignment of the jigs. Use clamps to keep the jigs aligned while the object cools.

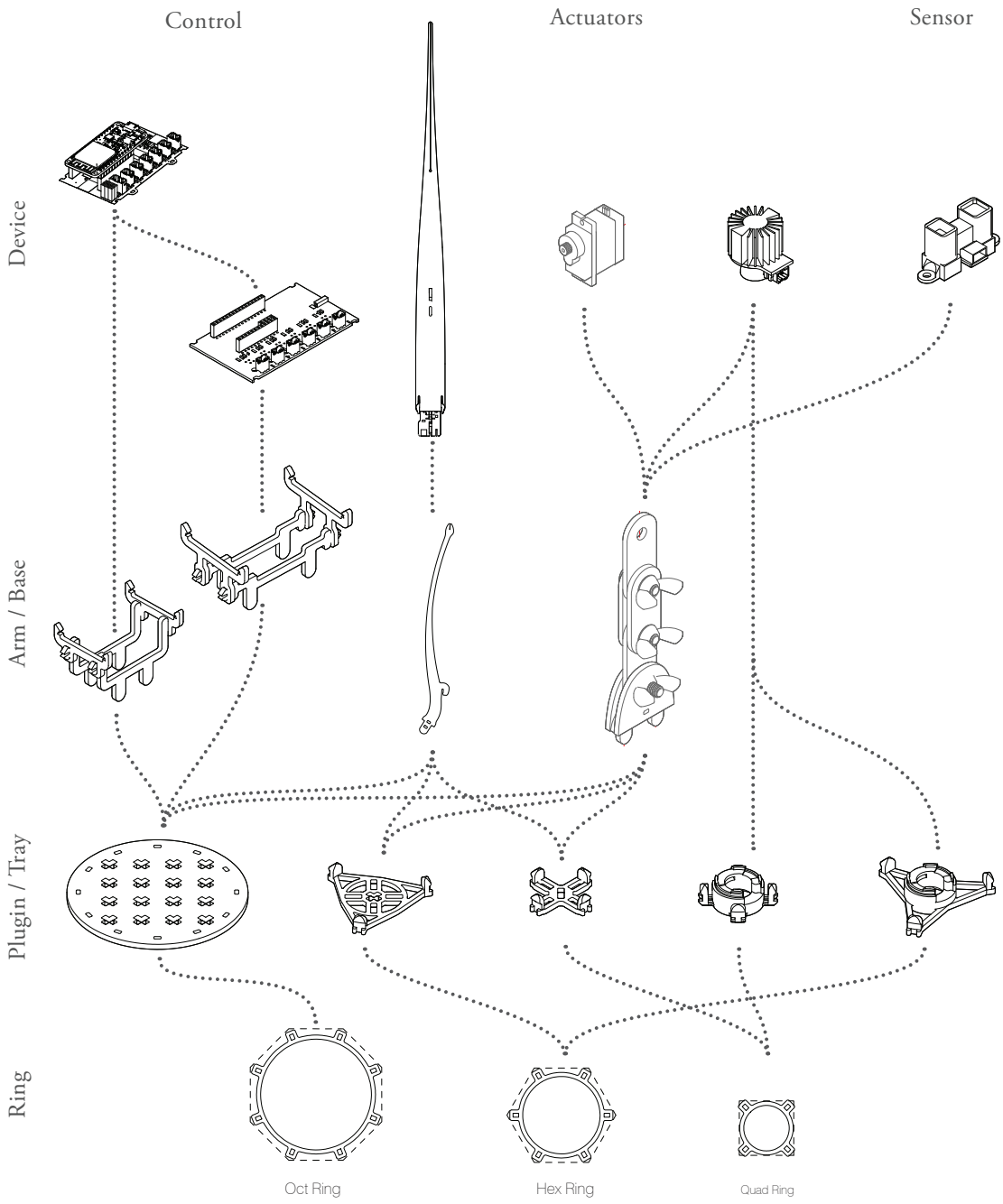




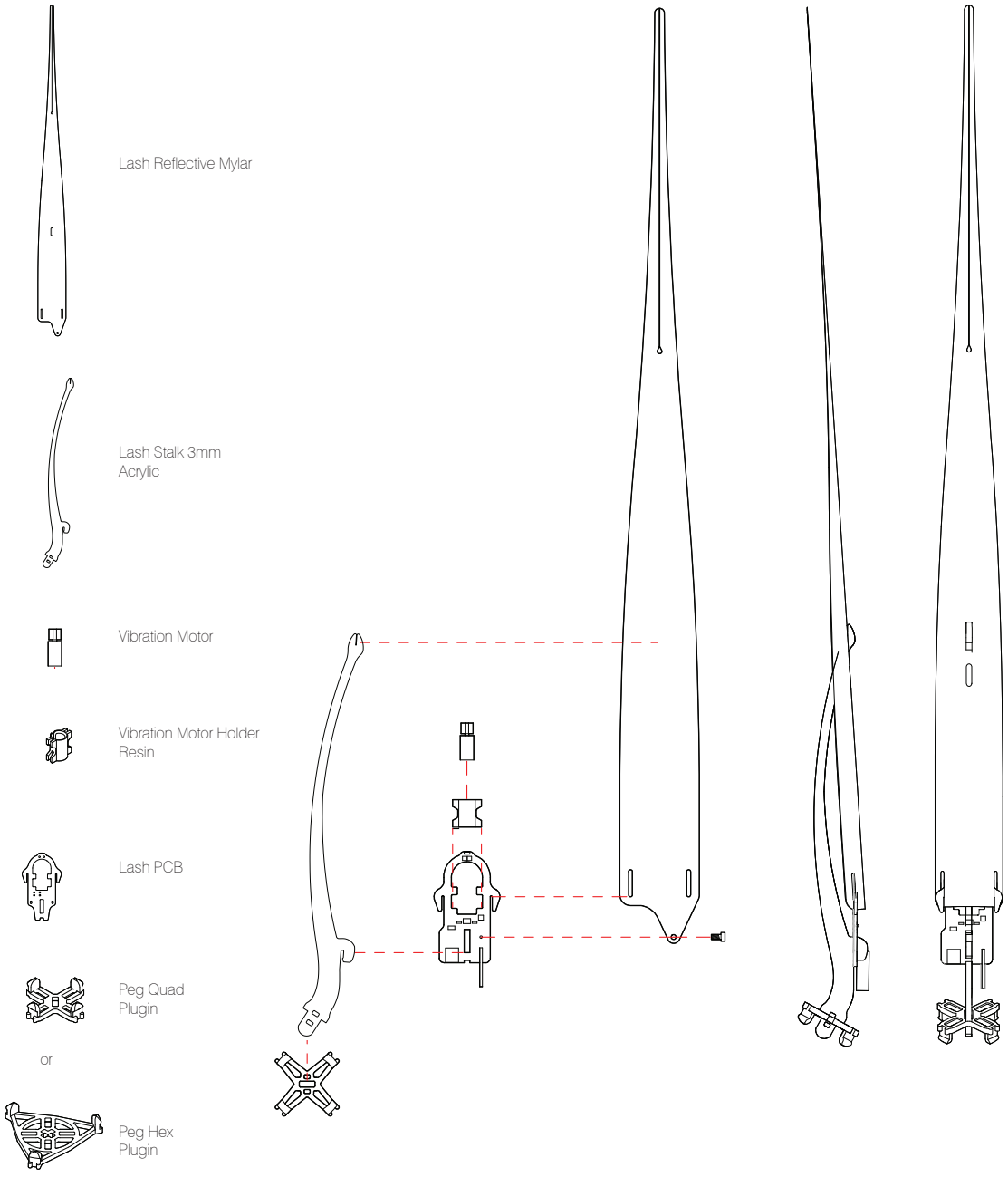
2

Actuators and Sensors

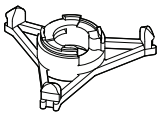




Device Attachment System

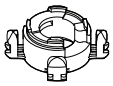


Vibrating Lash



Hex LED Base

OR



Quad LED Base



LED Cover



Collimator

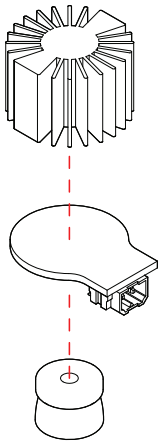


S4 LED PCB

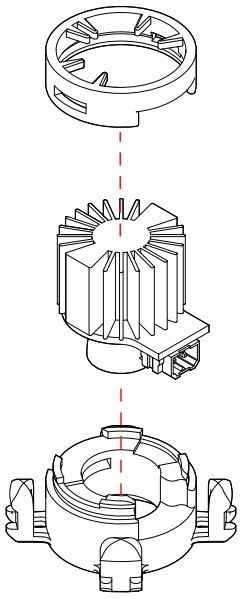


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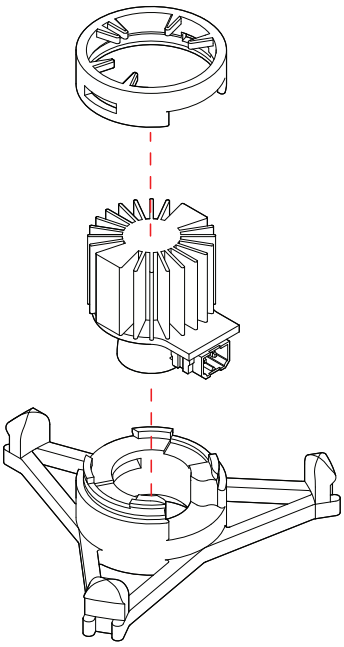
LED Assembly

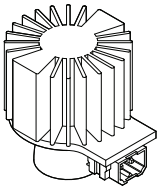


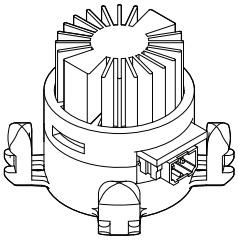
Quad Variant

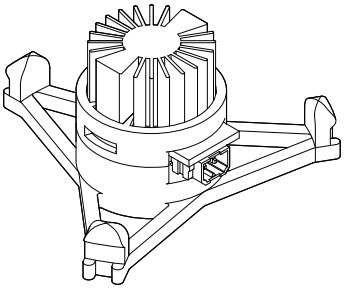


Hex Variant

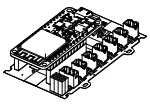




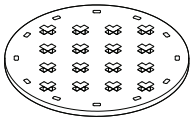




LED Light



Node Controller x1



Peg Tray x1
3mm Acrylic

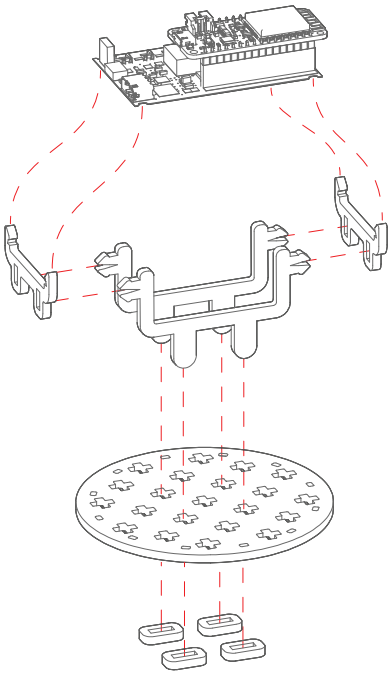


Node Controller Mount x2
3mm Acrylic

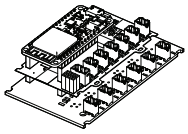


Node Controller Base x2
3mm Acrylic

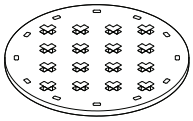
Tray Locking
Plate x4



Node Controller Tray



Expansion Board + Node Controller x1



Peg Tray 3mm Acrylic x1

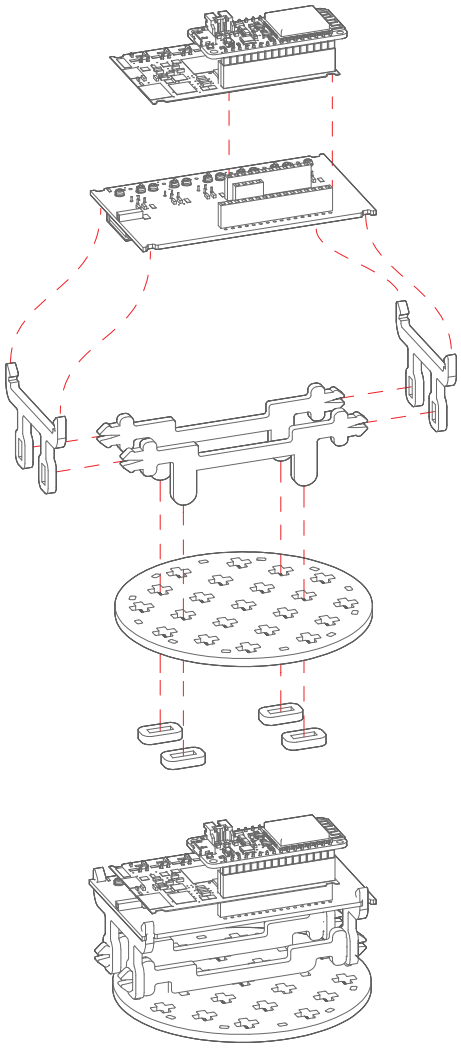


Expansion Board Mount 3mm Acrylic x2

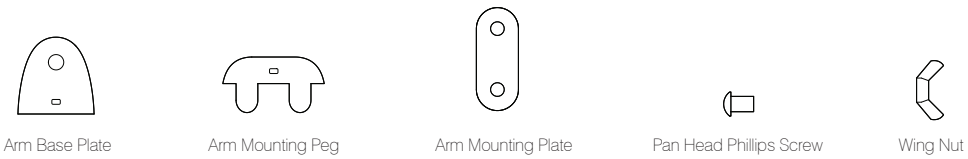


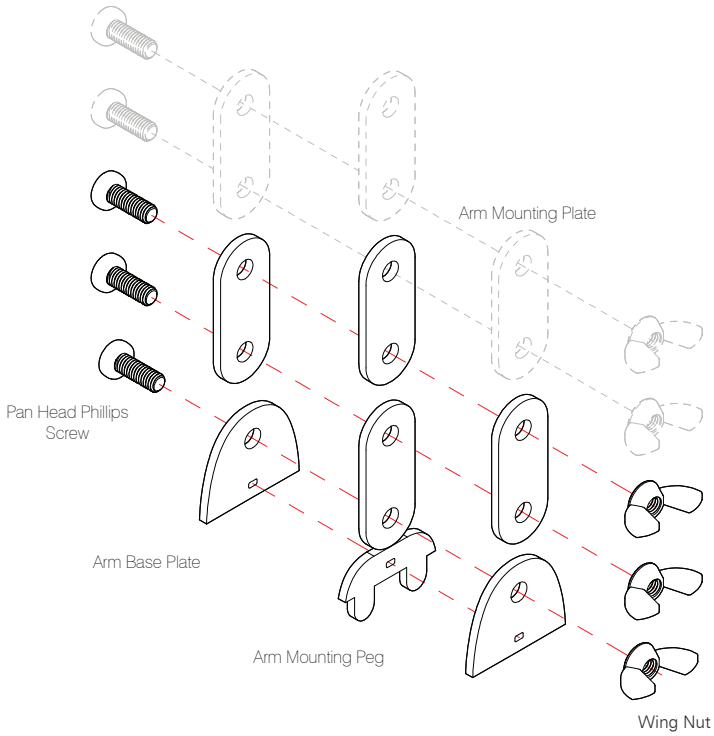
Expansion Board Base 3mm Acrylic x2

Tray Locking Plate x4



Node Controller Tray with Expansion Board





Extensible Rotating Arm



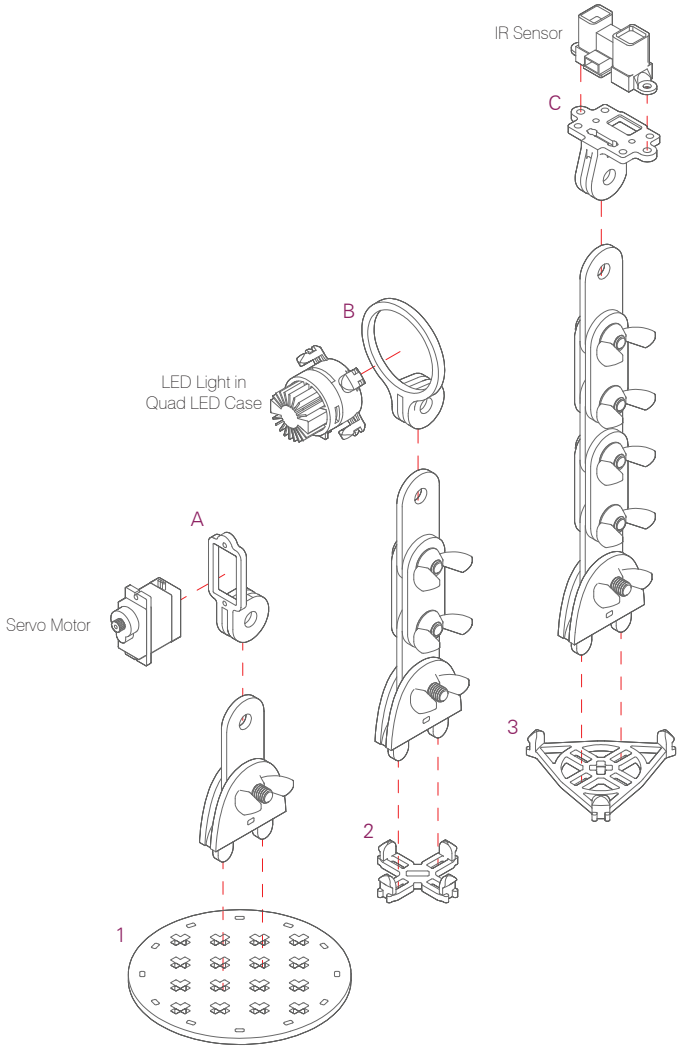
1 Peg Tray 2 Peg Quad Plugin 3 Peg Hex Plugin

Base Attachment Options



A Servo Mount B Quad Ring Mount C Board Mount

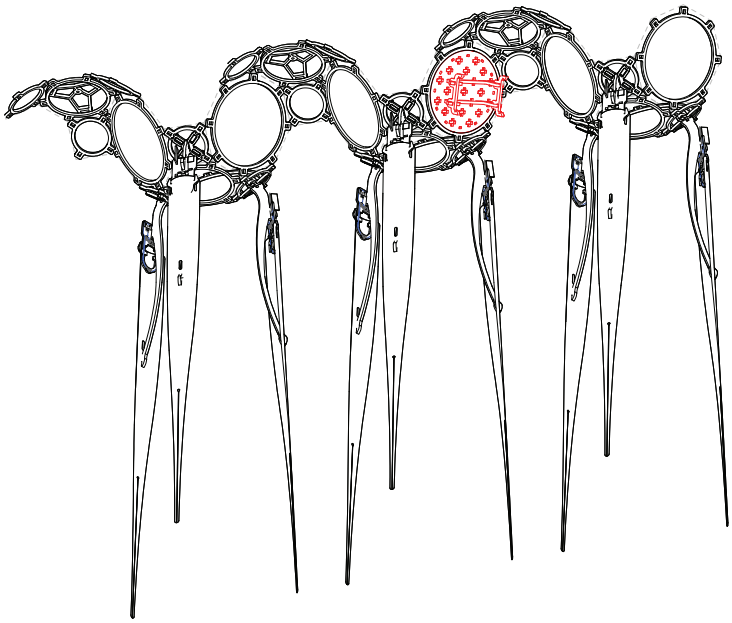
Top Attachment Options

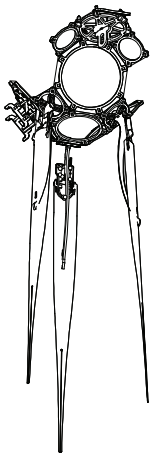


Extensible Rotating Arm Attachments

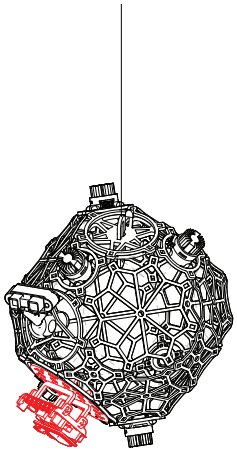
3

Integrated Assemblies

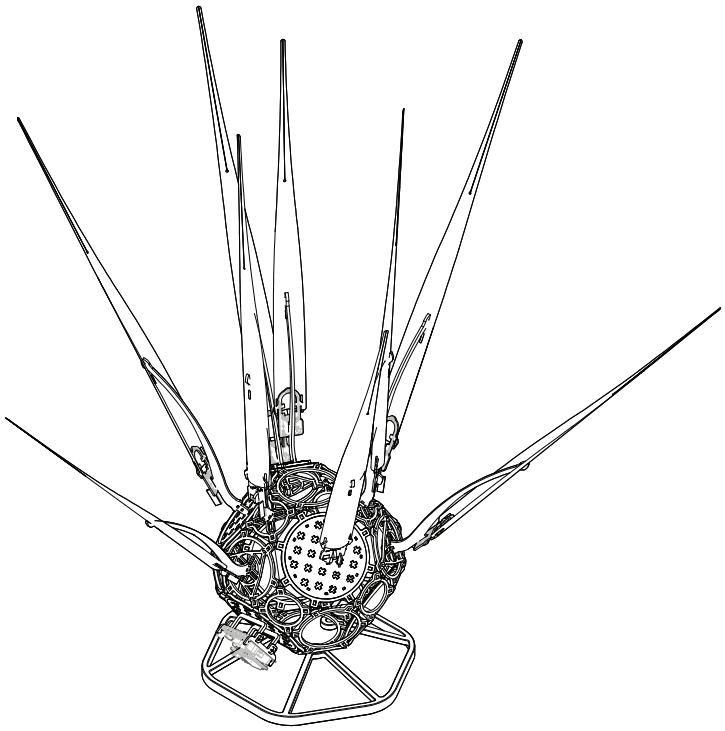




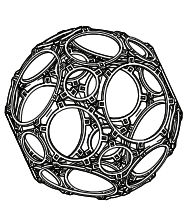
Waffle Cell Assembly



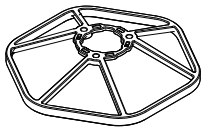
Light Cell Assembly



Lash Cell Assembly



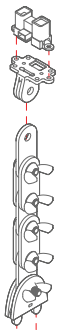
Truncated Cuboctohedron x1
Open Ring



Base Stand x1



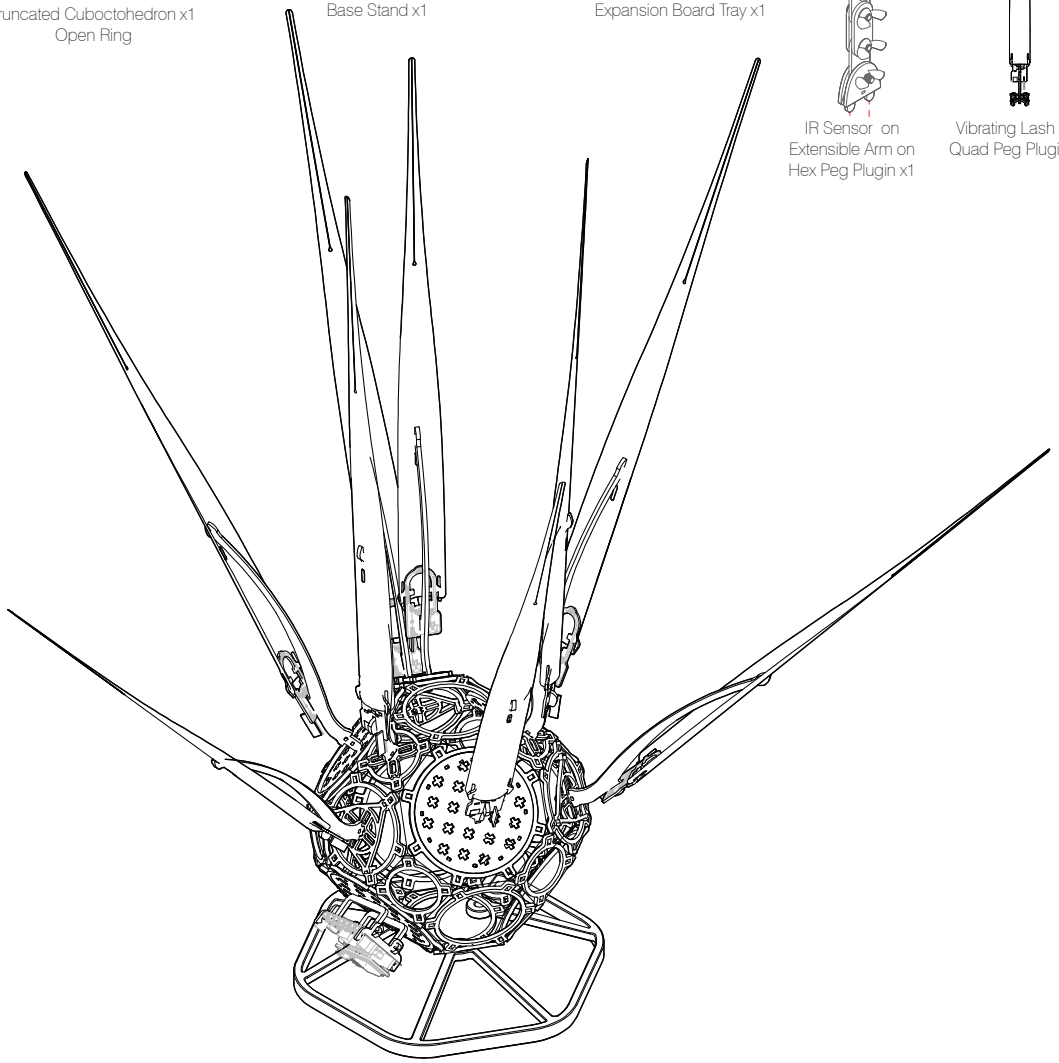
Expansion Board Tray x1



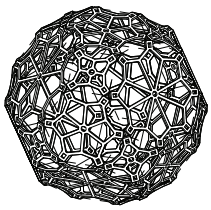
IR Sensor on
Extensible Arm on
Hex Peg Plugin x1



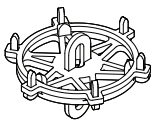
Vibrating Lash on
Quad Peg Plugin x9



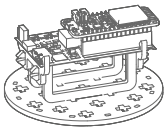
Lash Cell Assembly



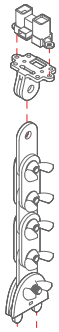
Truncated Cuboctohedron x1
Open Ring



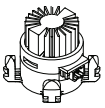
Hanging Point x1



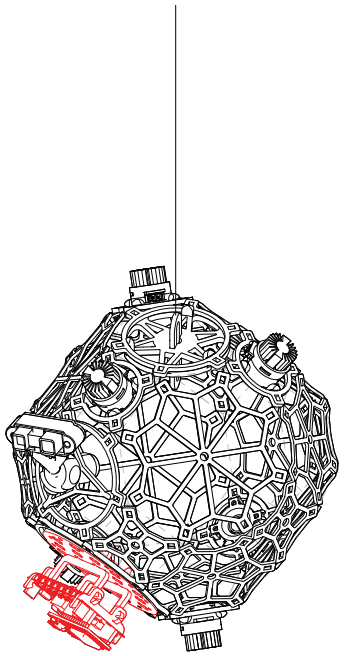
Node Controller Tray x1



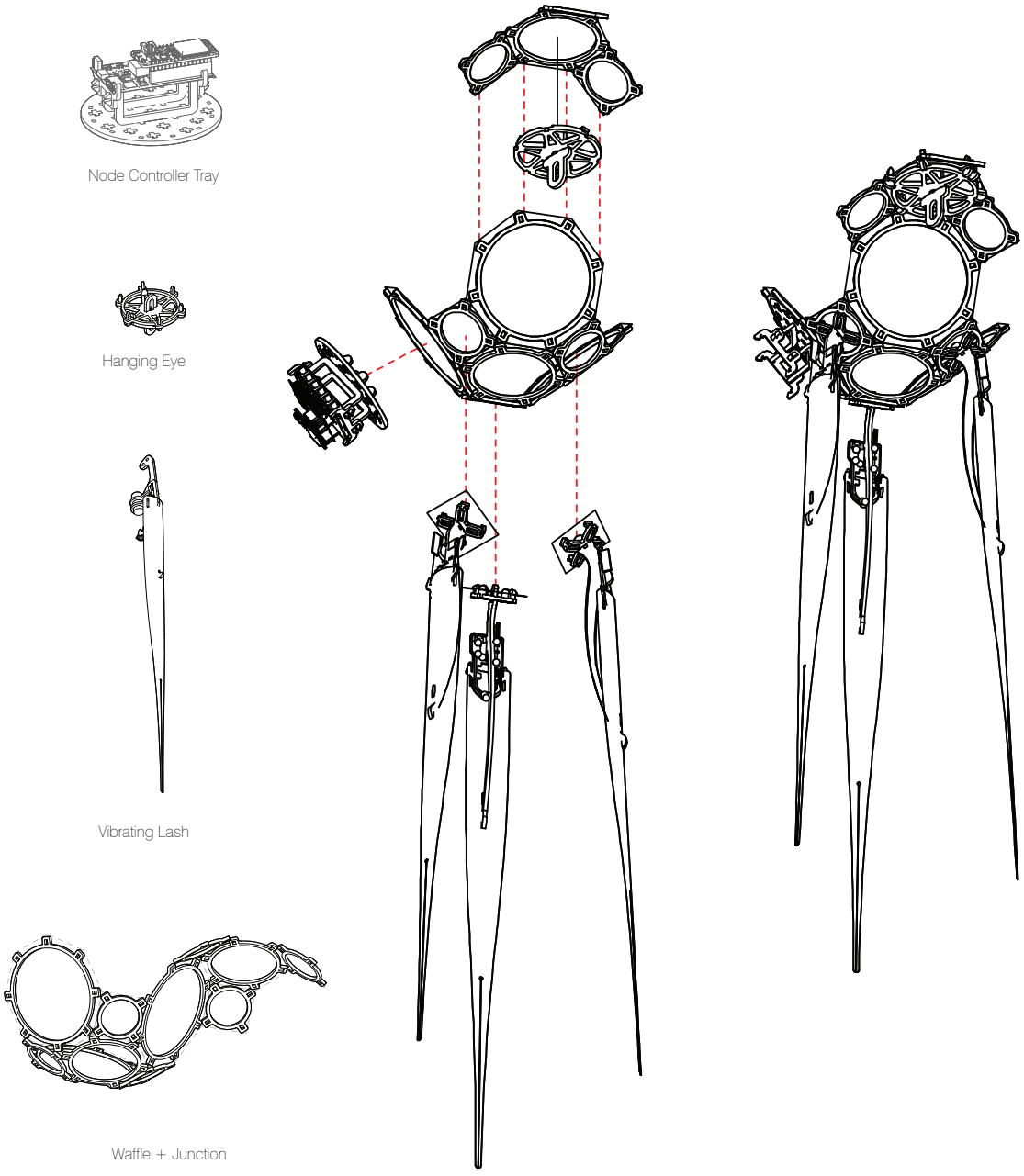
IR Sensor on
Extensible Arm on
Hex Peg Plugin x1



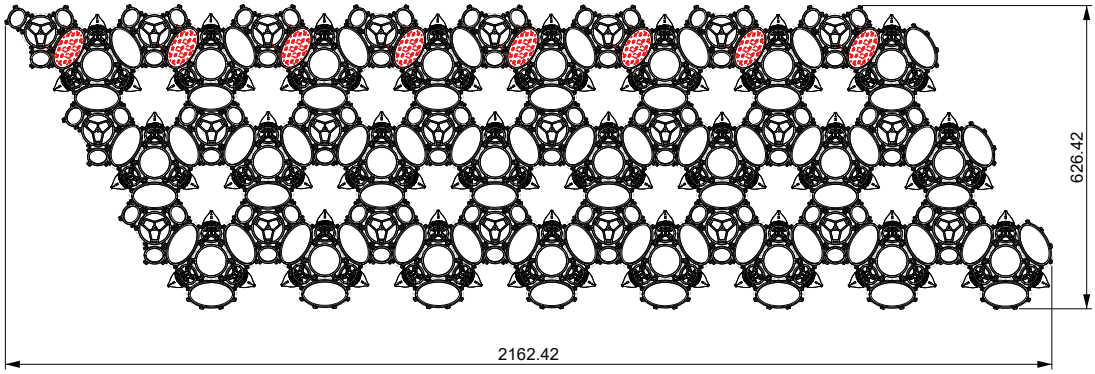
Quad LED x6

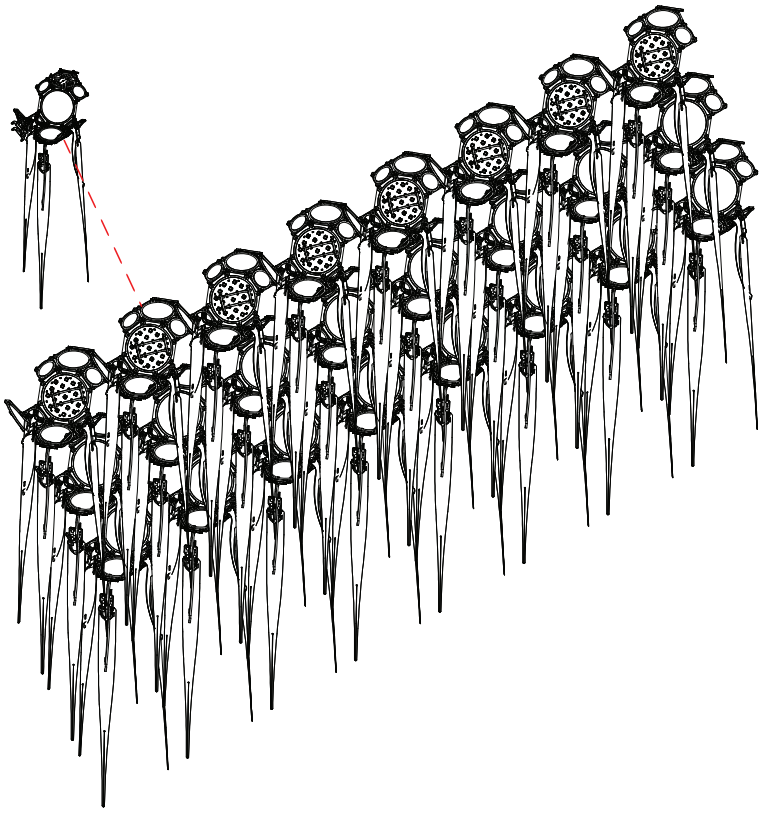


Light Cell Assembly



Waffle Cell Assembly

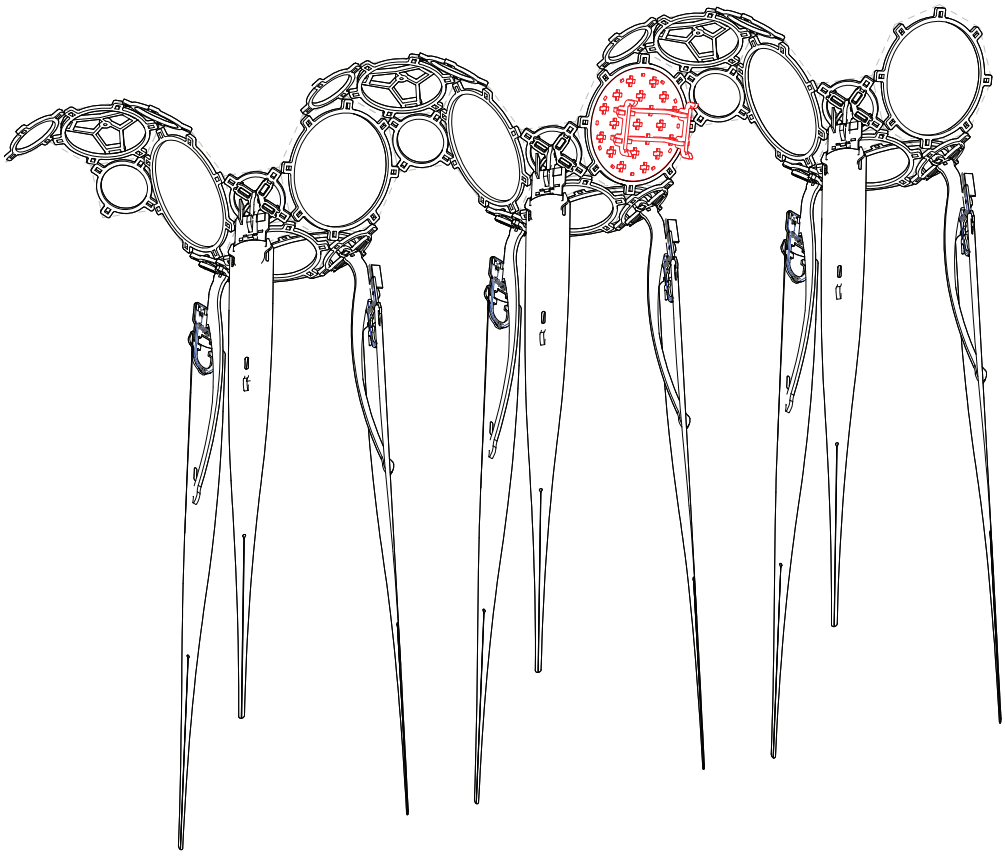




Canopy System Assembly

Appendix B

Interactive Environments Minor Workshop 2023
Manual (Scaffold Section only)
LASG
Drawings by Adrian Chiu



INTERACTIVE ENVIRONMENTS MINOR WORKSHOP 2023

MANUAL

Contents

1 Scaffolds

2 Actuators and Sensors

3 Electronics Hardware

4 Behaviour

5 Local Behaviour: Smart Cells

6 Additional Information

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Errors or omissions would be corrected in subsequent editions.

This book is set in Garamond and Zurich BT.

2023 Interactive Environments Minor: Workshop Manual |

Introduction

This manual is presented by the Living Architecture Systems Group (LASG) in collaboration with Science Centre Delft and the Interactive Environments Minor of TU Delft on the occasion of the 2023 Living Architecture Interactive Environments Workshop, Oct. 30-Nov.30, 2023. The manual provides download links that provide access to multiple components for fabrication, software and behaviour control systems developed by members of the Living Architecture Systems Group. The compressed print version of this manual supports introductory material. The digital version of the manual is expanded and includes extensive additional resources.

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. Large-scale interconnected arrays in both virtual and physical forms can be easily constructed by extending the system components that are provided in these kits. These patterns can be duplicated for personal non-commercial use, conditional on preserving credit for authorship and on preserving the original license within material that you copy or adapt.

The component designs have been developed as part of a research and creation initiative that is seeking to develop architecture that approaches the qualities of living systems. Qualities within the kit scaffold designs support minimal material use and compliant structures that are capable of accommodating multiple components and evolving functions. The structures that are documented here include filamentary triangulated skeletal frameworks for highly efficient waffle, shell and spherical envelopes.

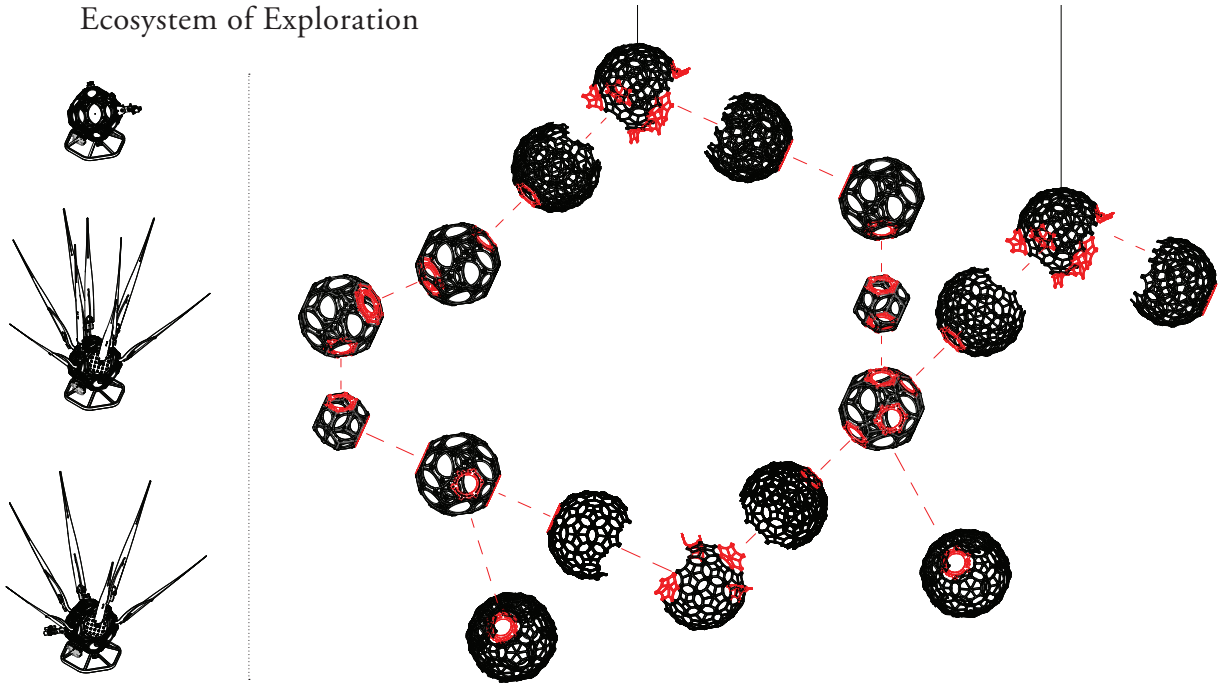
This manual describes the electronic components and software used in this kit. It demonstrates recommended connections between the "control" boards, and the actuators (motors, lights) and sensors. By following the recommended connections, the electronic components can be flexibly arranged in a wide variety of different configurations.

This flexible mounting system can support development of composite mechanisms, creating a diverse range of actuator and sensor components. This mount system includes cable-tie attachments that support precisely angled locations within the skeletal scaffold. A slotted tray design is included that accommodates a range of component mounts employing simple pegs, securable with locking washers.

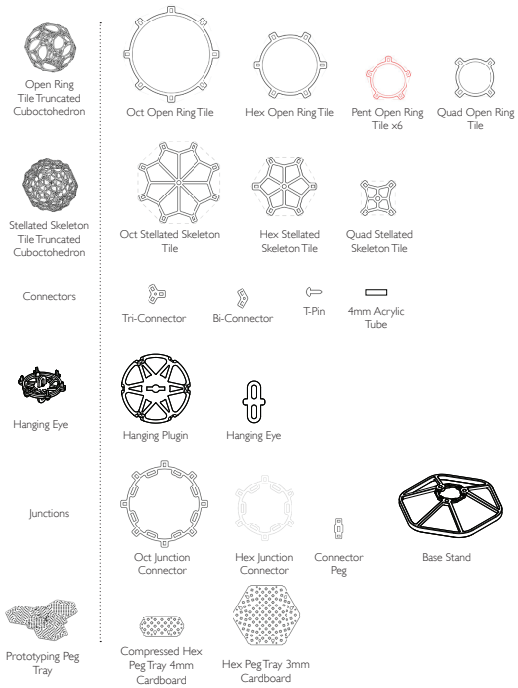
Descriptions of software include the "profile" configurations used to customize how the physical electronics behave. This software will allow you to finely tune the output of individual mechanisms, how they respond to external stimuli, and how they propagate through a system. It will also allow you to then plan out physical configurations and simulate larger systems on a virtual canvas.

2023 Interactive Environments Minor: Workshop Manual | Introduction

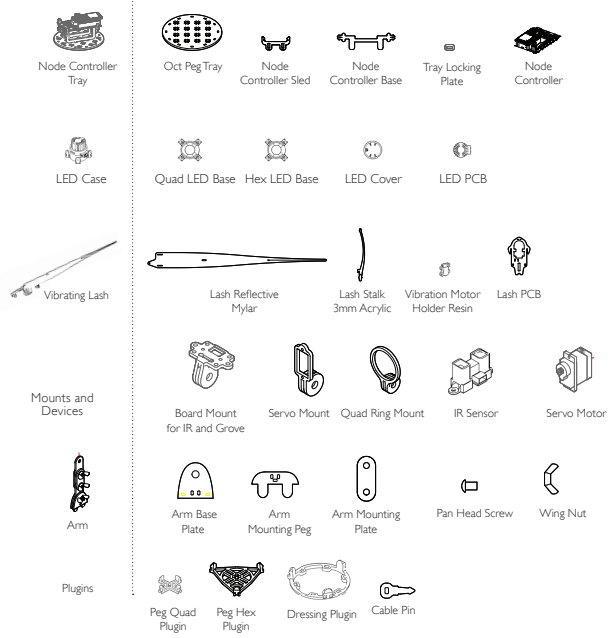
Ecosystem of Exploration



Scaffold Components

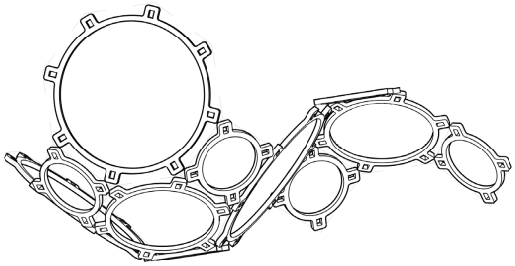


Actuator and Sensor Components



1

Scaffolds



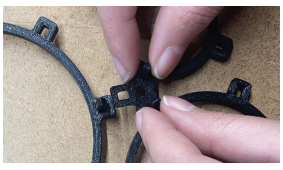
Ring Assembly Instructions

Step 1
Place T-pins into ring holes

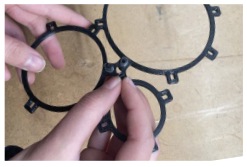





Step 2
Attach the rings together by placing a tri-connector over the t-pins

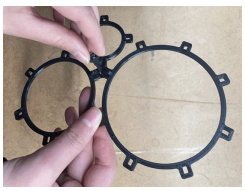
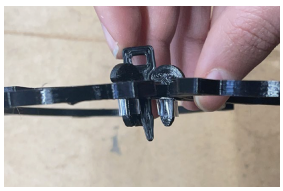



Step 3
Place a 4mm acrylic tube over the end of each T-pin to secure it in place




Cable Management

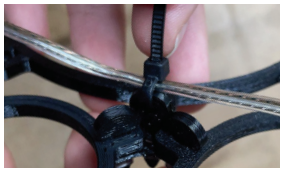
Step 1
If wiring is desired at this location, a Cable Pin can be added to the center hole of the Tri-connector, providing additional attachment capabilities at that junction

Step 2
Place a 4mm acrylic tube over the end of the Cable Pin to secure it in place



Step 3
Insert a zip tie into the hole of the Cable Pin and use it to attach a wire on top of the Cable Pin



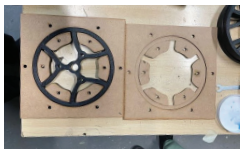
Introduction to Thermal Forming

Thermal Forming is the process of using heat to reshape a material. It is commonly used to give an object a more 3 dimensional shape when its manufacturing process would otherwise struggle to produce that shape.

Thermal Forming Instructions (Uniform Heating)

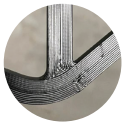
Step 1
Place the object to be formed (in this case a base ring) into a containment jig made of less malleable material. This helps to localize the heat to areas that need to be stretched, while protecting the areas that need to remain flat.

Each 3d printed face usually has a unique texture, a 'flat and smooth' side, and a side with more visible extrusions. For consistency, keep the 'flat & smooth' side facing up



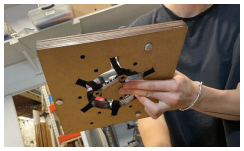


Flat & Smooth

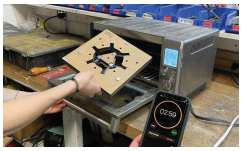


Visible Extrusions

Step 2
Attach the top pieces of the jig using screws and nuts in a triangle formation to ensure its stability.



Step 3
Have oven set at 450 - place jig into the oven for 3 minutes (heat and time may vary based on material size and required malleability)



Step 4
Remove the jig from the oven, and keeping the 'Flat & Smooth' side up, align the containment jig with the base jig, slowly and uniformly press down on the sides. Use center screw to guide the alignment of the jigs. Use clamps to keep the jigs aligned while the object cools.





Thermal Forming Instructions (Localized Heating)

Step 1
Place the Base Ring into a containment jig made of less malleable material. Keep the 'flat and smooth' side up (for more detailed process description: see step 1 of Thermal Forming Instructions - Uniform Heating)



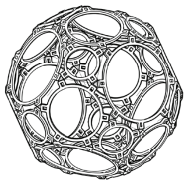
Step 2
Apply heat to the area that will be stretched using a heat gun. Make sure the heat gun is at least 10cm away from the object at all times to avoid overheating the jig. Heat until the Base Ring has a rubber-like consistency.

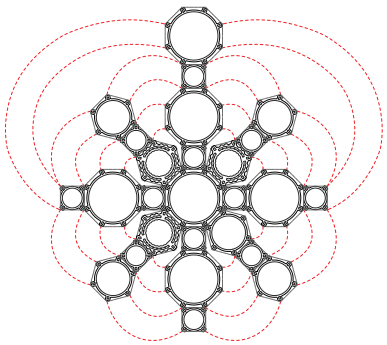


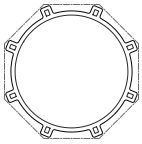
Step 3
Remove the Base Ring from the jig, and use the center screw to guide the alignment of the object to the base jig. Slowly and uniformly press down on the sides. Use clamps to keep the jigs aligned while the object cools.



Truncated Cuboctahedron Assembly







Oct Open Ring Tile x6



Hex Open Ring Tile x8



Quad Open Ring Tile x12

4mm Acrylic Tube x144

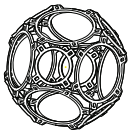


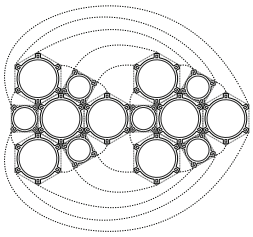
T-Pin x144



Tri-Connector x48

Truncated Cuboctahedron Assembly







Hex Open Ring Tile x8



Quad Open Ring Tile x6

4mm Acrylic Tube x108



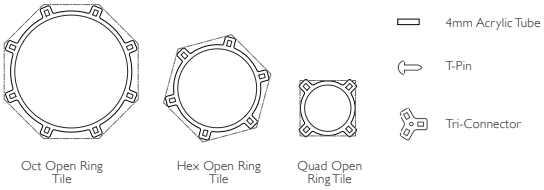
T-Pin x108

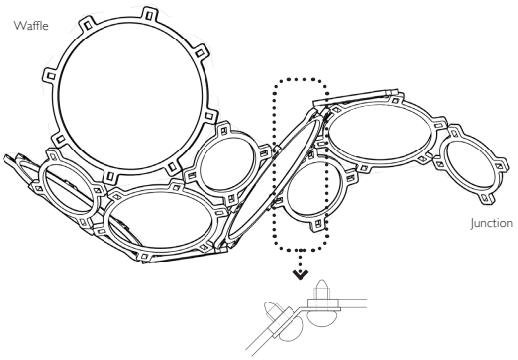


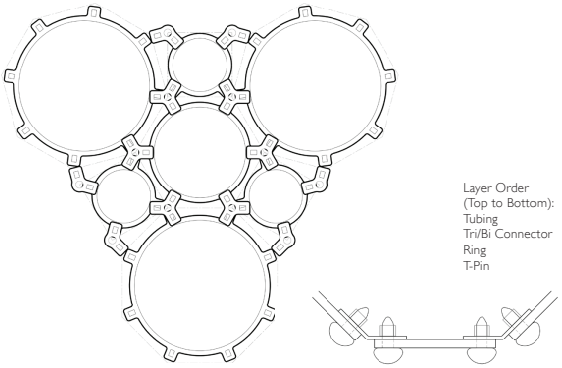
Tri-Connector x36

Truncated Cuboctahedron Net

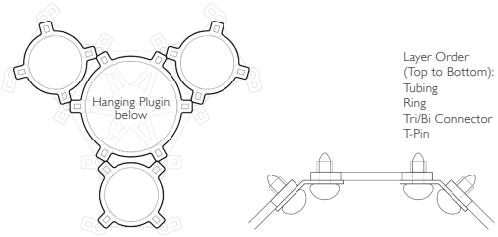
Waffle Assembly







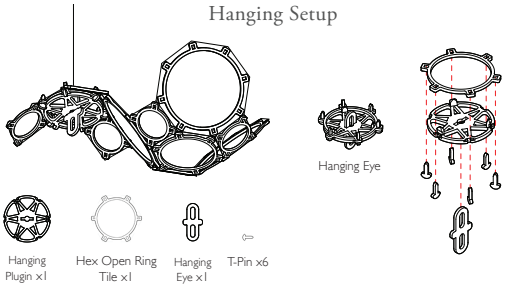
Canopy Waffle Net



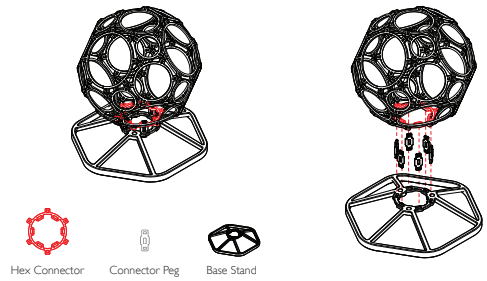
Canopy Junction Net

Hanging and Base Setup

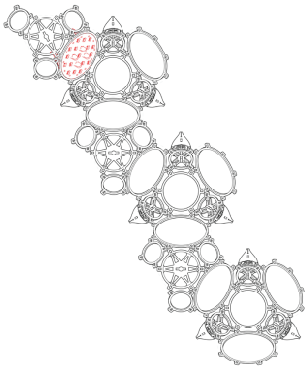
Hanging Setup

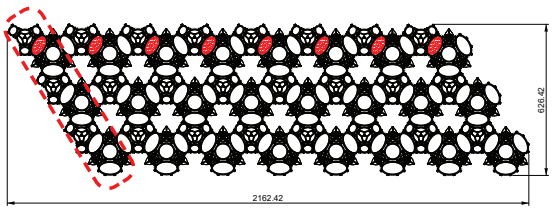


Base Setup



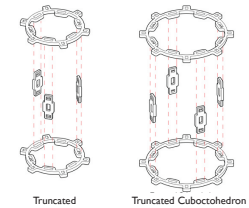
Canopy Segment Plan

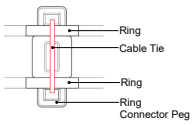


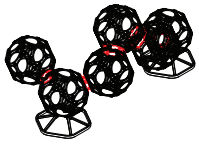


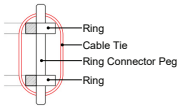
Connections Between Spheres

Ring Connector Junctions Assembly









Ring Connector Junctions Materials

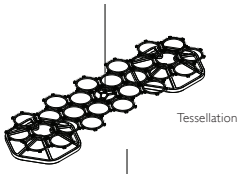

Oct Connector

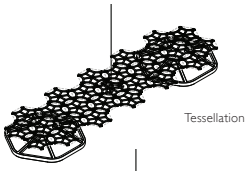

Hex Connector

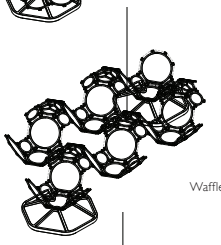


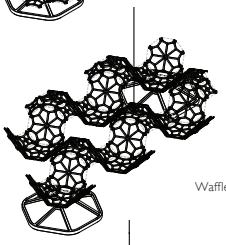
Ring Connector Peg

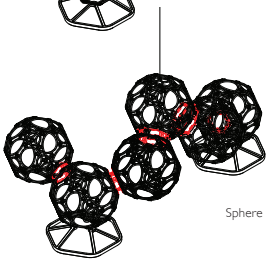
Tile Configurations

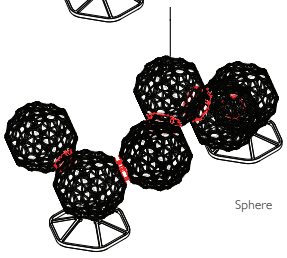

Tessellation


Tessellation


Waffle

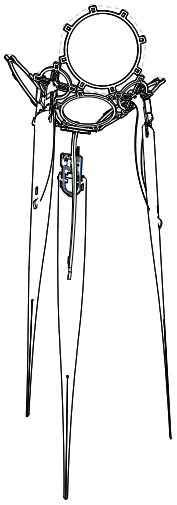

Waffle


Sphere

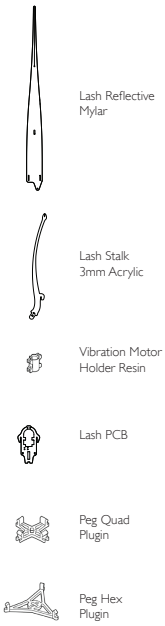

Sphere

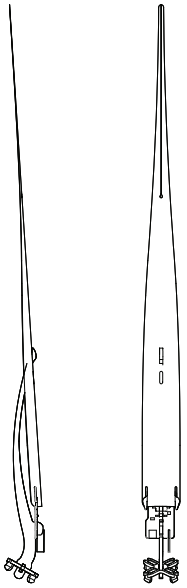
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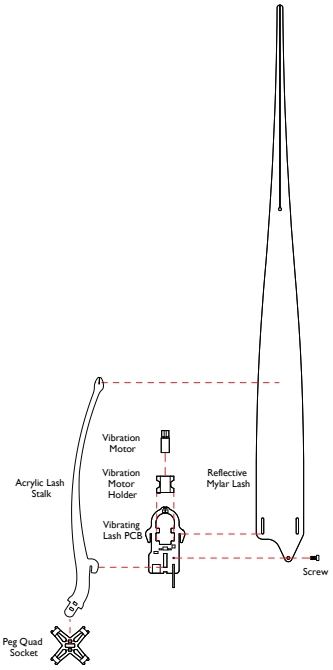
Actuators and Sensors



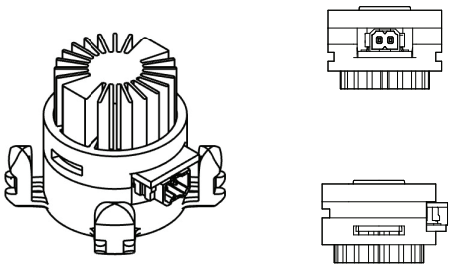
Vibrating Lash Assembly Instructions



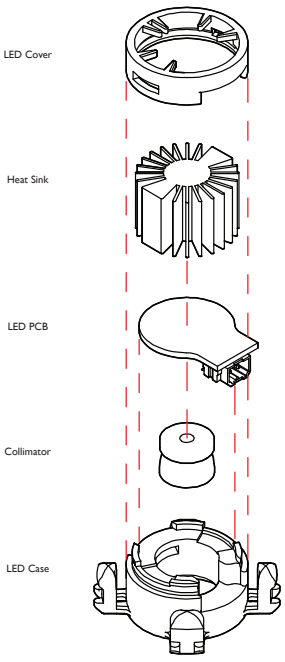




LED Light Assembly Instructions

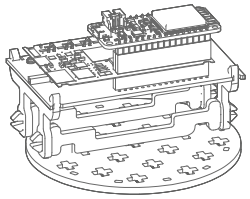


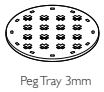




Node Controller Tray Assembly Instructions

With Expansion Board





Peg Tray 3mm Acrylic x1



Expansion Board + Node Controller x1



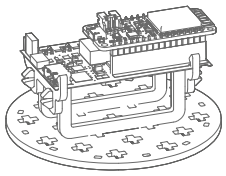
Node Controller Sled 3mm Acrylic x2

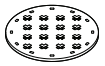


Node Controller Base 3mm Acrylic x2

Tray Locking Plate x4

Without Expansion Board





Peg Tray 3mm Acrylic x1



Node Controller x1



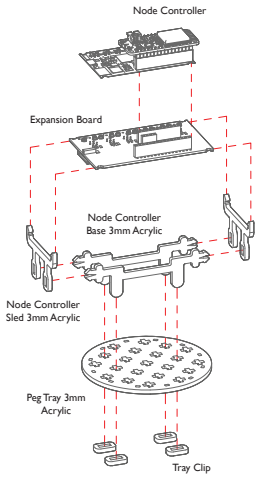
Node Controller Sled 3mm Acrylic x2



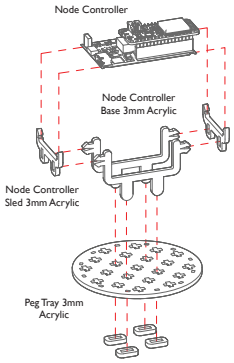
Node Controller Base 3mm Acrylic x2

Tray Locking Plate x4

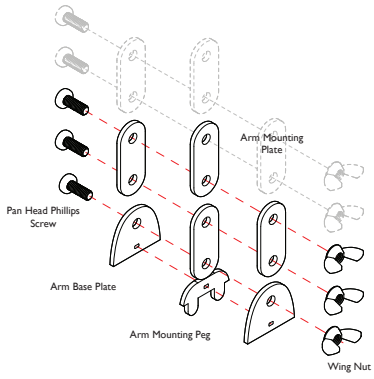
With Expansion Board



Without Expansion Board



Arm Assembly Instructions





Arm Base Plate



Arm Mounting Peg

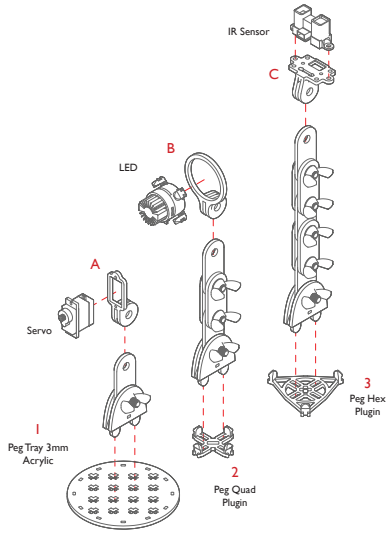


Arm Mounting Plate

Pan Head Phillips Screw



Wing Nut



Base Attachment Options

1 Peg Quad Plugin



2 Peg Hex Plugin



3 Peg Tray 3mm Acrylic

Top Attachment Options

A Servo Mount



B Quad Ring Mount



C Board Mount

Canopy System Assembly



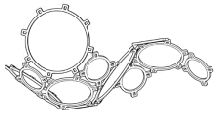
Node
Controller Tray



Hanging Eye



Vibrating Lash



Waffle + Junction

