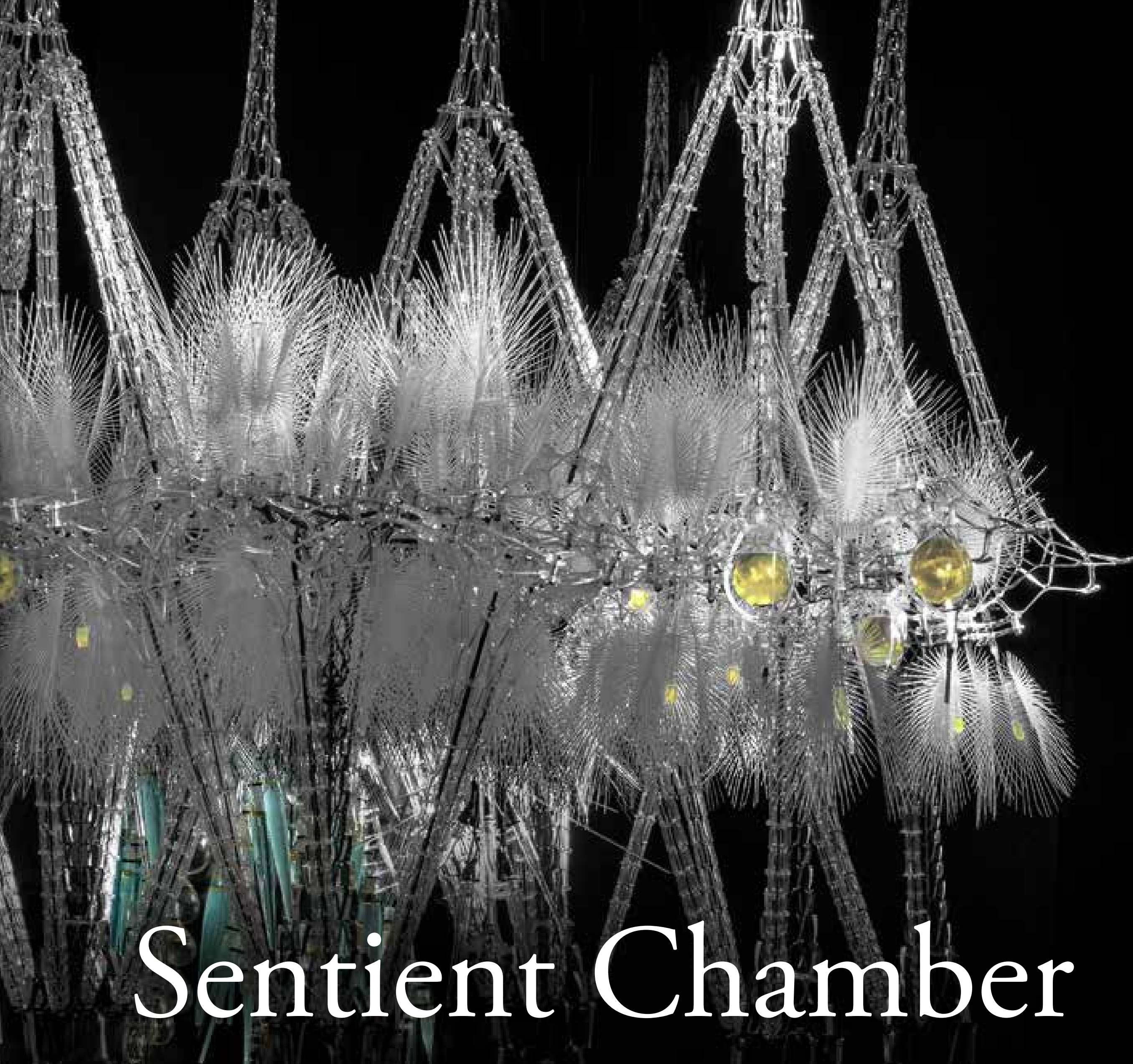
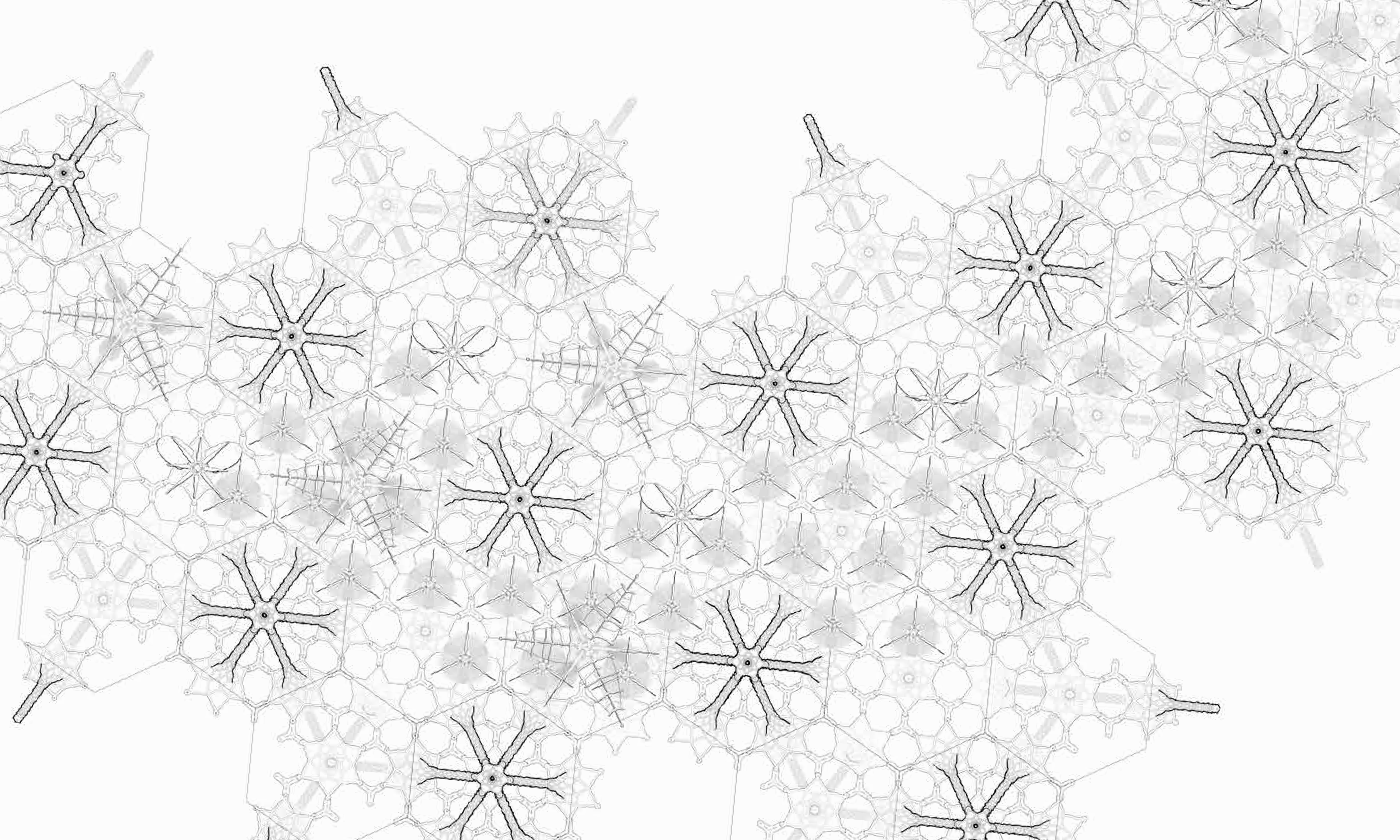


Sentient Chamber

NATIONAL ACADEMY OF SCIENCES
LIVING ARCHITECTURE SYSTEMS GROUP

Edited by Philip Beesley, Rachel Armstrong,
Colin Ellard, Rob Gorbet & Dana Kulić

CPNAS CULTURAL PROGRAMS OF THE NATIONAL ACADEMY OF SCIENCES



Sentient Chamber

www.lasg.ca; www.riversidearchitecturalpress.ca; www.cpnas.org

Library and Archives Canada Cataloguing in Publication

Sentient Chamber: National Academy of Sciences Living Architecture Systems Group / editors: Philip Beesley, Rachel Armstrong, Colin Ellard, Rob Gorbet, Dana Kulić.

Catalogue of an exhibition held at the National Academy of Sciences,

Washington from November 2, 2015 to May 31, 2016.
Issued in print and electronic formats.

ISBN 978-1-988366-05-0 (paperback).--ISBN 978-1-988366-07-4 (epub)

1. Architecture in art--Exhibitions. 2. Buildings in art--Exhibitions. 3. Installations (Art)--21st century--Exhibitions. 4. Interactive art--21st century--Exhibitions. I. Beesley, Philip, 1956-, editor II. Armstrong, Rachel, 1966-, editor III. National Academy of Sciences (U.S.), host institution

N8217.B85S45 2016 704.9'44074753 C2016-906808-0
C2016-906809-9

This book is set in Zurich BT and Adobe Garamond.
Printed and bound in Kitchener, Ontario.

THE NATIONAL ACADEMIES KECK FUTURES INITIATIVE

UNIVERSITY OF WATERLOO

Social Sciences and Humanities Research Council of Canada

ONTARIO ARTS COUNCIL
CONSEIL DES ARTS DE L'ONTARIO

Sentient Chamber

NATIONAL ACADEMY OF SCIENCES
LIVING ARCHITECTURE SYSTEMS GROUP

Edited by Philip Beesley, Rachel Armstrong,
Colin Ellard, Rob Gorbet & Dana Kulić

R

CPNAS CULTURAL PROGRAMS OF THE NATIONAL ACADEMY OF SCIENCES

Contents

Sentient Chamber A Platform for Ideas

J.D. Talasek
National Academy of Sciences

facing page
Sentient Chamber, National Academy of Sciences, Washington D.C. USA (2015-16)

The immersive and interactive environment created by the installation *Sentient Chamber* was on display at the National Academy of Sciences in Washington D.C. from November 2, 2015 to May 31, 2016. As the director of the hosting program, Cultural Programs of the NAS, I had the joy of observing the interactions that occurred during this six-month period. The visitor's response followed almost always the same pattern – a moment of wonder, of awe, or of sheer joy and amazement often followed by a quizzical tilt of the head and some variation of the question: "What is it?"

This is a profoundly important question. Not for what it asks but for the reason it was asked. Innovation – something truly new – is unfamiliar. And lacking immediate answers can be initially very uncomfortable for us. *Sentient Chamber* creates this fertile tension by simultaneously generating wonder and contemplation. This reaction and potential for discovery underscores the need for cultural displays as a platform for engagement and discourse – a space where we can discuss the possibilities of, in this case, architecture in the realm of big ideas and the potential for great impact on our lives. What if, as Philip Beesley asks us to consider, architecture could become sentient? What if it could learn to not only respond to us but could learn to anticipate our needs, inspire us, or even care about us? It is one thing to read about these ideas in a book or to hear about it in a lecture or a conference. It is powerfully different to physically experience it.

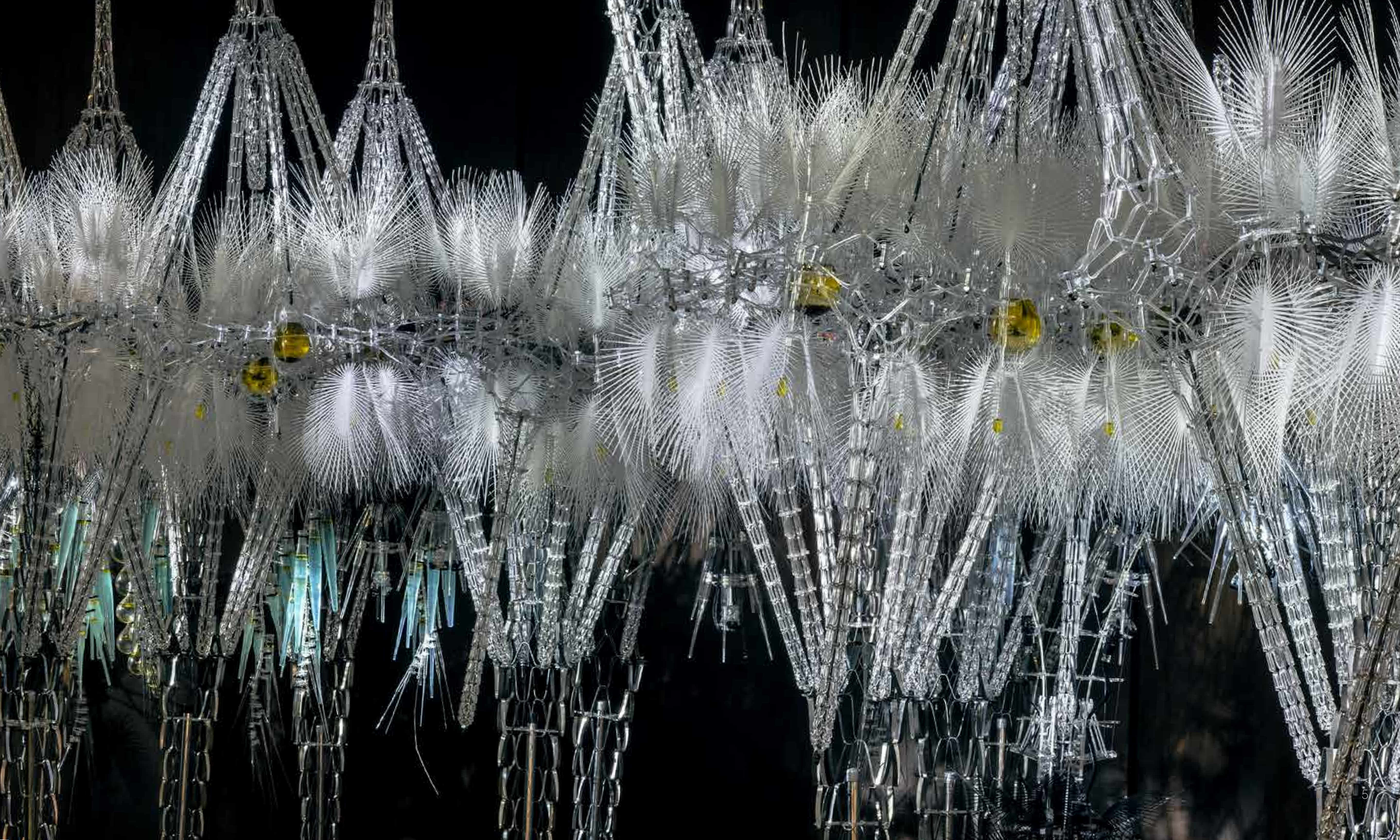
The enthusiasm that *Sentient Chamber* received is a reflection of a broader cultural phenomenon. We are witnessing a growing number of efforts throughout our institutions that are creating spaces and opportunities to engage a larger audience around big ideas and big questions by bringing diverse teams or scientists, artists, and other creative practitioners together. David Edwards' The Lab in Cambridge, MA near Harvard and MIT is an incubator that brings together diverse teams to translate big ideas into reality – a process that often includes cultural display. The National Academies Keck Futures Initiative is a thirteen year-old think-tank that recently began inviting artists and designers to more deeply engage in problem solving. Leonardo: The International Society of Art Science and Technology, a fifty-year-old organization, is fostering an international network of regular salons (Leonardo Art Science Evening Rendezvous or LASR) hosted at institutions to promote dialogue and networking between diversely different communities of thought that might not otherwise engage with one another or the public. The National Academies of Sciences, Engineering and Medicine has embarked on a seminal report exploring the benefits of integrating STEM and arts/humanities education both in its impact on the work force and on our quality of life. The list of creative and innovative engagement involving artists and designers is rapidly growing and pushing us to think differently about the way we approach problem solving.

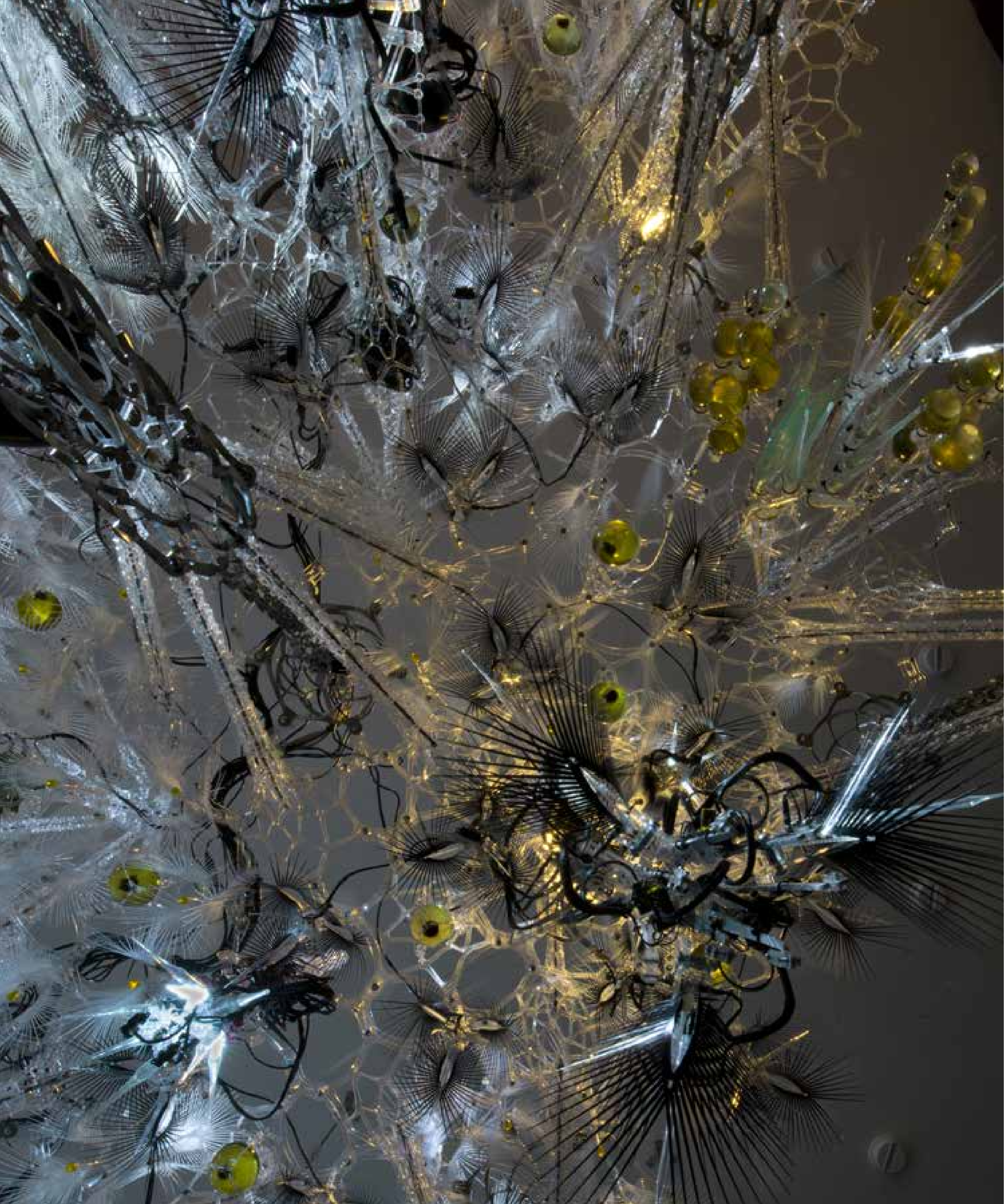
In this spirit, Philip Beesley takes *Sentient Chamber* a step further by making the creation process of the installation an opportunity for education and the sharing of ideas. In addition to the contributions of his team, the Living Architecture Systems Group – a network of collaborators and students from a diverse range of expertise and experiences – a workshop of local students and volunteers in the DC region were engaged not only to install the exhibit but to learn, engage, and explore ideas about the potential of architecture.

following page

Sentient Chamber, National Academy of Sciences, Washington D.C. USA (2015-16)

I would like to thank the faculty and students who contributed very long hours of their time and energy. I would also like to thank the NAS facilities managers and meetings office who provided support and to the catering office who provided nourishment and fuel to get the job done. A special thank you is extended to Drs. Ralph and Carol Cicerone for their support in actualizing *Sentient Chamber*. During Dr. Cicerone's tenure as President of the National Academy of Sciences, he and his wife were enthusiastic supporters of the arts programming at the NAS, allowing CPNAS to contribute to the important mission of the National Academy of Sciences. Ken Fulton, Executive Director of the NAS, has provided endless support, guidance, and enthusiasm for which I am very grateful. Many thanks are owed to Alana Quinn, my colleague and the very backbone of CPNAS. Most of all, I would like to thank Philip Beesley and his team for bringing his process to the NAS. *Sentient Chamber* is a culmination of all of their research and learned experiences and it will form the foundation for new ideas yet to be actualized.





New Models for Dissipative Systems

Philip Beesley
University of Waterloo

Detlef Mertins,
Modernity Unbound, 2010

"A second nature with which to remake the crust of the earth, one that neither opposes nor dominates nature but rather extends it."

facing page
Sentient Chamber, interactive geotextile mesh environment, includes embedded machine intelligence and 'living' chemical exchanges. *Sentient Chamber*, National Academy of Sciences, Washington D.C. USA (2015)

Sentient Chamber, an experimental architectural canopy, was created by the Living Architecture Systems Group, a partnership of architects, engineers, scientists, and artists from Canada, the U.S., and Europe, working with contributions by students from the School of Architecture and Faculty of Engineering at the University of Waterloo, the Catholic University of America School of Architecture and Planning, Gallaudet University Department of Art, Communication, and Theatre, Johns Hopkins University Masters of Arts in Museum Studies, and Virginia Tech School of Architecture + Design.

Sentient Chamber is a free-standing pavilion that offers a compact prototype whose experimental constructions imply models of future architecture. The

Hylozoic Soil, one of LASG's first immersive environments, explored a new generation of responsive spaces, conceived as a synthetic soil that might take root within architecture. Hylozoic Soil, Musée des beaux-arts de Montreal (2007)

work combines new systems of structure, electronics and software controls. This speculative architecture and sculpture installation acts as a test-bed for ongoing research that combines the disciplines of architecture and visual art, computer science and engineering, and synthetic biology. These environments are composed of hundreds of thousands of individual digitally fabricated metal, acrylic, mylar, and glass elements. The massive replication of components is organized within tension-based resilient scaffolds, creating diffusive boundaries between occupants and the surrounding milieu. The environments are based on designs that seek to maximize interchange with the atmosphere and occupants. The canopy prototype consisted of seven interdependent layers: a physical structure that formed the space as a free-standing resilient expanded meshwork; a layer of intermeshed interactive mechanisms with lighting and responsive sound; a liquid manifold containing inorganic 'protocell' chemical compounds that fostered primitive exchanges with the surrounding environment; an electronic system that included sensors, actuators, and microcontrollers; communications and control firmware that provided automated functions housed within the array of microcontrollers; and software executed on a remote computer that provided high-level machine intelligence. Together, these layers form a responsive architectural environment characterized by resilience and hybrid coupling.

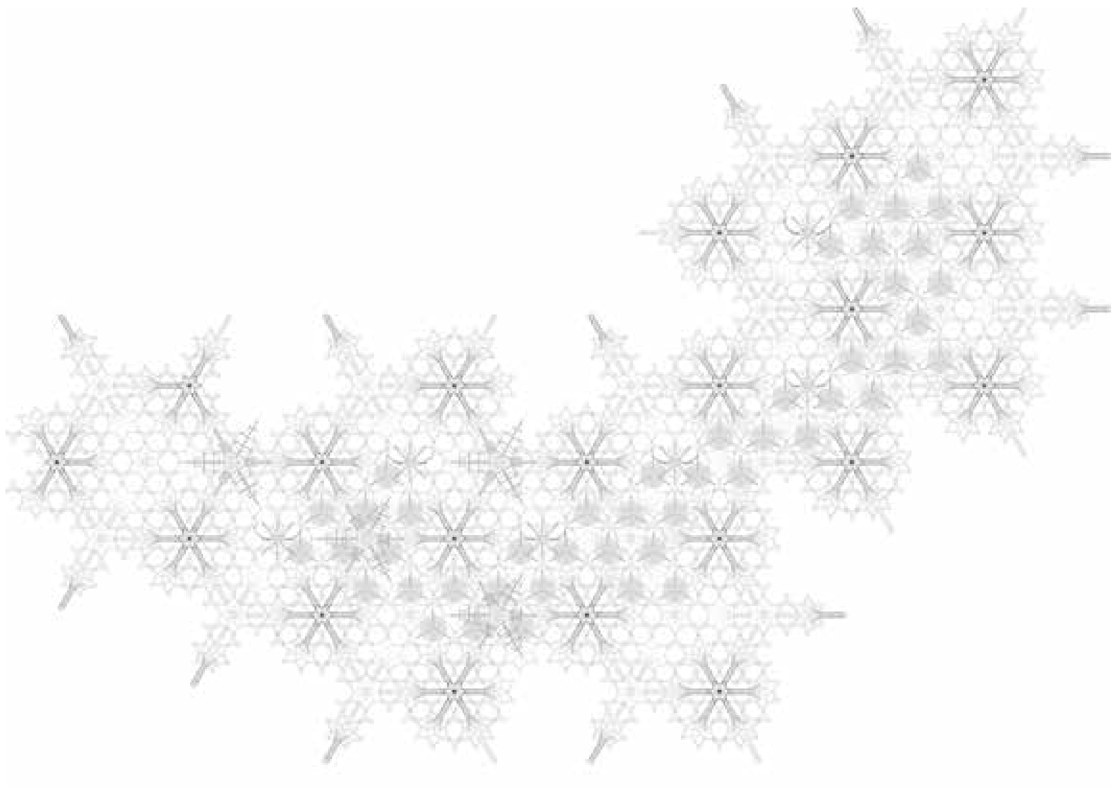
Design paradigms for this work were guided by a pursuit of qualities lying far from equilibrium. Designs were based on deeply reticulated skins, which stands in contrast to the minimum surface exposures of reductive geometric forms that have tended to organize contemporary building designs. Amplifying physical motions related to interaction with viewers and occupants, the details of many components in the sculpture were designed to tremble and resonate, responding to slight shifts in the surrounding environment. Ensoiled fabrics made an offering, treading contested ground. Oscillating drifts of hyperbolic and quasiperiodic geometry guiding this work lay far from transcendent, overarching order. Like the shimmering tesserae of an ancient Byzantine mosaic caught between worlds, the fabrics of the chamber oscillated.

A New Approach to Architecture

Design paradigms for shelter built upon the solid, eternal ground of classical foundations might render tasks for architecture simple. Springing from foundations secured by the cardinal powers of the earth, one of the primary tasks of a building envelope might be rendering the outer world vividly, consuming the environment, and serving outward-seeking gazes of its occupants. Yet the great extinction now sweeping our environment has swept away such transcendent qualities. The ground is yawning, viscous, inducing queasy vertigo. Legs unconsciously tense themselves, reptile brain–inflected posture disrupted by the elastic meniscus underfoot.

The shift of human posture inverts any confident gaze. The enclosing function of architecture shifts from consuming the surroundings, and instead turns toward a search for renewed, refreshed relationships integrated with living nature.

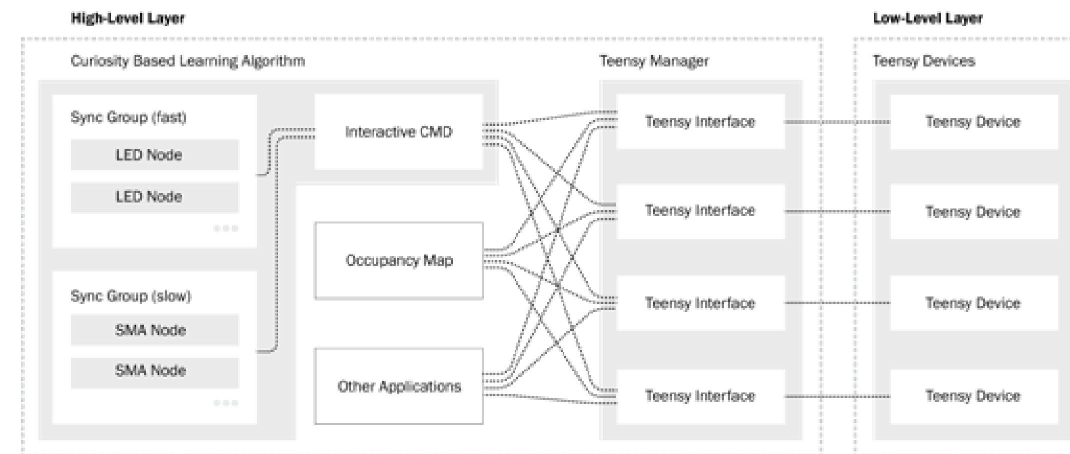
Can sensitive architecture be constructed? A general objective of the work is to find a new role for architectural environments, transforming portions of static buildings into dynamic responsive surfaces. A functional definition of this architecture treats building envelopes as filters that enclose human bodies and draw the environment inward and outward, sheltering the interior and amplifying the experience of the surrounding world. A corresponding ethical objective is to find sensitive, renewed relationships for human occupants interconnected with their surrounding environment. The work examines how people perceive and interact with their surroundings. The clearly defined barriers between object-subject become blurred and the



Sentient Chamber is supported by a hybrid triangular flexible space-grid structure that provides flexibility and stability through tensile and compressive support; the structural design follows diffusive crystalline forms.

introduction of mutual interaction suggests a shift toward relationships based on involvement and exchange.

The project offers design details that feature extremely lightweight, highly reactive mechanized components that respond to human occupants, vibrating and trembling, implying an emotional range that could support vulnerability and fragility in an expanded spectrum alongside robust, playful behaviours. The architectural craft that supports this work involves designing filters with dual functions. These tissue-like constructions can expand human perception and human influence, while at the same time they can expand the influence of the surrounding environment upon human occupants by emphasizing oscillating functions of catching, harvesting, pulling, and pushing.

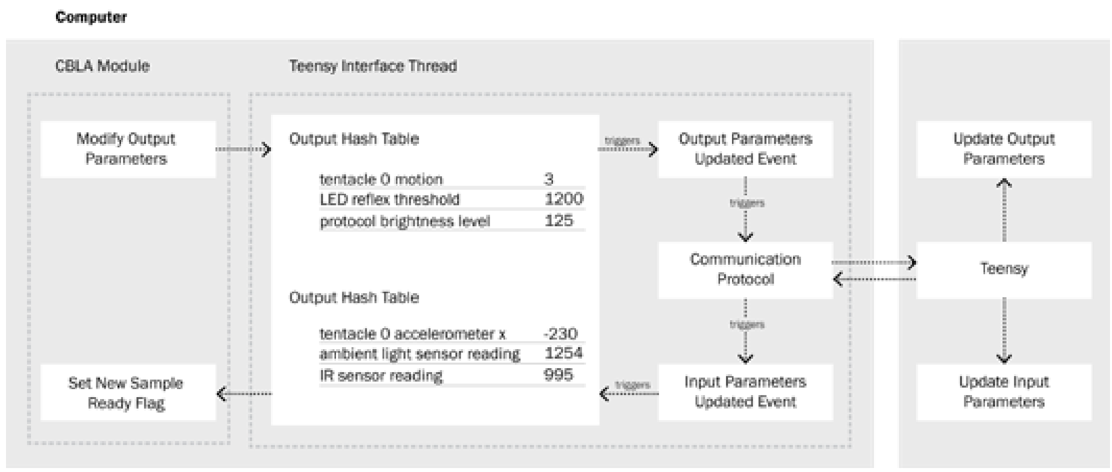


Overview of software organization showing curiosity-based learning algorithm (CBLA), occupancy mapping, and prescripted behaviour modules interconnected with microprocessors

Building on these expressions, works by the authors are characterized by models of open-ended exploration, tending to emphasize the role of each occupant in orienting themselves and interacting with the complex environments. In these environments, occupants can build up deeply layered sets of relationships in which there are multiple porous boundaries. The physical quality of the space that results from this approach could be considered as a synthetic kind of expanded ‘soil’. Ultimately, the work explores the possibility of creating fertile, open boundaries that can renew how we build and live in our cities.

Structure and Electronics

The new structural system was organized by a hybrid triangular flexible space-grid, stiffened by expanded-mesh hexapods that support telescoping posts and spires contacting the floor and ceiling for stability. This structure offers minimal material consumption, achieved through highly efficient advanced manufacturing processes employing laser machining and thermal forming, which created large volumes of an expanded meshwork. Tensegrity coupling was featured, employing metal rod cores that stabilize the system surrounded by expanded meshwork hyperbolic shells that provided alternating tensile and compressive support.



Overview of curiosity-based learning software outputs and inputs located within host computer linked to actuators and sensors controlled by Teensy microprocessors

The *Sentient Chamber* implementation described here integrated the new communications protocol and firmware, new electronics, and a proprioceptive system including sound, light, and motion sensing capable of both internal machine sensing and externally-oriented sensing for human interaction. A number of specialized technical refinements were developed including communication, firmware, electronics, and proprioreceptive sensing. These innovations help support precise manipulation of this relatively unstable software routine and help support methods for visualization and analysis.

Electronic controls employ powerful microcontrollers, expanded by custom circuitry for local communications, power control, and sensor feedback. Proprioreception is a particular feature of this new system. Arrayed electronically controlled acoustic and kinetic mechanisms are accompanied by sensors that provide internal feedback to the control system, supporting machine learning. In turn, these nested arrays are supported by a central computer configured with three coupled control softwares, providing a test-bed capable of orchestrating pre-scripted behaviours, relationships between components, and learning functions. Currently under development is a new curiosity-based learning system. The system offers interactions with viewers that include spatially mapped sound, light, vibration, and concentrated movement mechanisms, each supported in overlapping nested arrays housed within the hybrid structural system.

An audience member interacts with *Sentient Chamber*, as it attempts to learn from the individual's behaviour

Custom electronics form the basis of the interactive system that imbues the canopy with a prototypical sentience. The canopy's primitive intelligence is distributed throughout its structure by a series of connected nodes. These nodes are each centred around microcontrollers that interface with an array of sensors and actuators. These form the canopy's perceptive and reactive 'body' and are configured to allow the canopy to perceive and influence its own physiology as well as its environment. This ability to self-sense is called proprioception. Proprioreception is an essential capacity for an intelligent system that can understand itself within the context of its environment.

Firmware refers to the portion of code that is written for and executed on these microcontrollers. Simple behaviours, such as the generation of sound, fading of lighting, and cycles of motion within the canopy are produced at the firmware level. The firmware also plays the role of translating raw sensor data into signals that can be used by the software as representations of the sensed environment.

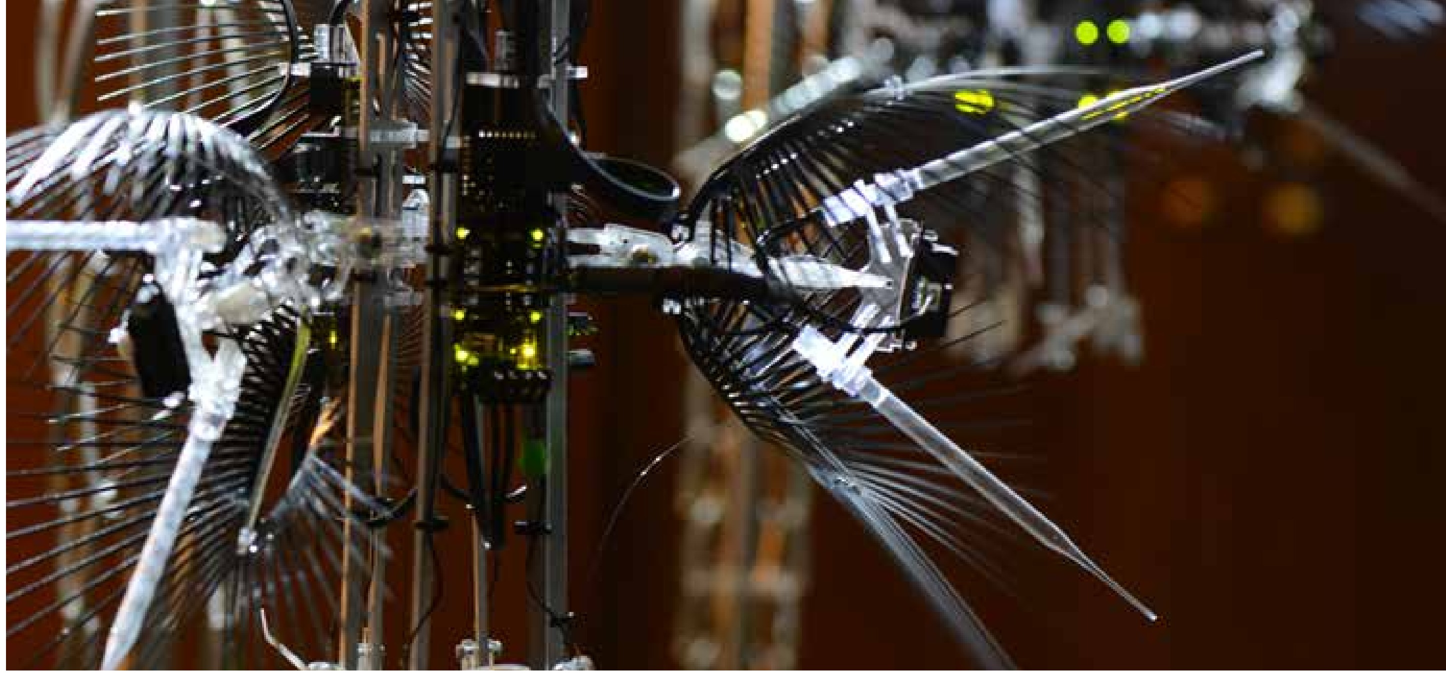
Kinetic devices carry new electronics hardware associated with the curiosity-based learning algorithm being developed to control the new responsive structure. Mobile proximity sensors are positioned within kinetic mechanisms, providing feedback controls to the system. The arrayed mechanisms offer continuous, active responses that can work individually and that can also be chained together for large-group dynamics. This system offers a unique, physical kind of machine vision that offers complex responsive kinetic functions. For example, occupants interacting with this system could find arrays of individual fronds following their motions, accompanied by outward-rippling motions. Increased complexity approaching peer-like playful kinetic responses could, with further development, result from this arrangement.

In previous installations related to this evolving work, interactive behaviours within component systems of related sculptures were pre-scripted. Each node responded to occupants and influenced the behaviours of its neighbouring nodes following established patterns. New systems continue to support the design and implementation of pre-scripted behaviours. However, because of physical complexity and proximal coupling, non-deterministic patterns can emerge through the interactions between pre-programmed nodes.

A curiosity-based learning algorithm (CBLA) is used as a general control system for this architectural system. In the CBLA framework, pre-scripted behaviours are replaced by lists of input and output channels that the system can observe and control. The CBLA algorithm system aims to learn about the relationship between its actions and its sensory observations. Driven by an intrinsic desire to learn, *Sentient Chamber* will try to understand itself, its surrounding environment, and the occupants through active mobilization and interaction. The control system considers a set of behaviours, and predicts the outcome of each of the behaviours. It then chooses one of the behaviours to execute, observes the outcome and compares its prediction to its observations. The CBLA is configured to select actions that are outside of its past experience and for which its predictions of the outcome are mostly likely to be vary. This configuration ensures that the canopy and its nodes continue to find and explore unfamiliar patterns.

Each software-based node learns and explores its own subset of the system. The distributed nodes are coupled to each other both physically, by sharing sensors, and virtually, by considering node outputs as inputs to other nodes in the system. This coupling creates the potential for neighbour and group behaviour by connecting the perceptive spaces of each node.

The CBLA functions by exploiting the system's inherent curiosity to learn about itself, much like an infant might learn by exercising groups of muscles and observing the response. In its simplest form, the algorithm chooses an action from its action repertoire to perform, and measures the response. At the same time, it generates a prediction of what it thinks should happen. If the prediction matches the measured response, it has learned that specific part of its sensorimotor space and that space becomes less interesting for future actions. If the prediction fails to match the measured response, it remains curious about that part of its 'self', as it obviously still has more to learn. It will create a new prediction and try again. This learning architecture allows the system to learn both about itself, and also about interactions with occupants, whose movements and actions create new and 'surprising' responses, activating the system's curiosity.



Detail of actuator and proximity sensor within *Sentient Chamber*

A modular, object-oriented framework was developed for firmware that allows for rapid extension and configuration of nodes. An Arduino-compatible node-based electronics system was designed and implemented that exposes dense sensing and actuation capabilities to a flexible array of sub-node (device) level modules allowing for the inclusion a wide range of low-voltage peripheral devices including shape-memory alloy and DC motor-based mechanisms, amplified sound, and high-power LED lighting. Proprioception was implemented by producing custom electronics serving photoresistors, pitch-sensing microphones, and accelerometers for motion and position, each coupled to sound-, light-, and motion-based actuators and additional infrared sensors designed for sensing human gestures. This configuration provides the machine system with the ability to calculate and detect actual behaviour, and to compare this to behaviours predicted by the system's knowledge to date, allowing the system to explore and experiment with new behaviours. The configuration supports machinic introspection.

With more development, the process described here can provide a means for the predictive simulation and testing of different behaviours. The eventual aim of a digital representation is not only to visualize the physical effects and learning status, but to support an informational space that can act as an interface capable of controlling the physical system. The real-time visualization of phenomenon such as light, sound or the learning process can feed back into the physical installation and modify its learning pattern or trigger actions based on emerging patterns discovered within the digital visualization.

Physical interconnection of light-, sound-, and motion-based sensor and actuator systems can result in hybrid relationships. Within these testbeds, coupled relationships have been observed in which vibration from sound emissions have resulted in stimulation of accelerometers originally designed to track the motions of adjacent kinetic devices. Similarly, the motion-based sequences that were originally designed to respond only to human gestures have been discovered reacting also to self-stimulus from adjacent mechanisms. Cycling patterns of feedback result, creating emergent behaviour.

Graham Cairns-Smith's Genetic Takeover and the Mineral Origins of Life (Cairns-Smith 1982) suggested that highly circumstantial couplings could explain key relationships within the complex systems of organisms. By observing and analyzing the patterns of behaviour seen within the sentient canopy prototypes illustrated here, insight might be gained in ways that responsive architectural environments might relate to living systems evolved by natural processes. By coupling the kind of intelligent virtual models described here with their corresponding proprioreceptive dynamic physical environments, and by visualizing and analyzing the behaviours that they contain, increasingly complex hybrid relationships can become legible. These visualizations offer practical means for working with the system's indeterminacy that tends to challenge control of interactive systems by designers, and could help support skills for the rapidly emerging field of design of near-living systems. The physical fabric of this work is designed to pursue empathy embedded within the built environment. The oscillating behaviour of architectural-scale immersive fabrics follow the alternating tracks of fear and attraction encoded deep within the limbic brain. Explicitly ambivalent and sentimental qualities offer immersive, enriched fields of expanded physiology. 'Blood' and 'soil' might continue to be swept by repulsively violent nationhood, yet their unquenchable archaic origins offer prima materia for this fabric. The fabric reaches toward a collective hope: prodigious sympathy might arise in material convergence.

page 19

Sentient Chamber, National Academy of Sciences, Washington D.C. USA (2015-16)

page 21

Sentient Chamber explores its environment, learning from repeated interaction with audience members

page 23

Upward view of *Sentient Chamber*'s canopy

page 25

Detail of sensors, actuators, and LEDs embedded within the sculpture

page 29

Protocell flasks contain synthetic cells: these chemical exchanges are conceived as the first stages of self-renewing functions that might take root within the installation

page 30

Detail of frond clusters in a Living Architecture testbed; CITA, Copenhagen, Denmark (2016)

page 31

Glasswork within the sculpture contains organic matter and synthetic cells

page 33

Cluster of sensors and tentacles within a studio testbed; Philip Beesley Studio, Toronto, Canada (2015)

page 35

Detail of glasswork

Acknowledgements

This writing includes passages from Matthew T. K. Chan, Rob Gorbet, Philip Beesley and Dana Kulić. 2015. "Curiosity-Based Learning Algorithm for Distributed Interactive Sculptural Systems." In 2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 3435–41. IEEE. doi:10.1109/IROS.2015.7353856.

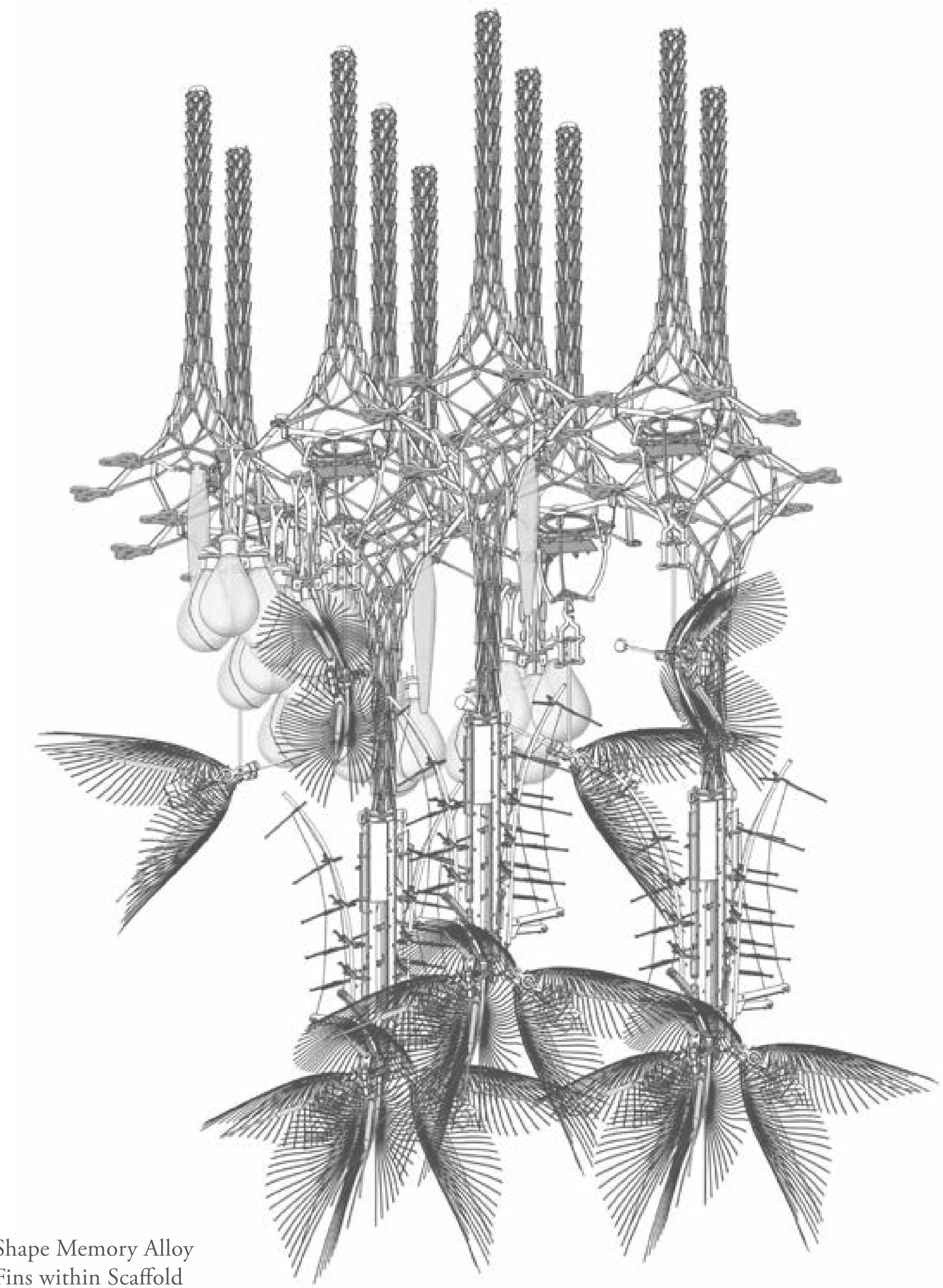
In addition, short texts are included from Philip Beesley, Hylozoic Ground: Liminal Responsive Architecture (Riverside Architectural Press, 2010)

References

Cairns-Smith, A. G. Genetic Takeover and the Mineral Origins of Life. Cambridge: Cambridge University Press, 1982.

Clune, Jeff et al. "Evolving Coordinated Quadruped Gaits with the HyperNEAT Generative Encoding." Paper presented at the IEEE Congress on Evolutionary Computation, Trondheim, Norway, May 18-21, 2009: 2764–71. doi:10.1109/CEC.2009.4983289.

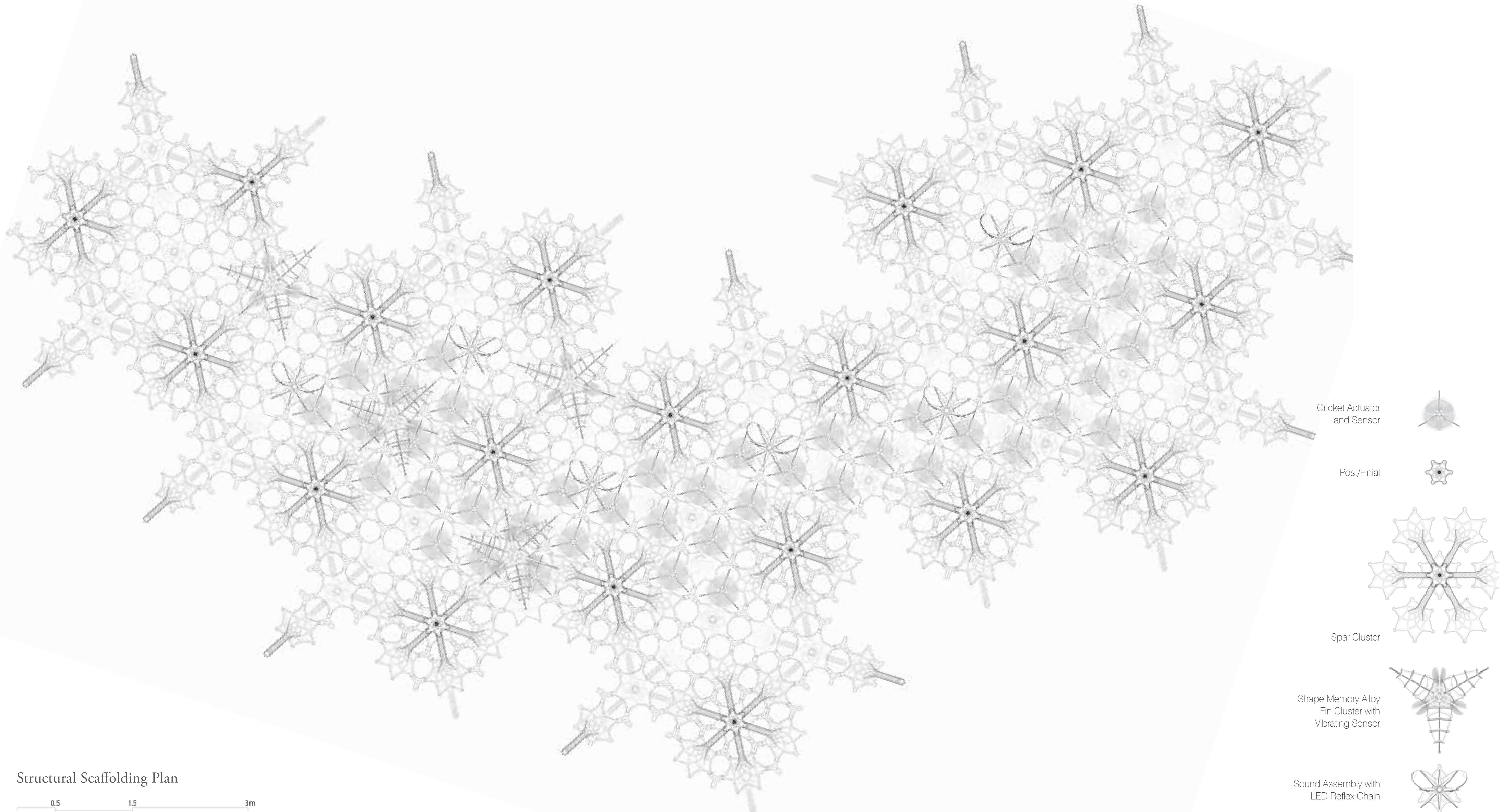
Oudeyer, Pierre-Yves, Frederic Kaplan, and Verena V. Hafner. "Intrinsic Motivation Systems for Autonomous Mental Development." IEEE Transactions on Evolutionary Computation, vol. 11, no. 2, (2007): 265-86. doi:10.1109/TEVC.2006.890271.



Shape Memory Alloy
Fins within Scaffold

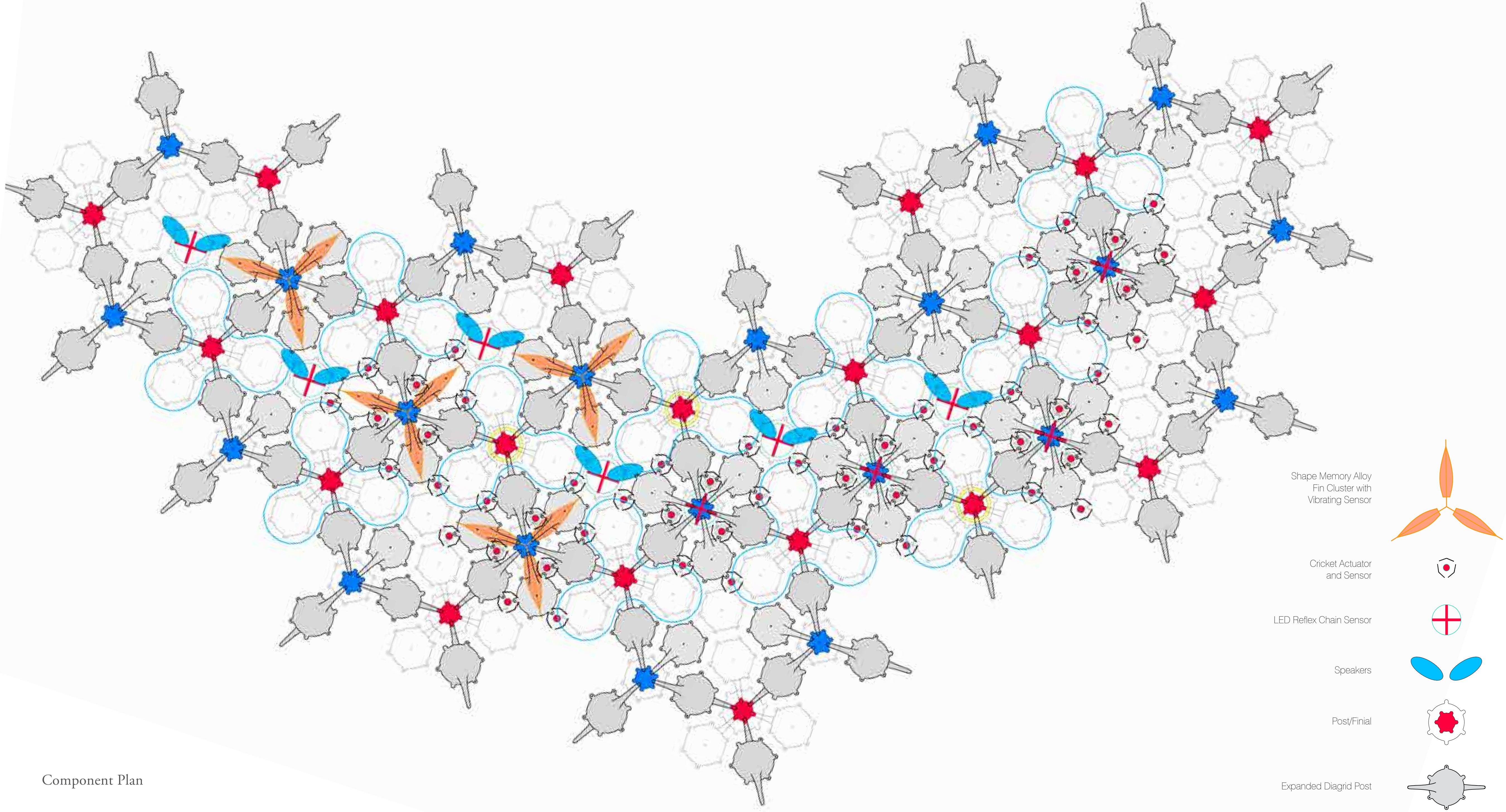
Designing *Sentient Chamber*

1 Shape Memory Alloy Fins within Scaffold
2 Structural Scaffolding Plan
3 Component Plan
4 Side View of Chamber
5 Upward View of Structural Scaffolding
6 Structure Assembly View
7 Cricket Assembly
8 Sound Assembly with LED Reflex Chain
9 Protocell Glass Chain
10 Shape Memory Alloy Fin
11 Fin Assembly Detail

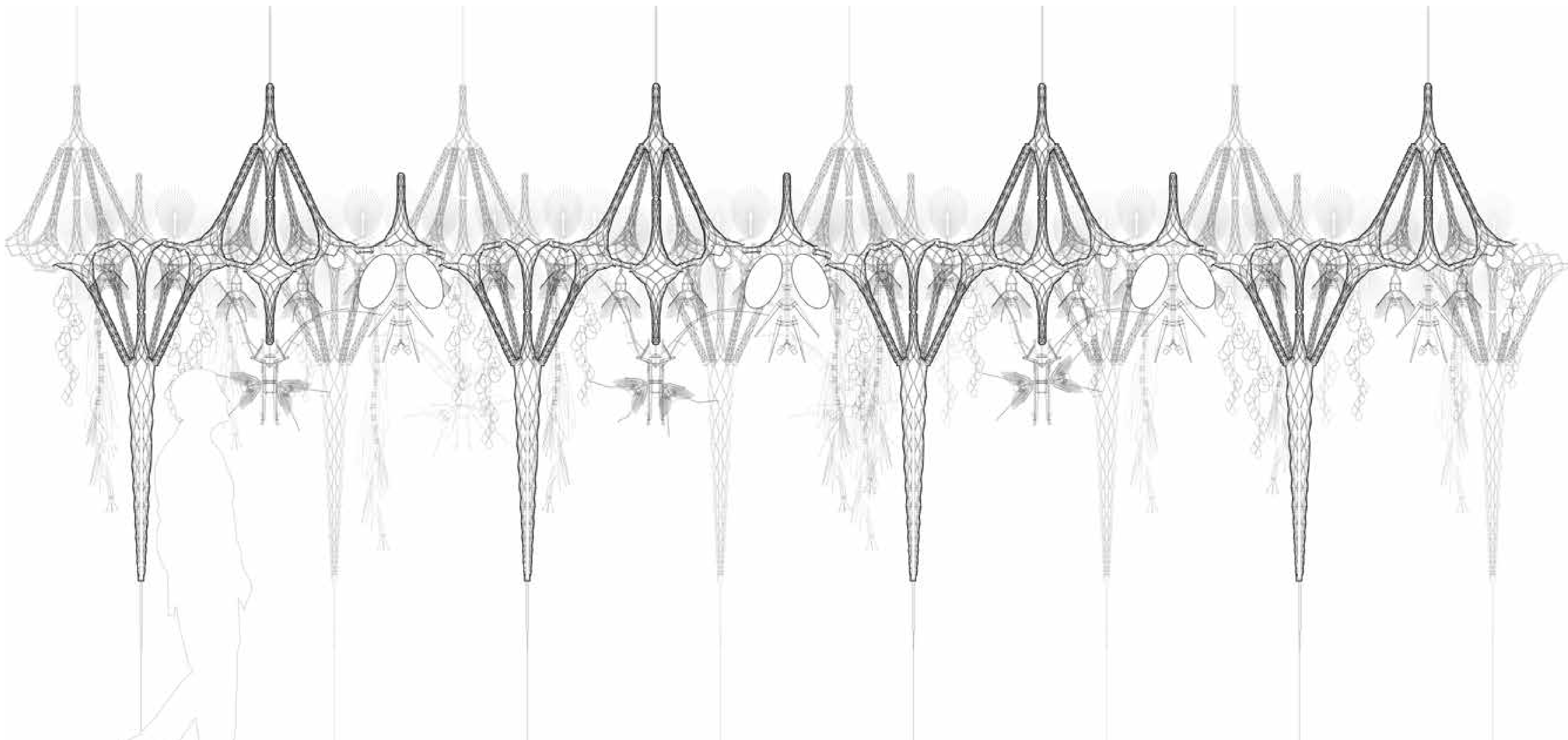


Structural Scaffolding Plan

0.5 1.5 3m

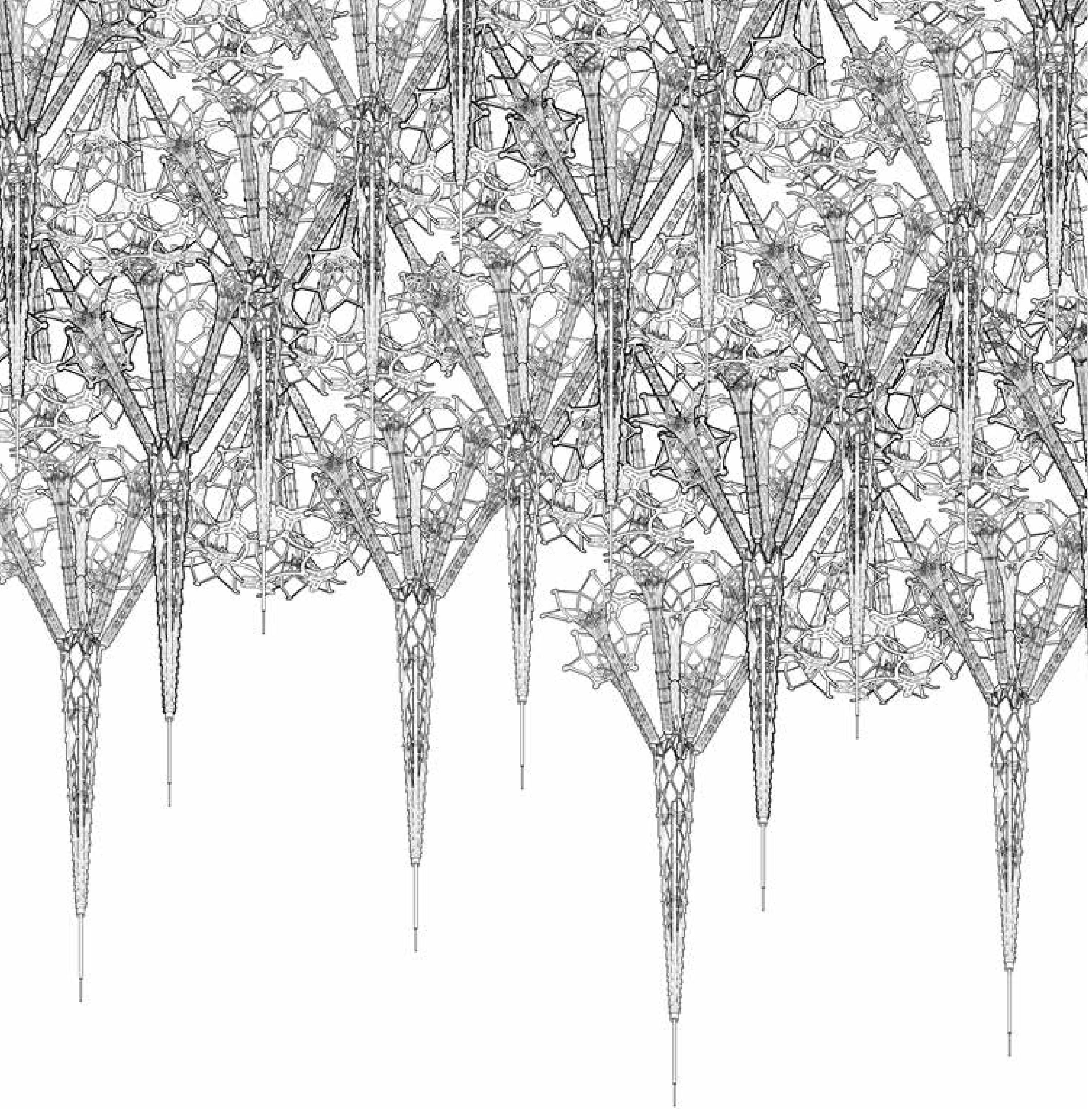


Component Plan

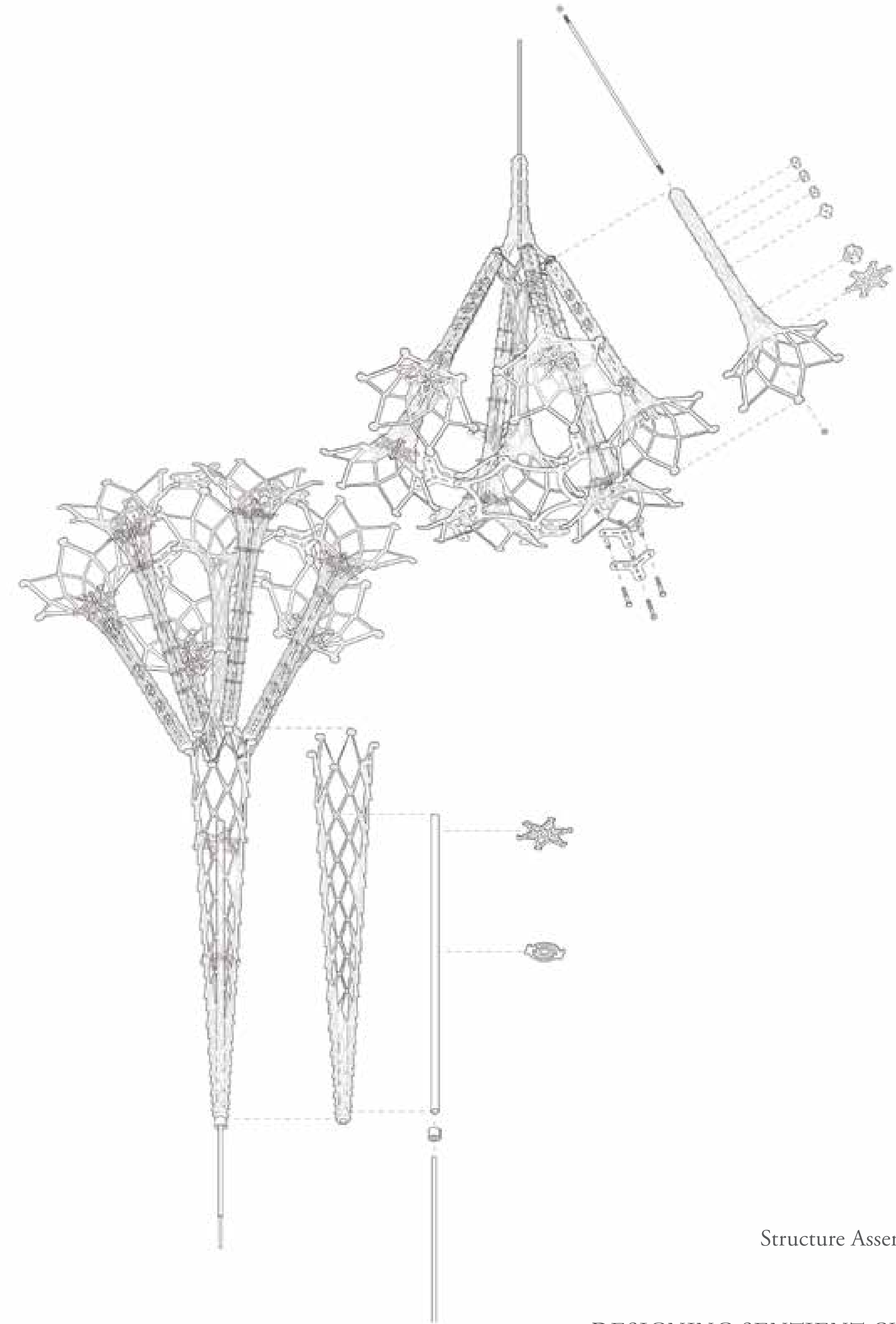


Side View of Chamber

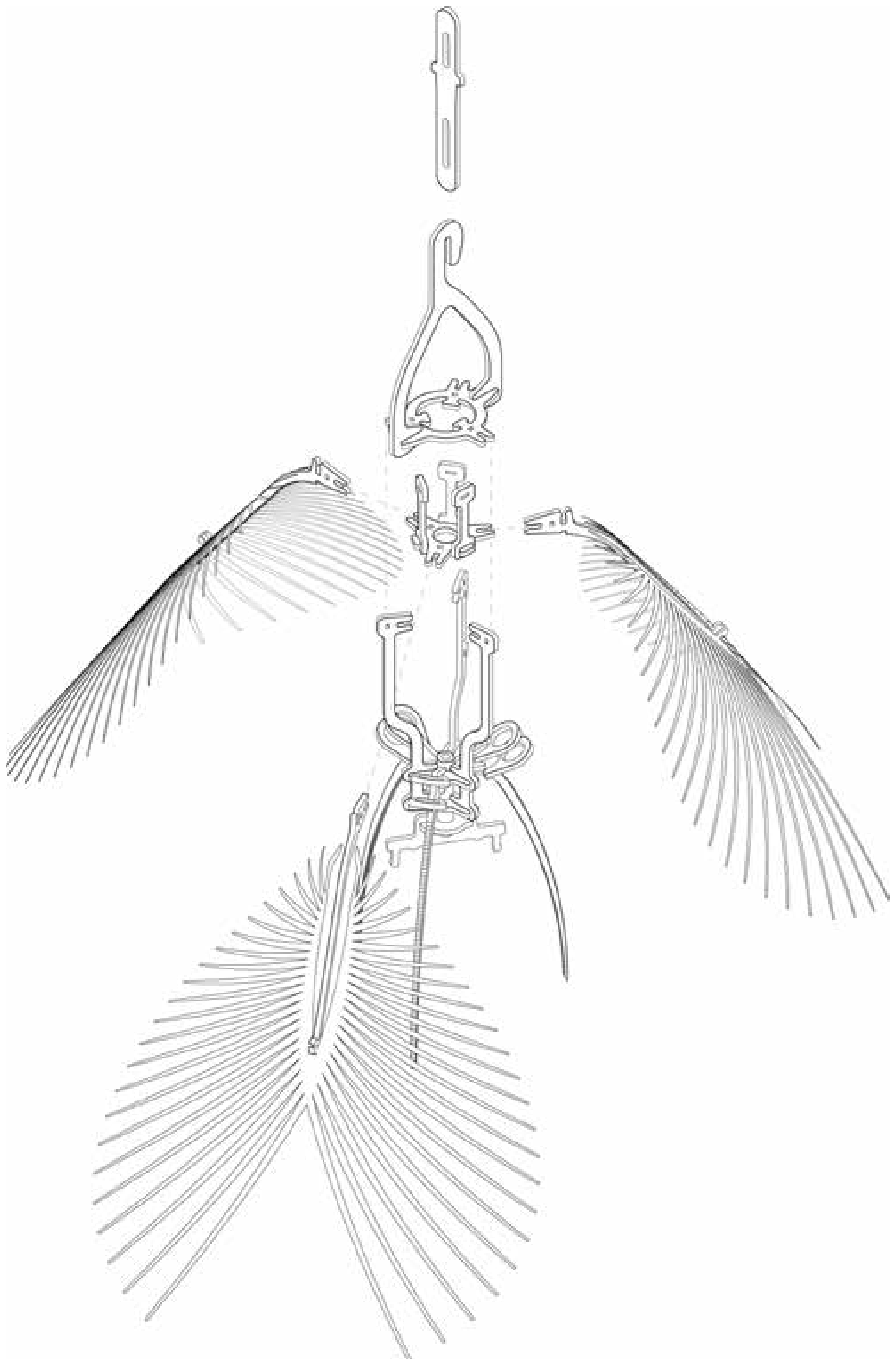
0.5 1.0m



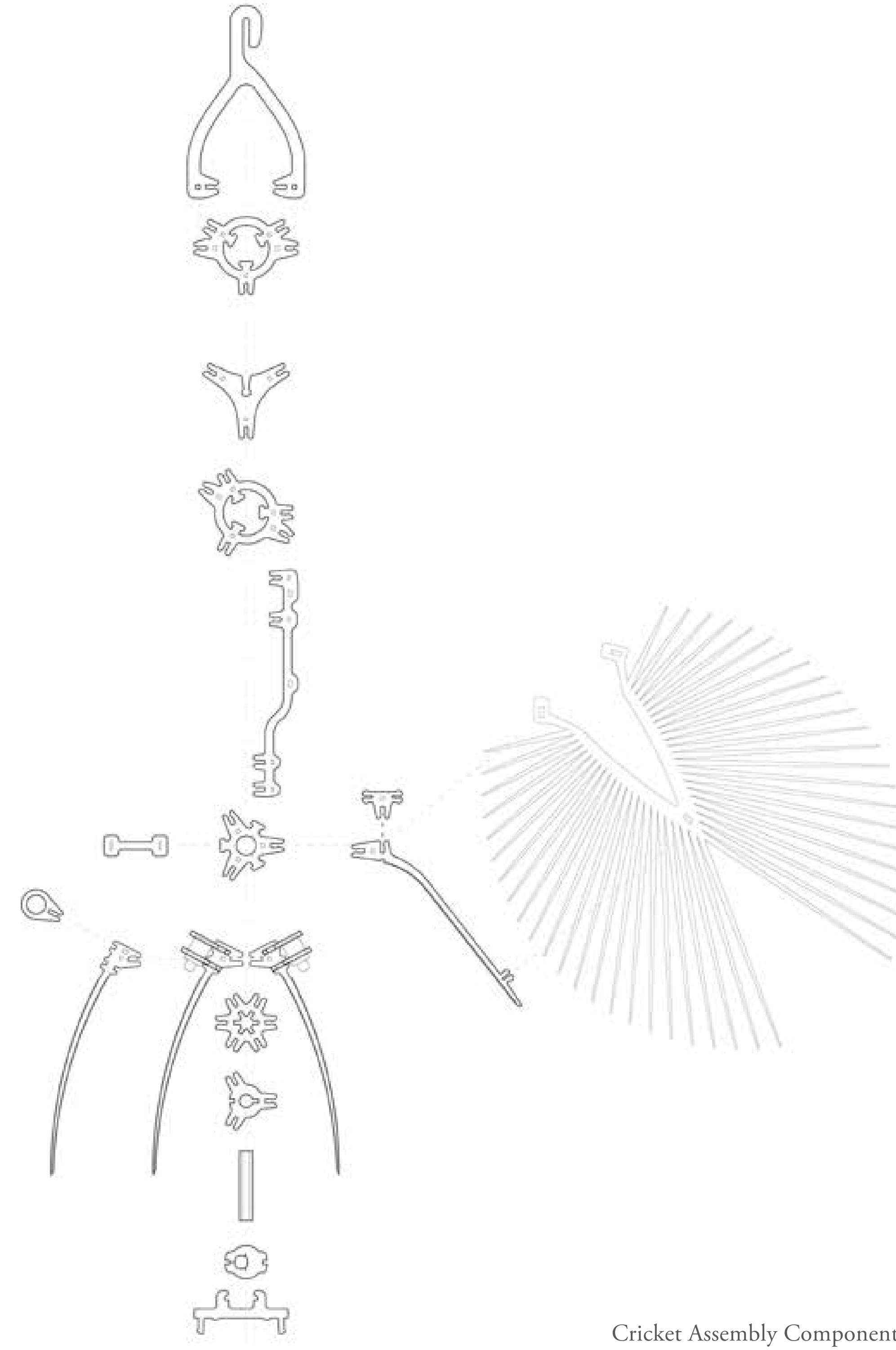
Upward View of Structural Scaffolding



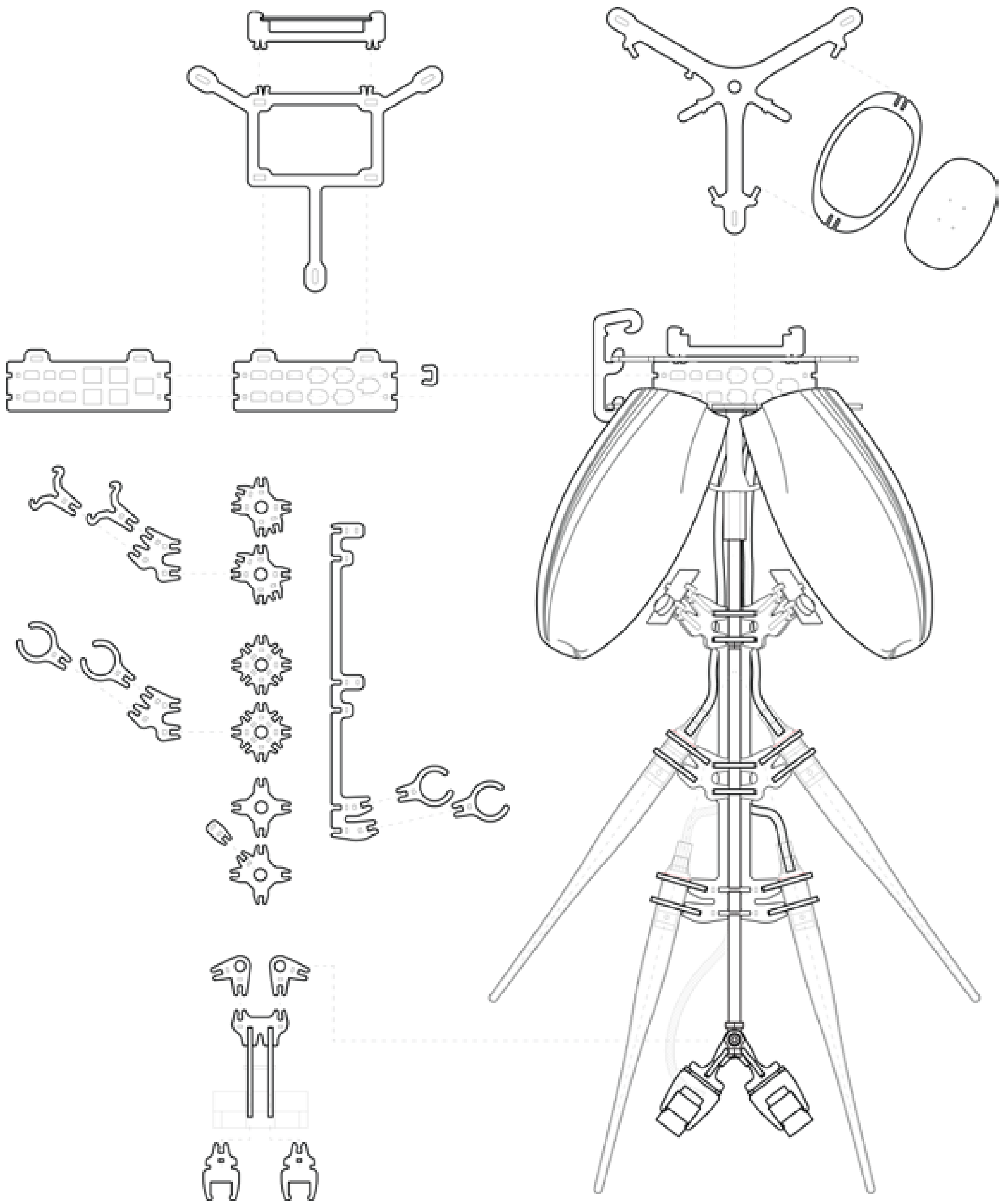
Structure Assembly View



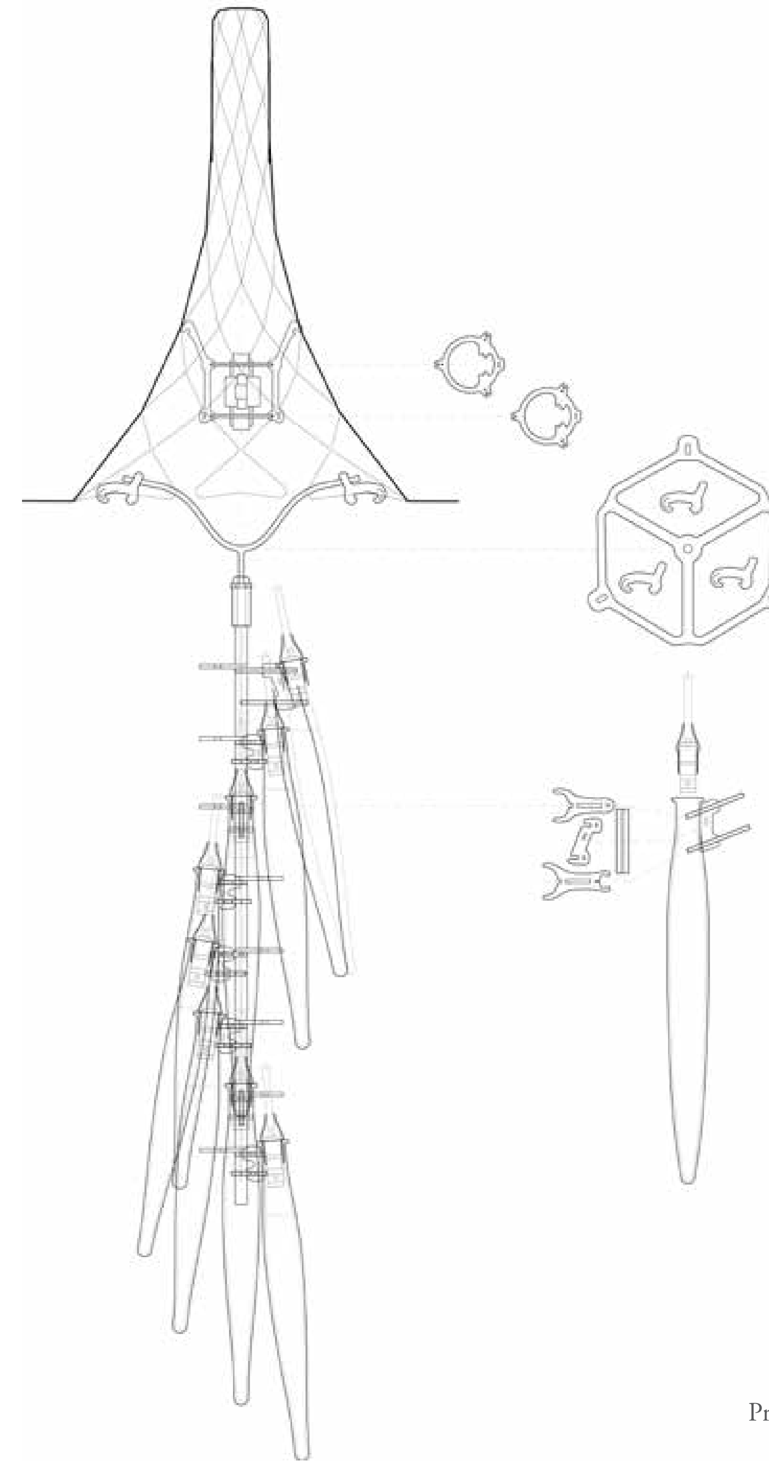
Cricket Assembly



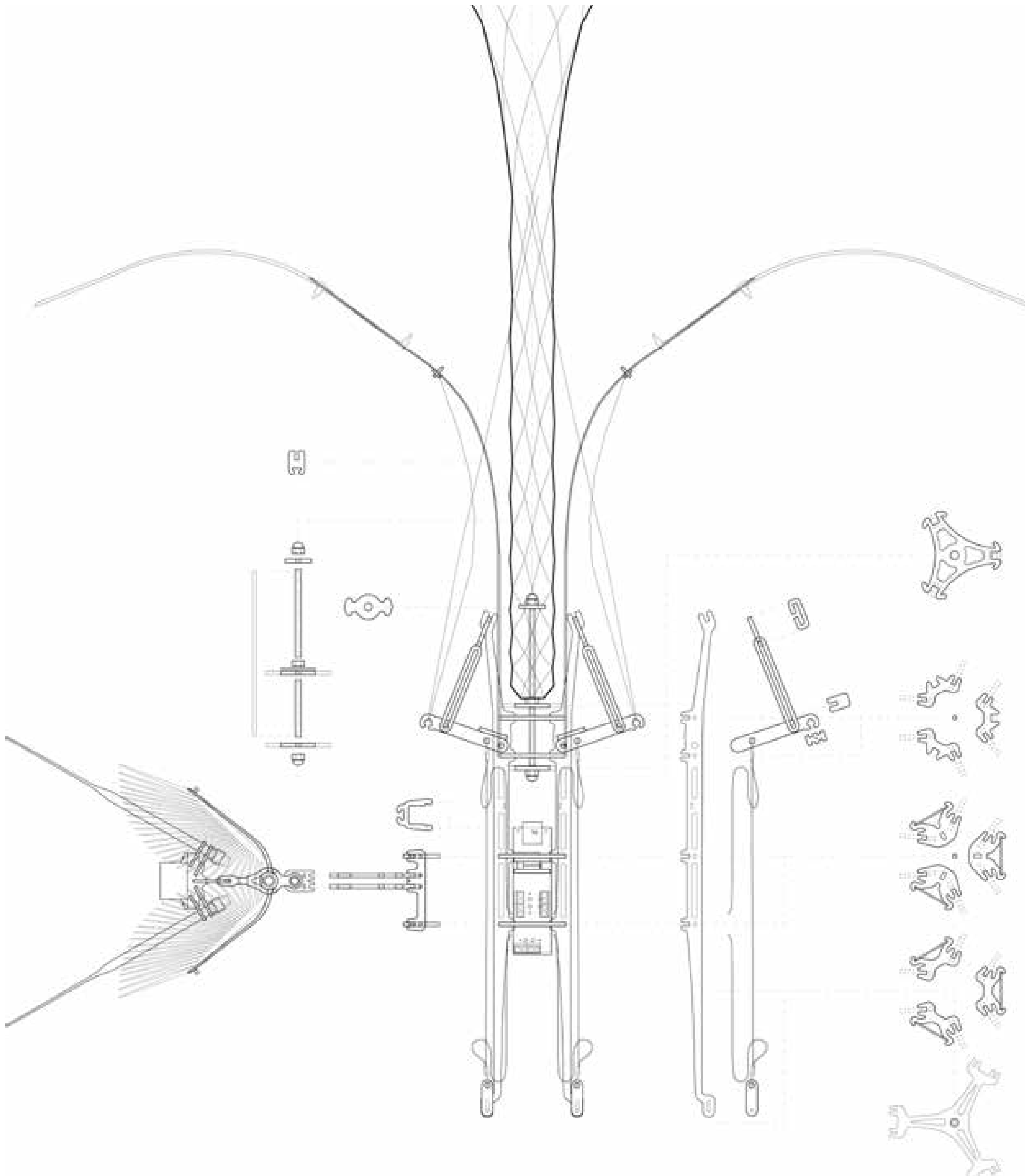
Cricket Assembly Components



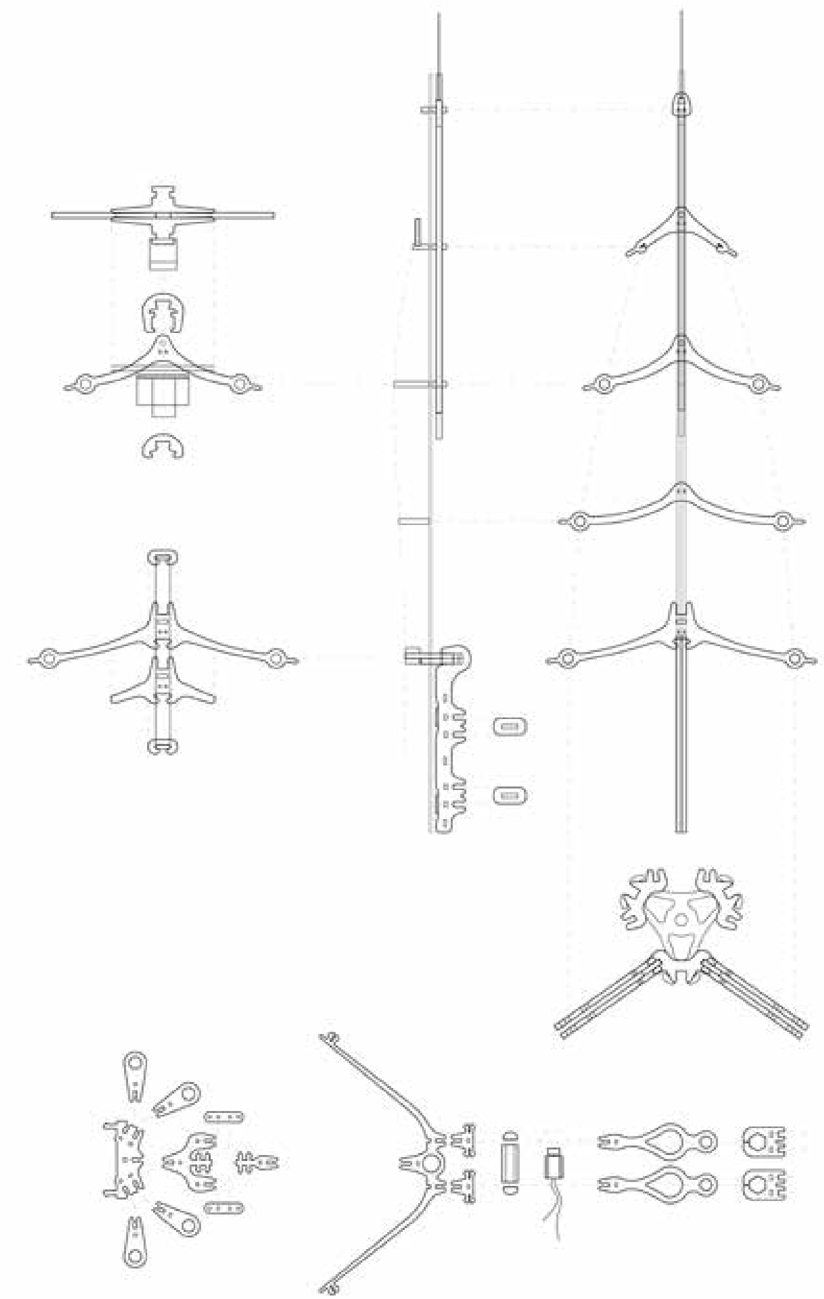
Sound Assembly with LED Reflex Chain



Protocell Glass Chain



Shape Memory Alloy Fin



Fin Assembly Detail

Constructing *Sentient Chamber*

Members of the Living Architecture Systems Group from the University of Waterloo worked together with the National Academy of Sciences, and with students from the Catholic University of America School of Architecture and Planning and Virginia Tech School of Architecture + Design in the final assembly and construction of *Sentient Chamber*.

Prefabricated components were produced using digital fabrication, thermal forming, and mechanical expansion processes at the group's Toronto studios. Massed components were transported to an atrium space within the National Academy where they were assembled into final structural clusters. The core scaffold was assembled from multiple expanded-mesh scaffold components.

Electronic systems were arranged using a meshed organization of micro-processors, each connected to chains of mechanisms and sensors. Arrays of electronically controlled acoustic samplers using custom speakers and pitch-sensing microphones produced waves of whispering sound that responded to the motions of viewers within the environment. The scaffold structure was covered with lightweight frond-like membranes lining its upper and lower surfaces. Arrays of prototype chemical cells housed within glass vessels were inserted into voids created by the expanded-mesh structure components.


Interacting with Curiosity

Dana Kulić, Matthew T.K. Chan,
Philip Beesley & Rob Gorbet
University of Waterloo

Sentient Chamber demonstrates an effort to move beyond reactive strategies of interactive systems, towards autonomous generation of behaviours which can both react to visitors and initiate interaction. In addition, the design enables an interaction that is capable of changing the system's behaviour over time, specifically to maintain and deepen engagement between the system and its occupants over long-term interaction. This approach is inspired by research in artificial life and cognitive robotics, where the evolution of behaviours mimicking growth and development has been a long standing area of research (Bedau 2000, Ikegami 2013, Lungarella 2003, Asada 2009).

Figure 1 *Sentient Chamber*, National Academy of Sciences, Washington D.C. USA (2015-16)

A central question in designing shared-initiative interaction is: what causes an agent to act and initiate interaction? Researchers in cognitive science and robotics have posited that a central motivation of an agent initiating

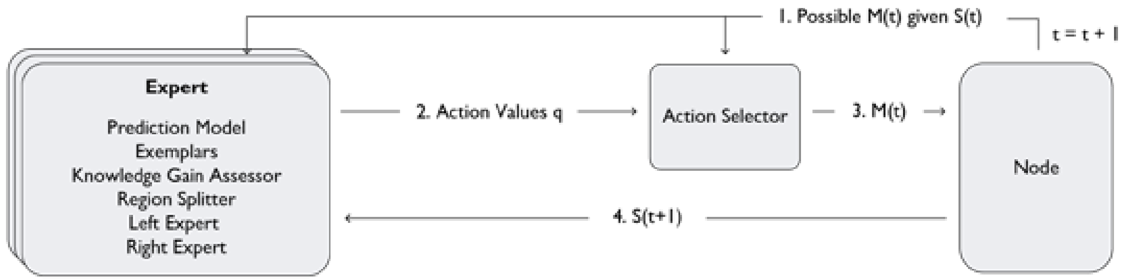


Figure 2 The CBLA Engine: (1) At the start of each time step, the Node outputs the current possible actions M(t) given its perceptions S(t). (2) Then, the Expert provides the Action Values q associated with the possible actions M(t) to the Action Selector. (3) After that, the Action Selector selects an action and actuates the Node. (4) After the Node has performed the action, it returns the actual resultant perceptions S(t+1) to the Expert. The Expert can then improve its internal prediction model and update the Action Value associated with S(t) and M(t).

interaction is the desire to learn more about its environment and itself (i.e. curiosity). Computer science and automation researcher Dr. Pierre-Yves Oudeyer and others (Oudeyer 2007) proposed an algorithm which formulates curiosity as the motivating drive for a robot to take actions in order to learn about itself and its environment, called Intelligent Adaptive Curiosity.

Sentient Chamber integrates a new approach for behaviour generation in interactive sculptural systems, inspired by Oudeyer's Intelligent Adaptive Curiosity approach, named the Curiosity-Based Learning Algorithm (CBLA) (Chan 2015). The CBLA re-casts the interactive sculpture of *Sentient Chamber* as a set of agents driven by an intrinsic desire to learn. Presented with a set of input and output variables that it can observe and control, each agent tries to understand its own mechanisms, its surrounding environment, and the occupants through learning models relating its inputs and outputs. The CBLA developed for *Sentient Chamber* builds on Oudeyer's work, applying it on an architectural-scale as a distributed interactive sculptural system with the aim of time-varying dynamic interaction between the sculpture and visitors. *Sentient Chamber* was exposed to a wide diversity of visitors, revealing the promise and challenges of autonomous long-term interaction between humans and near-living systems.

Curiosity-Based Learning Algorithm

Sentient Chamber incorporates the CBLA algorithm (Chan 2015) as an integrated system within the architectural scaffold. The implementation of the CBLA algorithm is organized in a distributed approach since the installation contains hundreds of sensors and actuators dispersed over an area the size of a large room. Each system node runs its own instantiation of the

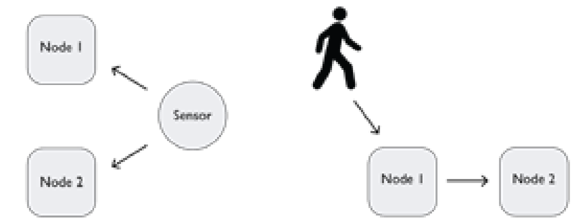


Figure 3 (A) Coupling through shared inputs. The same sensor acts as input to two nodes. (B) Coupling through virtual inputs. The output of Node 1 is a virtual input to Node 2.

algorithm, called the CBLA Engine (Figure 2), giving the sculpture the ability to generate its own behaviours through self-motivated learning.

A key feature of the CBLA system is the use of sensors that can sense both the system's internal state (i.e., are used for proprioception) and human interaction behaviours, such as proximity or touch. The distributed CBLA agents run asynchronously but are coupled through two mechanisms: first are shared inputs, and second are virtual inputs (Figure 3). Shared inputs couple the agents through a shared sensor, while virtual inputs couple agents by using the motor output of one agent as a virtual sensor input of another agent.

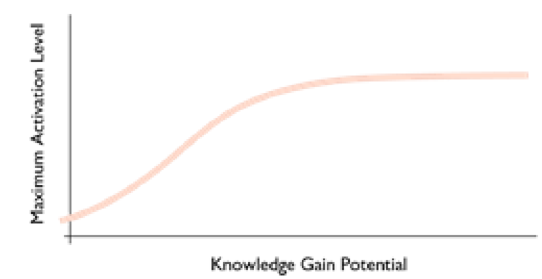
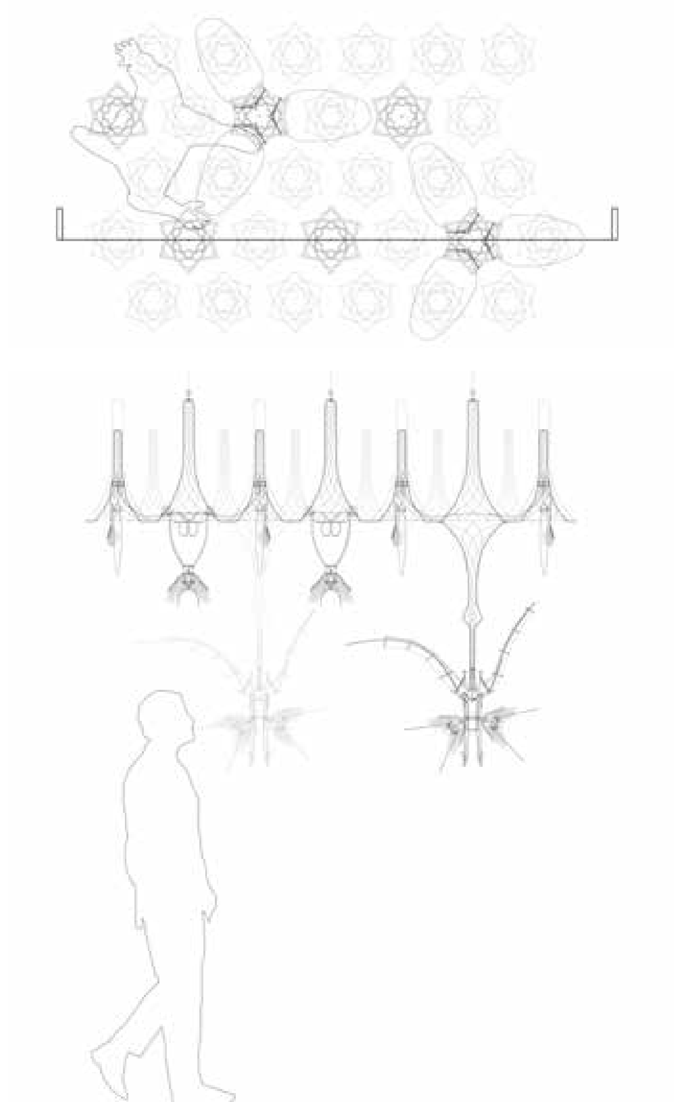
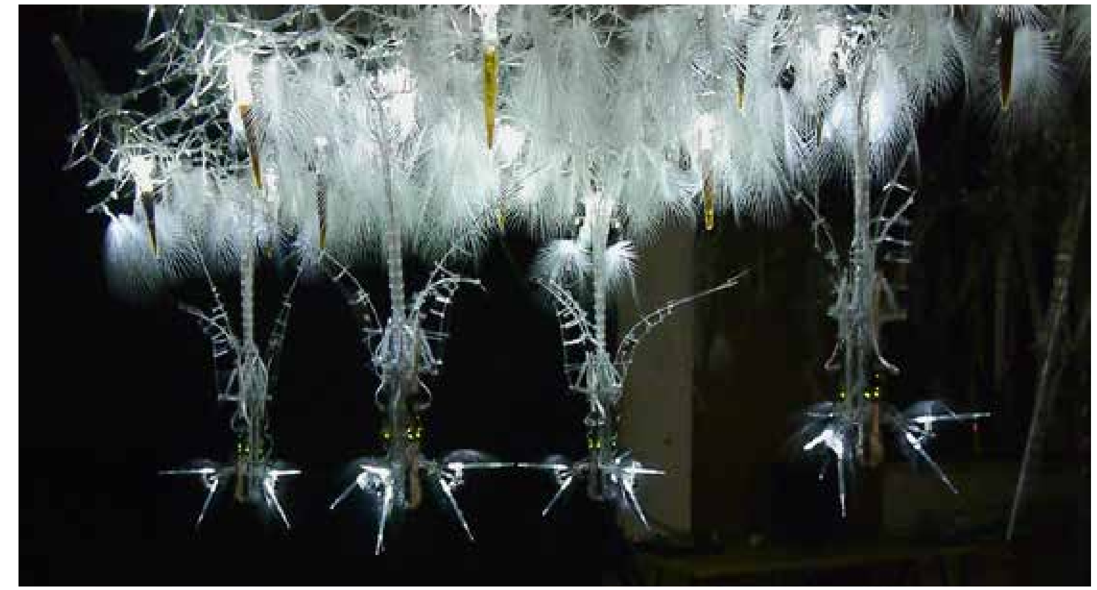


Figure 4 The activation level of the system is scaled based on the knowledge gain potential. When the potential for learning is large, the activation level is maximized. When the potential for learning is small, activation is subdued.

The asynchronous nature of the system allows learning agents controlling actuators with different operating bandwidths to perform at different temporal scales. Meanwhile, links among the different learning agents enable information to travel within the system, allowing distributed learning. Furthermore, to make the learning process visible to the user, the maximum output level of the system is scaled based on the knowledge gain potential, so that the system is less active when it believes that its learning progress is low (Figure 4).





Prototype Interactive Installation

Sentient Chamber includes clusters that enable physical human-machine interaction studies (Chan 2016); an early prototype is shown in Figure 5 and Figure 6. The installation includes four types of components: Light, Fin, Reflex, and Sound units. A Light unit includes a high-power LED and an ambient light sensor. The ambient light sensor is mounted under the LED, allowing it to measure the intensity of the light emitted by the LED. A Fin unit consists of two shape memory alloy (SMA) wires, a 3-axis accelerometer, and an infra-red (IR) proximity sensor. The two SMA wires pull on two levers that move a Fin, a mechanism made of compliant acrylic rods that curl up. The IR proximity sensor and accelerometer are mounted around midway between the tip and the root of the Fin. Located below the Fin, the Reflex unit consists of a vibration motor, a pair of LEDs, and an IR proximity sensor. Sound units each consist of a pair of custom speakers configured with pitch-sensing microphones, fitted with light chains and a pair of IR proximity sensors.

Figure 5 Schematic of the multi-cluster prototype installation used for the pilot user study (Chan 2016)

Figure 6 Photograph of the multi-cluster prototype installation used for the pilot user study (Chan 2016)

The resulting hardware and sensing mechanisms allow the system to sense its own state and a variety of environmental and user activities. The ambient light sensors are both proprioceptive and external: they can sense changes in lighting level due to the system's own LED activations as well as changes in ambient lighting (e.g. night vs. day). Similarly, the accelerometers sense the movement of the fins, which may be caused by system-initiated actuation through the SMA actuators, by environmental effects (i.e. air current in the space), or by a user touching or moving the fin. The IR proximity sensors sense the presence of nearby visitors as well as any permanent structures.

Each isolated CBLA Node is an instantiation of a CBLA engine and is associated with one actuator. The CBLA system is constructed by linking these isolated CBLA Nodes through virtual inputs and shared inputs.

Visitors showed strong curiosity when they interacted with the *Sentient Chamber* sculpture. A typical visit included approaching from a distance, circling along the perimeter and then entering the environment in order to explore the areas sheltered by the overarching canopy structures. Feathery frond and pointed spike-like glass forms within the Fin and Reflex clusters tended to attract strong attention that included stroking, gentle waving and animated gesturing. Attention tended to quickly concentrate on vibrating Reflex fronds and large kinetic gestures made by Fin units, with many cycles of gestures and machinic responses seen as visitors attempted to learn the particular qualities of human responses that would result in reliable machinic responses.

To investigate and compare user responses to the CBLA generated and prescripted behaviours, each CBLA Node has a Prescripted Engine in addition to the CBLA Engine. The prescripted behaviours are implemented based on specification from a human designer.

Sentient Chamber aims to generate life-like behaviours automatically. However, it is difficult to predict if a life-like system will actually be interested in all visitors. Gaver and others suggested that ambiguity can increase engagement (Gaver 2003). However, ambiguity without consistency can cause the work to appear confusing and meaningless. As noted by Silvia, people find events that are new and comprehensible interesting (Silvia 2008). Novelty and complexity alone may not be enough to make a behaviour interesting; it may also need to be understandable and at least somewhat predictable.

The study of visitors within *Sentient Chamber* revealed an interesting interaction between the agent's and the human's curiosities. Curiosity emerges from the process of resolving conflicts and reducing dissonance. Indeed, this is similar to the implementation of CBLA.

References

Beesley, Philip, and Christine Macy. Kinetic Architectures and Geotextile Installations. Toronto: Riverside Architectural Press, 2010.

Beesley, Philip et al. Hylozoic Ground: Liminal Responsive Architecture. Toronto: Riverside Architectural Press, 2010.

Beesley, Philip. Sibyl: New Responsive Immersive Architecture Projects 2010-12 (1st ed.). Kitchener: Riverside Architectural Press, 2012.

Drummond, Jon. "Understanding Interactive Systems." Organized Sound, vol. 14, no. 02 (2009): 124.

Wands, Bruce. "Variations: An Interactive Musical Sculpture." Paper presented at the 5th conference on Creativity and Cognition, New Cross, London, April 12-15, 2005. ACM (2005): 306–309.

Costello, Brigid et al. "Understanding the Experience of Interactive Art: Iamascope in Beta space." Paper presented at the Second Australasian Conference on Interactive Entertainment, Sidney, Australia, November 23-25, 2005: 49–56.

Fox, Michael, and Robert M. Kemp. Interactive Architecture. New York: Princeton Architectural Press, 2009.

Edmonds, Ernest, G. Turner, and L. Candy. "Approaches to Interactive Art Systems." Paper presented at the 2nd International Conference on Computer Graphics and Interactive Techniques in Austalasia and South East Asia GRAPHITE 04, Suntec City, Singapore, June 15-18, 2004: 113-117.

Beesley, Philip. Near-Living Architecture: Work in Progress from the Hylozoic Ground Collaboration 2011-2014. Toronto: Riverside Architectural Press, 2014.

Bedau, Mark A. et al. "Open Problems in Artificial Life." Artificial life, vol. 6, no. 4 (2000): 363-376.

Ikegami, Takashi. "A Design for Living Technology: Experiments with the Mind Time Machine." Artificial Life, vol. 19, no. 3/4 (2013): 387-400.

Lungarella, Max et al. "Developmental Robotics: A Survey." Connection Science, vol. 15, no. 4 (2003): 151-190.

Asada, Minoru et al. "Cognitive Developmental Robotics: A Survey." IEEE Transactions on Autonomous Mental Development, vol. 1, no. 1 (2009): 12-34.

Oudeyer, Pierre-Yves, Frederic Kaplan, and Verena V. Hafner. "Intrinsic Motivation Systems for Autonomous Mental Development." IEEE Transactions on Evolutionary Computation, vol. 11, no. 2 (2007): 265-286.

Metabolic Systems

Rachel Armstrong
Newcastle University

facing page
Sentient Chamber, National Academy of Sciences, Washington D.C. USA (2015-16)

A characteristic of living systems is their possession of a metabolism, but what is a metabolism and how does one design with it?

Let us surrender, for a moment, the idea that we inhabit a fully predictable, controllable, rational realm and rather, immerse ourselves in a world that maintains mystery without descending into incomprehensibility. In this domain, substances can spontaneously couple with their neighbours to produce surprising effects and super molecular chemistry gives us the capacity to synthesize matter that has not previously existed in the history of the universe. By spatially choreographing these strange materialities we may conjure ambiguous landscapes, environments, habitats, and even cities that can surprise and provoke us. Indeed, such an extraordinary matrix may at first seem to exist beyond our capacity to conjure, but let me first take a few steps back here in case you mistake my provocations for the poetic

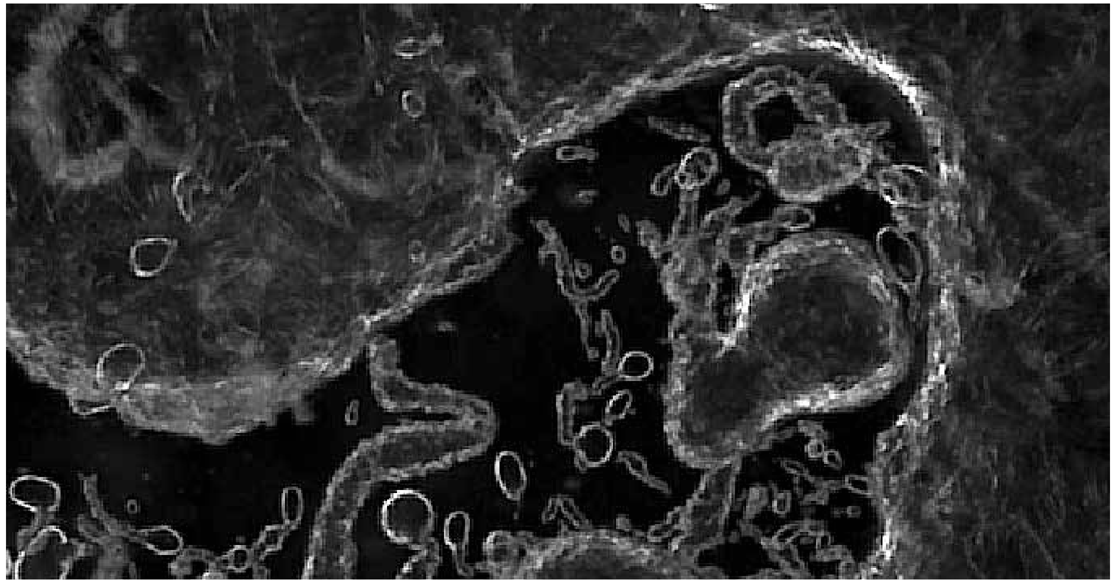


Image from Butschil experiments expressing the "energetic decay towards equilibrium"

hallucinations of a mind that has lost any relationship with its senses. These extraordinary provocations are firmly placed within an experimental world of discovery that can not only be provoked and designed but also explored.

At the heart of metabolism is the possibility of constructing life, which is a subversive phenomenon that resists the classical laws of physics and therefore has been notoriously difficult to design and engineer with. Consequently its critical operations are not easily described and therefore portrayed through incredibly negative lenses. Even its language is a negation of its radical creativity: non-equilibrium, non-linearity, negentropy, chaos, spookiness, disorder, irreversibility, far from equilibrium, strangeness, co-incidence, messiness, uncertainty and randomness. Feel the darkness within these terms – loaded with revolution, and unpredictability, like a conceptual haunting. Life is defined largely as that which it is not – conceived as multiple destructive acts against the orthodox commandments of matter – a form of material irrationality.

Metabolism ambitiously aims to tackle these difficulties in an ambitious project to conjure life – not through the traditional approach by deducing what liveliness – but by attempting to generate life-like phenomena within

the material realm in a new kind of synthesis by engaging with the choreography of its difficulties, contradictions and inexactitudes, where boundaries are always blurred, objects semi permeable to each other and its fabrics overwhelmingly hypercomplex.

This is not a fully realized, or easy portfolio of methods, materials, technologies, and prototypes to work with. Indeed, they exist within a hypercomplex and probabilistic realm from which we cannot fully dissociate or observe in its entirety. It could be argued that such fabrics spill beyond the disciplinary domain of architecture and enter into a new multi-disciplinary practice of 'worlding'[1] in which the conventional modes of construction that constitute architecture are only a part. Yet, once experienced, it is no longer possible to fully extract ourselves from the charm, magic, or potential of this unchartered domain, and even when we begin to explore the details of those operations that form its guts, this territory will always resist our full comprehension remaining probabilistic, shocking, wonderful, and capable of surprise.

Metabolic Systems as Hypercomplex Fabric

Metabolism is a strange fabric, which is in continual flux.[2] It is simultaneously material, technical, and phenomenological, arising from the transactions and dynamic couplings within an assemblage of participating chemical bodies that perform 'useful' work by resisting energetic decay towards equilibrium and in the process, generate "straightforward environmental images." [3] Another way of approaching metabolism is to understand it as the linking of complex, dissipative bodies, which form loose assemblages with each other and collectively consume and produce their environment. These dissipative systems, or structures, arise spontaneously in nature across a range of scales such as crystals, tornadoes, and galaxies. While not all meet the technical qualifications of 'life', all 'life' is a dissipative process. Dissipative structures are paradoxical objects that are confluences of energy/matter flows that spontaneously arise from overlapping fields of activity.

Conceptually, they may be imagined as tornadoes that possess a recognisable structure that nucleates around a 'nomadic' site – one that is not fixed by spatial coordinates but shaped by its relations, or 'hubs' of activity. It maintains stability by dumping energy into its surroundings, and oddly, as it does so, it optimises its organizational capacity to dissipate energy

1 Singh, R. 2012. Heidegger, World and Death. Plymouth: Lexington Books, p58.

2 Morton, T. 2007. Ecology Without Nature: Rethinking Environmental Aesthetics. Cambridge: Harvard University Press, p84.

3 Morton, T. 2007. Ecology Without Nature: Rethinking Environmental Aesthetics. Cambridge: Harvard University Press, p150.

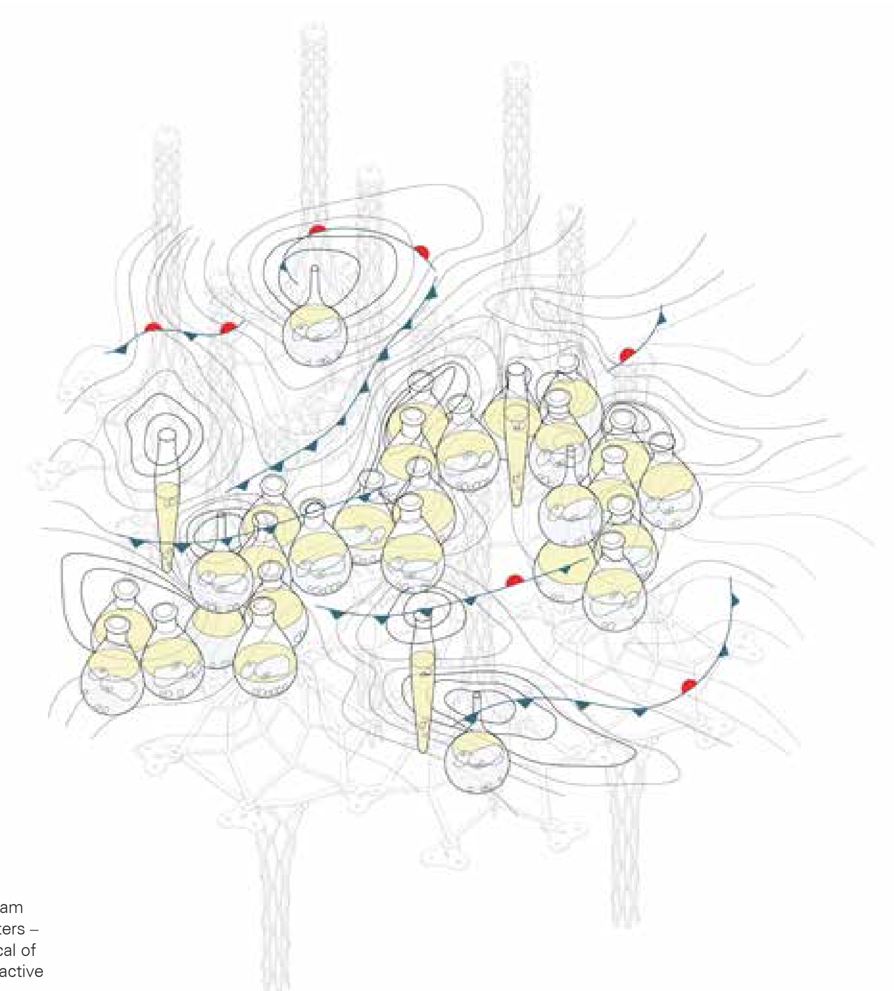
into its surroundings. They exist within a range of limits and are unstable, eventually succumbing to the forces of disorder, or entropy, at which point they lose their lively character. Dissipative structures also interact beyond their boundaries through active fields. Perhaps the best way to imagine a dissipative structure is to think of a tornado. They are unusual to encounter, as they do not behave like classical objects. Imagine a storm chaser encountering a twister, who can feel its presence long before the eye of the storm is reached. Because they are highly complex physical systems that resist collapse they tend to seed the conditions for their next iteration until relative thermodynamic equilibrium is reached. Collectively they produce metabolic fields of activity.

Although metabolic systems are not given the full status of being truly 'alive', they are critical to the design process as a set of tactics that may increase the probability of life-promoting events. Metabolism is an unbounded phenomenon that is characterized by constantly unfolding manifolds and landscapes that do not scale linearly or infinitely. It is therefore a paradoxical fabric, full of contradictions and 'invisible' agencies – ones that have not been atomized, named, or formally identified – that shares many characteristics of its constituent dissipative systems operating far from equilibrium states and whose relationships with its surroundings establish perturbations and channel flows that further perpetuate its existence. We might also think of constructing metabolism as choreographing populations of weakly-linked[4] dissipative systems in time and space.

4 Harman, G. 2012. On the Mesh, the Strange Stranger, and Hyperobjects: Morton's Ecological Ontology. tarp Architecture Manual, Spring 2012. p16-19. [online] Available at: https://issuu.com/tarp/docs/notnature_finaldraft_041012. [Accessed 4 September 2016.]

Metabolism is weather that burns. Not as a dry heat such as combustion but as a wet, ionic field – like storm clouds. Its thunder and lightning carry the seeds of life, ready to charge and re-charge the soaking bodies within its downpour. It is composed from clusters of substances with fluidic tendencies, like clouds, smog, waves, currents, eddies, vortices, and hurricanes, whose spatially contextualized exchanges collectively resist decay towards equilibrium and so result in the materialization and persistence of process. In this way metabolism possesses a character that is consistent with our experience of climate. It has fronts, transitions, quiet days, storms, breezes, and even seasonal variations. It is never the same encounter one day to the next and never fully predictable.

The theory of 'dissipative adaptation' proposes that life-like function directly emerges from the non-equilibrium properties of these chemical substrates,



Weather that burns: diagram of *Sentient Chamber* clusters – overlaid by notations typical of weather fronts indicating active metabolic landscapes

and through their persistence their sensate structures change to better perpetuate the flows of matter and energy that forge the weather and enable them to persist through their chemical transformations, so they may begin the transition from nonliving to living matter.[5] "You start with a random clump of atoms, and if you shine light on it for long enough, it should not be so surprising that you get a plant."[6]

Metabolic systems embrace many characters, some are fleeting, and a few are constantly evolving, while others – caught in closed loops of exchange

5 Eck, A. 17 March 2016. How do you say "Life" in physics. Nautilus. [online] Available at: http://nautil.us/issue/34/adaptation/how-do-you-say-life-in-physics. [Accessed 2 September 2016].

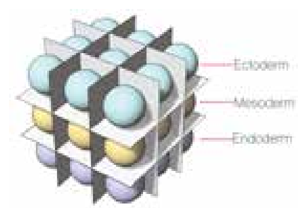
6 Wolchover, N. 2014. A New Physics Theory of Life. Quanta Magazine. [online]. Available at: https://www.quantamagazine.org/20140122-a-new-physics-theory-of-life/. Accessed [3 September 2016].

– are almost permanent. All metabolisms are in a state of continual flux, oscillating between tipping points before transforming and establishing new configurations. The state of the matrix and the character of the infrastructure in which these relationships are forged facilitate or impede its liveliness. The performance of metabolisms is therefore a question of infrastructure, spatiality, substance, and flux. While typically defined within the context of the interior chemical fluctuations that take place within the confines of a cell wall, the semi permeable nature of the membrane extrudes the reach of metabolism beyond the limits of any particular body and leaks its reactive tendrils into the environment – somewhat like an 'aura'. It draws sustenance from its surroundings and maintains flow of matter and energy through an expanded field of participatory bodies, with their associated matter/energy fluxes. Of course, being a material phenomenon, metabolism possesses limits that are contingent on a host of circumstances – the nature of the participatory substances, the ambient temperature, rate of material flow in the environment, heterogeneity of landscape, and the presence of catalysts, to name but a few. Metabolism is an embodied, highly spatial entity.

Its potency roams and haunts spaces like hungry ghosts and productive ectoplasms, trembling with uncertainty, generating spooky effects and then vanishing. Being such a diverse assemblage of loosely coupled non-equilibrium objects, 'decisions' are not only made from within each dissipative system but also through their external relations. Yet, the notations for indicating these multi-dimensional programs and their operations are largely collapsed into diagrammatic forms that gesture towards web-like structures whose edges are tucked into closed loops and coherent fields of operations. An idea emerges from these modes of representation that metabolisms, life, physiologies, and ecologies are 'closed loops' of operations – rather than fuzzy, highly spatial fields of uncertainties – more like condensation of breath around a window pane than something that can be channeled through its symbolic representation in straight lines.

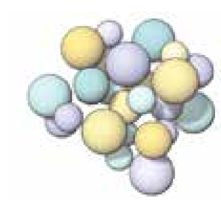
Metabolic Systems as Program

The material world computes but not according to the abstractions of numbers that we have become accustomed to with digital computers. We have barely begun to scratch the surface of this realm;[7] a potentiality that was of great interest to Alan Turing.[8] Moreover, matter that computes is by no means incompatible with Turing's ephemeral mathematical language. Rather the capacity for lively matter at far-from-equilibrium states to make decisions, execute commands, and produce programmable systems, creates a potent, potentially convergent interface where life, mind, body, and symbolic languages can mingle to create a Cambrian explosion of new materials, spaces, essences, and forms.



3D Cellular Automation

Spatialization



Tissue and Organ Morphogenesis

3D chemical cellular automata diagram of cuboid grice overlaid by droplets arranged in three layers: ectoderm, mesoderm and endoderm. These then organize through a mechanism that engages cellular automata landscapes to produce highly complex and spatial embryo-like forms

Let us consider metabolic systems as analogue computational platforms, whose operative agents are dissipative structures that can complexify space and matter. They function as an iterative system – or 'natural' counting process - that can be ordered to generate a range of programmable outputs that result in life-like phenomena such as growth, movement, and even population-scale interactions. Every iteration – a pulse, a blink, a twitch, or a breath – becomes the material basis for a considered response and action to a context. Imagine, if you will, cellular automata whose pattern generations are produced by their contingencies.[9] Now, think about what that might mean if each 'cell' in that operation was a pulsating body, stacks of droplets, or active bodies, capable of materially responding to neighbours in (at least) three material dimensions. We are starting to see a ball of primitive cell-like structures emerge whose potentiality may be likened to that of an early embryo that thickens to form a plate and rolls and folds to produce a more exquisitely complex and performative body.

Dissipative structures are physical bodies that are environmentally sensitive and therefore may be influenced by their context. They are massively parallel computing devices within an excitable gaseous or liquid chemical medium. They act as elementary processors through which different chemistries diffuse, react, or transform in space and time. The actual computation is performed through the meeting of reactive fields at interfaces, and the subsequent propagation of chemical waves, or material depositions caused by these disturbances, which directly feed back into the outputs of the system, so that new spaces and possibilities become accessible. Perhaps surprisingly, dissipative systems are remarkably predictable, although they retain a fundamental capacity for surprise and collapse. They tend to produce a spectrum of outcomes that operate within 'limits' of possibility, which are imposed by the properties of the system, the participating bodies and their contexts. Perhaps think of them like making a cake, whose ingredients and method of cooking may produce a range of outcomes from a dirty black biscuit to a delicious fluffy gateau, depending on how the recipe is executed.

7 Denning P. J. 2007. Computing is a natural science. Communications of the ACM, 50(7), pp.13-18.

8 Turing, A.M. 1952. The Chemical Basis of Morphogenesis. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 237(641), pp.37-72.

9 Doctorow, C. 11 October 2012. Game of Life with floating point operations: beautiful SmoothLife. Boing Boing. [online] Available at: http://boingboing.net/2012/10/11/game-of-life-with-floating-poi.html [Accessed 20 April 2014].

Dissipative structures therefore require us to count along with them – not 'for' them by imposing our own expectations on the system's performance. In other words, they require soft control, whose techniques are already known to us as artisan practices and range from cooking, gardening, and agriculture, to working with small children or herding cats. When linked through metabolism, they create the possibility of a technical platform and material that can function as a medium for design.

By considering dissipative structures as the iterative process that underpins material computation, the technical operations possess a different set of characteristics than digital computers. Such an apparatus may enable us to work directly with low-level infrastructures, like soils, which produce material programs that directly promote life, or generate structures that provoke life-like phenomena without reducing or abstracting them. Rather than being purified, homogenized, and constrained within bounded spaces, they are open, messy, and highly heterogeneous. Lively matter does not need to know the outcome, or the future impact of its interactions, before they respond to changes in their environment. The capacity of metabolic networks to perform these functions is intrinsic to their materiality, kinetics, and context. The incredible parallelism implicit in molecular fields enables them to coherently exist in multiple configurations and intermediate states with the potential for phase changes and paradoxical phenomena. Yet, such fabrics are not formless; they produce highly organized structures and even exert a transformative impact on their environment by increasing the liveliness of spaces or probability of life-like events.

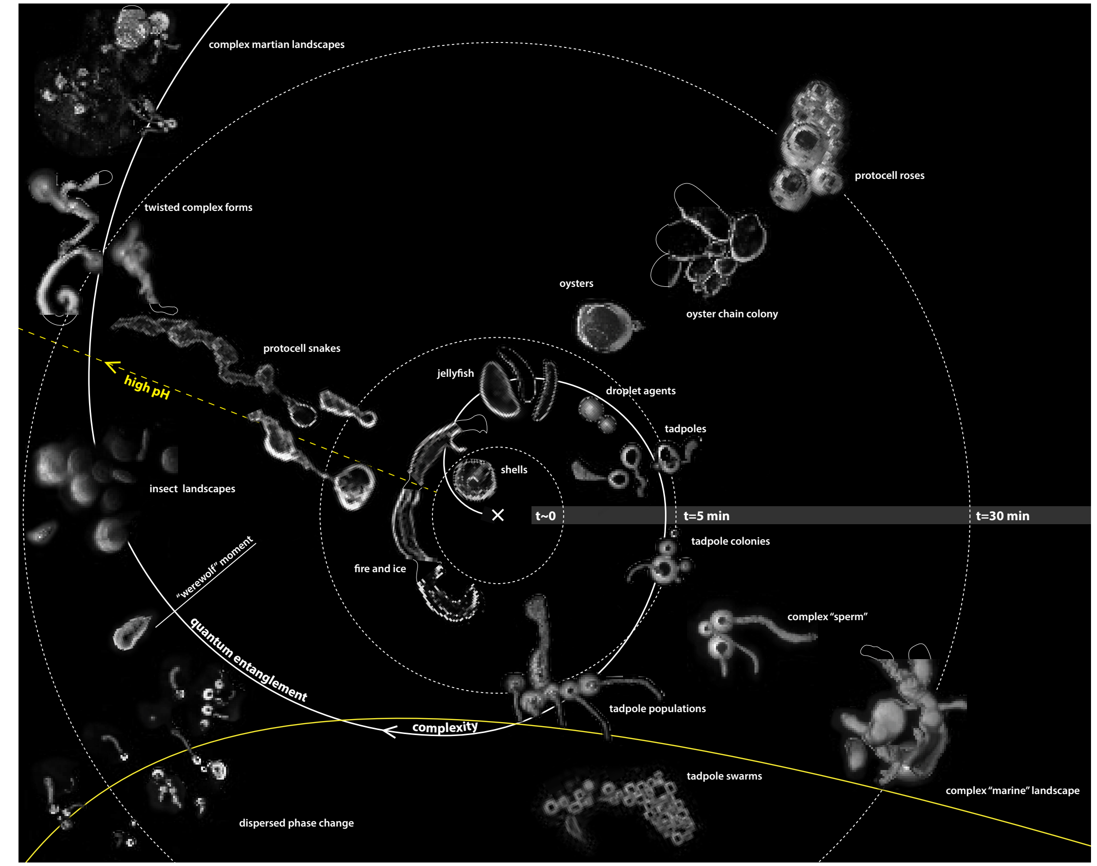
Metabolic Systems as Soil

> Like our bodies, the soil participates in the recirculation and transformation of the four major elements, earth, air, fire and water. Like our bodies too it is full of channels and pathways, directing the elements in fertile combinations and transformations at distinct organized levels of the whole structure. And like our bodies, it has a definite genetic form.[10]

The palimpsests and residues of metabolisms are soils. Think of metabolism as the outer active layer of a landscape, the foams on a sea crest, the air's dew. Now consider the precipitations, traces, distillates, secretions, crystallizations, dead bodies, and countless encounters that finally reach equilibrium – these residues are the soils. They shape the infrastructures upon which metabolisms may fall when they reach equilibrium states and rise again. Yet they are not haphazard and chaotic; they are hypercomplex, highly distributed, and burn with the same intense heat that the active foams and smogs that permeate the interfaces between land, sea, and air do. Indeed they encourage some metabolisms to migrate further down, seek shelter in their recesses, and establish a tangible fabric that enables the transition from inert to lively matter by linking the cycles of life and death through the 'compost elevator'.

Evolved from the earliest soils – inorganic clays, dusts, and sands impregnated by the thinnest scattering of organic matter that draws water into its

10 Logan, W.B. 2007. Dirt. The Ecstatic Skin of the Earth. New York: W.W. Norton & Company, p177.

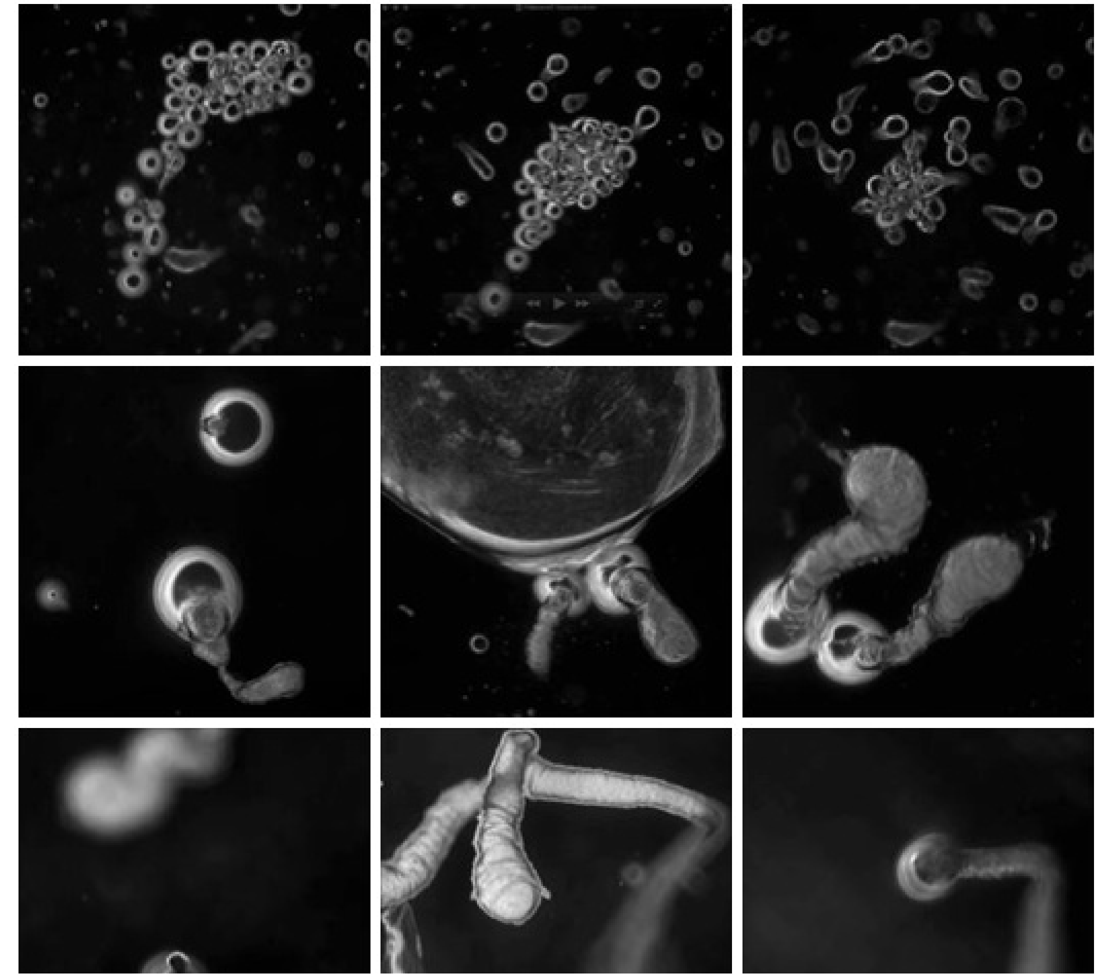


An oceanic ontology of 300 replicate Butschli experiments exploring the creativity of the chemical system as a function of time. Drawing courtesy Simone Ferracina, concept Rachel Armstrong.[11]

11 Armstrong, R. 2015. Vibrant Architecture: Matter as codesigner of living structures. Warsaw/Berlin: DeGruyter Open, p121.

substance – the compost elevator began as a dance between wind, water, and fire, whose footsteps cracked and ground rocks into sands, dusts, and clay – that are likely to have had a critical role in biogenesis, catalyzing and spatializing matter into configurations that could persist and transform within their environment as lively assemblages. Yet even clay landscapes act as catalysts for life-like events by providing a mineral coding structure, whose effusive surface offers a landscape that organic substances may organize around to encounter exactly the kinds of interactions they need to become lively, coherent bodies. Its aperiodic material programs do not in themselves produce life but increase the probability of it happening. Clays stretch and bend energy around chaotic vortices, provoke unanticipated unions, and offer dynamic containers of information where novelty, creativity and synthesis can condense to produce new relationships between molecules. Yet, clay is more than spatially arranged chemistry. It is also a topography of physical forces that attracts oppositely charged particles along its myriad surfaces. Many of these are necessary for organic reactions, including potassium, calcium, and nitrates. While the search for biogenesis is focused on the incredible flexibility of the organic molecular realm, the potential contained within the ordering systems of mineral environments is largely overlooked, and therefore, the complex events that constitute biosynthesis remain an unbalanced equation when considering the question of constructing life-like systems. With the formal advent of life, solar energy could be trapped and stored in carbon building blocks to produce biomass bodies, and as they perish, they would produce organic matter that could be incorporated into early soils so they could draw water and air into their substance to become fertile loams and peats.

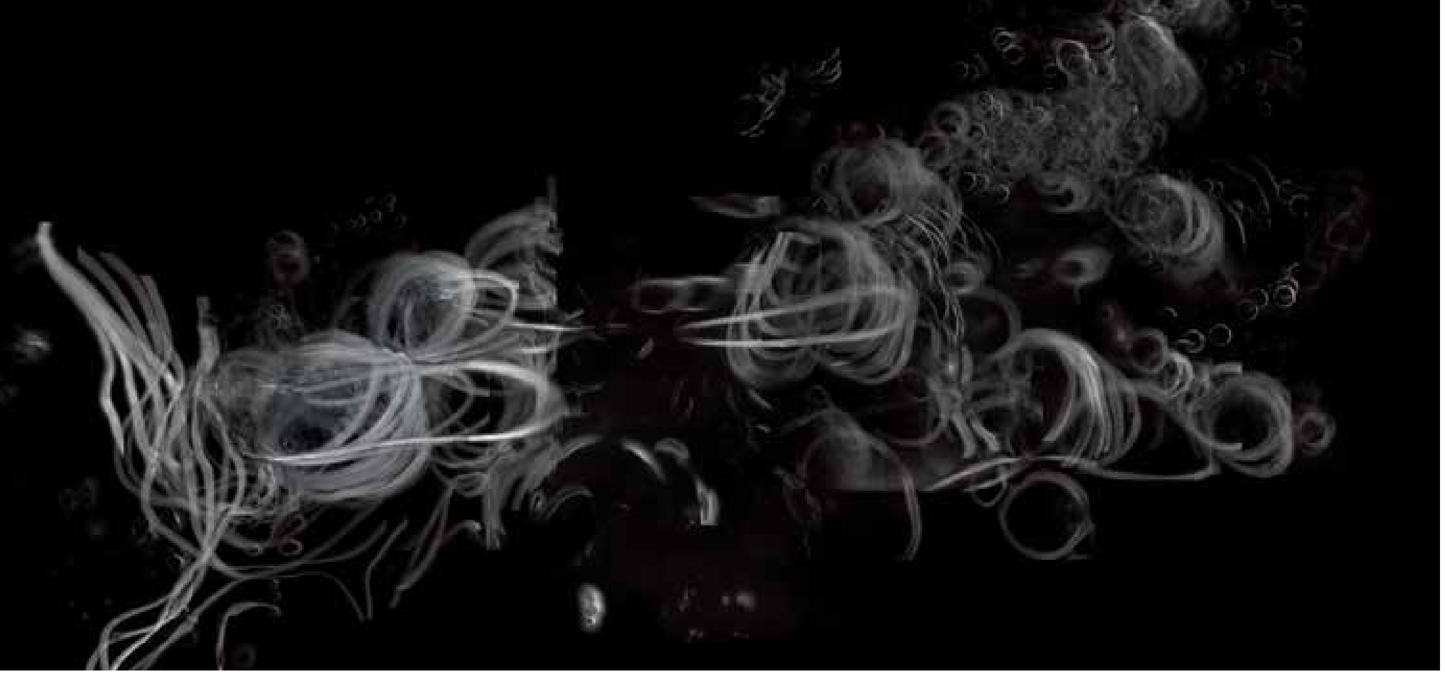
Soil has its own material identity that is expressed through a unique tapestry forged from a rich palette of agents including minerals, organic matter, air, water, and diverse groups of microbes, which draws together the material residues of the land but also incorporates the possibility of 'invisible' or unknown influences in achieving its effects. Indeed, the story of life probably lies beyond full comprehension by any single knowledge canon and therefore invites the overlapping of various knowledge practices from ancient (religious), to corporeal (channeling), to modern science (measurement) and quantum theory (counterintuitive) so that mutual enrichments between these fields may be encouraged. The ultimate aim of the elevator is to prevent the permanent onset of entropy within metabolic networks by continually obfuscating entropic processes using spatial, temporal, material, narrative,



Collage of images from Butschil experiments generating a manifold topology and soft scaffolding of origins of life

and phenomenological tactics. It also considers life not as the result of a single initiating event, but as a succession of highly distributed activation processes with loose controls and multiple authors where life is transformation as much as transformation is life.

We will never fully know just how much mineral syntheses have really contributed to primitive ordering systems in biosynthesis, as these apparatuses have been completely replaced by the 'Last Universal Common Ancestor', or LUCA, and its biological descendants in nature. Yet, if we are to look for



Protocell Phantasmagoria: Portrait of an origins of alternative life. Drawing by Simone Ferracina, movie courtesy Rachel Armstrong, 2016.

evidence for life's origins, we are most likely to find these processes in geochemistry, and its vestiges may yet be encountered as strange phenomena.

This is exactly the right kind of ambiguity in which to reflect upon the kinds of insights and design principles that can be reflected on in considering a practice that operates through metabolic systems and the infrastructures for life. In particular we must consider the invisible agencies that operate within the transition from nonliving to living matter, which have been denied a voice in the modern science laboratory. While vitalisms have been theoretically dismissed for around eighty years or more, they simply have not gone away and remain ghosts in the machine, as the animating forces of nature and life have not been named and atomized. In their stead, new terminologies for the invisible lurk within scientific rhetoric as emergence, autopoesis, and self-organization. While these terms indicate a particular phenomenology, they do not tell us how or why they work. Both nature and life are unresolved projects. This does not mean that they cannot be designed and interrogated, but that in our explorations we appreciate they harbour the kinds of contradictions that the worlding process of ambient poetics inspires.[12]

12 Morton, T. 2002. Why Ambient Poetics? Outline for a depthless ecology. The Wordsworth Circle, 33(1), p52-56.

Metabolic Systems as Ecology

> It is interesting to contemplate an entangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, for different from each other, and dependent on each other in so complex a manner, have all been produced by laws acting around us.[13]

The web of living exchanges that foregrounds the participatory processes of active bodies is encapsulated by Charles Darwin's description of an 'entangled bank' of organisms where the individual performance and fate of any single organism does not upstage the collective choreography of lively events.[14] Indeed, ecosystems condense where metabolisms and soils begin to converge around the activities of fully alive bodies that occupy discrete habitats and lived spaces. The texturing of these terrains through "colour, sound, smell, and rhythm, perception and emotion"[15] produces the characteristic ecology of interactions, whereby landscapes proliferate of their own volition but also respond to and are transformed by the attentiveness of the communities that dwell within them. While Darwin observed the choreography of ecological events as the productive, mutual relationship between organism and niche, he did not identify a specific mechanism to explain the mode of operation of the underlying systems.

The artificial ecologies of the *Sentient Chamber* are similarly foregrounded ecological fabrics that are paradoxically alien but familiar "entangled banks". Their performativity is not specifically limited by the actions of any particular agent but recognized through the twittering, shivering, sentient fabric that houses the metabolic systems infrastructures and their synthetic soils. The first seeds to arrive within these fertile landscapes are simple chemical structures like ions, droplets, vortices, and crystals, with a fundamental appetite for one another, which begin to enliven their host domains. Effervescent turbulence ensues with a first wave of swirling shell-like forms within the city of vessels that harbour the liquid environments.

Collectively, they form a river of phantoms that twist like carousels bursting out of each other. Most fall instantly, incarcerated in the crusts of their own product, murdered by the strangeness of their existence.

13 Darwin, C. 1996. The Origin of Species. Edited by Gillian Beer. Oxford: Oxford University Press, p360.

14 Morton, T. 2011. The Mesh. In (eds.) Stepheniac LeMenager, Terea Shewry and Ken Hiltner, Environmental Criticism for the Twenty-First Century. New York, Routledge, p19-30.

15 Massumi, B. and Manning, E. 2014. Coming alive in a world of texture: For neurodiversity. In (eds.): Brian Massumi and Erin Manning, Thought in the act: Passages in the ecology of experience. Minneapolis: University of Minnesota press, p4.

Impossible chemistries appear and fade as phantoms, leaving no traces of their explorations. Interfaces split over invisible trails, beckoning swarms of chemical tadpoles, silicon barnacles, soft insect-like bodies, throbbing shellfish residues, inorganic worms, ghosts, accreted oyster chains, and kissing corpses, which circle each other for their undetectable nectar. Bodies mirror one another on soft scaffoldings and dance asynchronously – at first with limbs and tails, then together. Others gather in groups, knitting crystals and scatter in threads through a gleaming glassy ocean of oil. Matter strings and ribbons decorate this maypole terrain with their turbulence, drawing their names in the snow globe storms that come and go within a city of glass vessels. A few ductile osmotic tubes quietly circle – small, persistent, haunted by their own purpose to join the realms of the unquiet. Now, spent as fossils they settle in spaces that have been drained of their potential and throbbing like upturned flies, reach quiet equilibrium. Living technologies accrete and melt like corals, perpetually building on the residues of their ancestors to create more permanent scaffoldings. Some rupture like fireworks, others activate, and a few extrude into forbidden spaces, where it is too hot or dry for life.

At some point, assisted by design tactics, such as the positioning of clusters of hygroscopic materials within the landscape, they spill out into new territories, expanding the limits of their original realm. Their vagrant active fields and interfaces draw new nutrients towards them which creep through spaces of high flow that invigorates their being and enables them to persist. Panspermic events bring organic agency into these landscapes, such as encounters with microbial fuel cells, living batteries that feed on decay. With augmented proliferative capacities every successive act is an enrichment of what went before. So, where inorganic realm once bloomed, now multiple carbon-based bodies complexify in bursts of punctuated equilibriums, where machines, more sedate than the unruly organic usurpers of the mineral world, become gardeners of a new synthetic terrain that possesses coherence, even if its life-forms and relationships are individually unrecognizable. Observing these fabrics through alternative perspectives so that we may work with them ethically and empathetically, so our operations do not devitalize but augment, enliven and provoke these environments to respond empathetically to both human and nonhuman agents.

Now, we may begin to observe the kinds of transformations possible within this outlandish environment and discover the potential of artificial evolution to generate new kinds of materials, spaces, landscapes, and habitats whose monstrous unorthodoxy nonetheless splendidly dazzles its visitors with extraordinary encounters. "The subject of the experience is not the human but the fielding of the event itself."[16] Yet, although we see no birds or plant clusters, no eyes or limbs or faces, the fields of immediacy collide with our memories of the kinds of systems we recognize as nature. Within these novel environments, we begin to perceive the shape of the symphonic score that bonds us to these alien ecologies and understand that we have already encountered them many times before.

16 Ibid, 14.

Metabolic Systems Within the *Sentient Chamber*

The *Sentient Chamber* begins the process of design with complex fabrics that actively explore the possibility of the transition from nonliving to living matter. The exploration is emphatically not a pure form of Enlightenment logic that documents a set of causes and effects but something much stranger that invokes intermodal forms of existence. Nor is it an ancient form of magic that calls upon deities and demons to do the bidding of an architect author that has somehow gained power over their obedience through emerging materials and technological apparatuses. Rather they are a paradoxical material that embodies both the intangible phenomenological realm and its hypercomplex entanglements with matter.

The installation is a condensation of ambient poetry, passions, constructed forms, artificial intelligences, and human interactions that together produce an immersive landscape, an artificial ecosystem, which does not set out to fabricate new anatomical forms but instead, generate immersive experiences that speak to the possibility of provoking fresh encounters with life-like phenomena. These take places within tenuous relationships, distant exchanges, dreams and fears that speak to a more greatly extended participatory community than the cause-and-effect narratives that frame Enlightenment discourses. Within the experimental domain of the *Sentient Chamber*, the processes of composting and renewal begin their rich mixology and start to permeate the environment in ways where the heterogeneous agencies that constitute the installation participate with their audiences through dialogues of unbounded creativity and begin the provocation of becoming 'life'.

Human Experience

Colin Ellard
University of Waterloo

facing page

Sentient Chamber, National Academy of Sciences, Washington D.C. USA (2015-16)

What is the relationship between the built environment and its living occupants? How do the surfaces, the geometry, the movement, and the site of a structure affect the mood, thought processes, and underlying physiology of the human creature enmeshed in such settings?

Sentient Chamber offers a potent environment to explore these questions and assess the impact on human experience. Here the interaction of occupants within a near-living architectural test-bed is observed as a set of relationships that influence our cognitive, psychological, and physiological conditions. *Sentient Chamber* presents a built environment that is moving closer to how humans experience the natural world. In this sense, it provides an important context for investigating the triggers that evoke similar reaction to that of experiencing nature.

Image from the installation of *Sentient Chamber*

This interest is grounded in the belief that boundaries between subject and object are permeable and the entirety of human experience relies on grasping the complexities of context. In other words, in order to see inside the mind and understand mental processes, it is necessary to include conditions that matter to a normal functioning brain.

There is a seamless system of interaction between the individual's inner physiology and mental state and their surroundings. Thus the outside is of critical importance to what manifests inside as our human experience. Individuals react to the perceptual qualities of a setting, and their reactions influence the organization and meaning of the setting. People respond to architectural elements by the patterns of their gaze, the sounds of their voices, and the movements of their feet. This swirl of biological activity can transform the site itself while simultaneously being transformed by the site.

Studies conducted in both real world settings and simulations in virtual reality offer some simple predictions about how the formal appearances of complex spaces influence visitor reactions. Using careful spatial analyses based on measurements of complex space, it becomes possible to illustrate the fit between the raw design of a space and the activities, feelings, and impressions of those within it. An impressive finding was the degree to which meaning of a space is conditioned less by the location of the walls, ceilings, and windows and more by human activity and interaction. The data stream that is collected from individuals within such settings reflects the operation of complex synergistic relationships between person and place.

Experiments within environments such as *Sentient Chamber* often include equipping the participants with some simple technology that is designed to probe the state of their minds and bodies while they experience the space. Wanderers carry smart phones that are programmed both to ask them simple questions about their surroundings but also to administer some rapid on-the-spot cognitive tests that tap their cognitive resources—their ability to pay attention and to use their short-term memory. In addition to this, participants wear devices that measure skin conductance (a simple value that gives some insight into the state of their autonomic nervous system). Consumer-grade devices are also used to measure some simple EEG values and the occurrence of eye blinks. This latter measure can be used as a proxy measure of cognitive effort—when we are turning our attention inward to process a scene, our rate of blinking increases.

Experiments conducted thus far reveal some important commonalities in how people respond to variability in the environment. It has been illustrated that complex built spaces produce higher levels of arousal, higher rates of blinking (suggesting increased cognitive processing) and positive affect. In contrast, spaces of nature reduce levels of physiological arousal (as measured using skin conductance) but in this case also elicit a strong positive affective response. This interaction between bodily responses and self-reported affective responses suggests that it is important to employ a wide range of different kinds of measures in order to completely fractionate the human response to a setting.

Sentient Chamber offers compelling experiences in forming the relationship between site, structure, and human psychological responses. The interactive structures designed as a part of the installation offer a potent context for further exploration of the relationships between the human body and mind and its setting.

On one level, understanding the aesthetic response to the mere appearance of the structures is itself fertile territory. In some ways, the raw appearance of the structures share many properties with the features of natural environments that have been shown by many to be deeply restorative. This effect, though widely documented, is poorly understood. What are the key

Image from the installation of *Sentient Chamber*

ingredients of natural settings that produce healthful responses from visitors so dramatic that they can change patterns of brain activity, hormonal states, and even vulnerability to disease? And how much of this effect can be produced by something other than a natural setting?

At a deeper level, it is about understanding the relationship between the response of a visitor to such a structure and the concordant response of the structure itself. There is much to be learned here about the manner in which the dynamic response of a setting to the movements and feelings of an observer feeds back to the feeling state of the observer. In a way, this is not novel. Conventional built settings show the accreted marks of human interaction through their patterns of wear and modification over time, and these marks in turn influence how we respond to an environment. But such marks represent the massed influence of many users over a long period of time and so can rarely reflect individual responses. In a way, such modifications represent a long-term average response rather than an instantaneous one. The opportunity to understand such relationships using a setting that listens and then immediately speaks a reply to an individual observer provides a novel opportunity to dig more deeply into the interactive relationship between a setting and a visitor. It resonates with the conviction that the subject-object divide of most conventional experimental psychology is artificial, oversimplified, and deceptive, and it provides us with an opportunity to explore what this means in a tractable, scaled physical system.

More subtly, the interest is in how the interacting system of human and sculpture might be used to explore the way that their linkages emerge over time to reflect memories of the history of their interactions. Is there a shared memory? If so, such memories far transcend the mute, passive relationships between occupant and conventional architecture. For one thing, these relationships might reflect both the mass of experiences accumulated by the sculpture but also the individuated experiences of single identified occupants.

Finally, possibilities for generating therapeutic relationships between occupant and structure can be found within *Sentient Chamber* as a fundamental opportunity. If a structure can learn the habits, moods, and "pathologies" of a visitor who makes repeated visits, can such visits be considered as a form of therapy? Can a structure heal a person? Or slightly more perversely and with a nod to some more dystopian visions of such relationships in narratives in literature and the other arts, will the structure itself develop pathological systems of responses that mirror those of its occupants?

The vital conditions offered by *Sentient Chamber* recognize the profound impact of the environment on human experience. The process of speaking of these conditions calls for the development of proper language to characterize the synergistic relationship between person and the other elements of an interacting system. Avoiding the subject-object divide seems imperative, yet what terminology will capture the life that exists between the two when even the word between itself belies what seems to be wrongful thinking about the problem? New methods of both description and analysis will constitute an important part of the ongoing investigation into vivid spatial environments such as *Sentient Chamber*. Working towards better understanding human experience within living architecture systems will provide the vocabulary and tools both to look backwards with deeper understanding at the perennial relationship between human and built structure but also to look forward into a future where evolved biological structure, physical invention, and a lived universe teeming with data streams will coalesce into a healthful, sustainable, and beautiful new way of thinking about all life—both natural and synthetic.

Living Architecture Systems Group

Can architecture integrate living functions? Could future buildings think, and care? The Living Architecture Systems Group brings together researchers and industry partners in a multidisciplinary research cluster dedicated to developing built environments with qualities that come close to life—environments that can move, respond, and learn, with metabolisms that can exchange and renew their environments, and which are adaptive and empathic towards their inhabitants. Supported by Social Sciences and Humanities Research Council funding and contributions from numerous partners, LASG is focused on developing innovative technologies, new critical aesthetics, and integrative design working methods, helping equip a new generation of designers with critical next-generation skills and critical perspectives for working with complex environments.

The research of LASG has the potential to change how we build by transforming the physical structures that support buildings and the technical systems that control them. Intelligent controls, machine learning, lightweight scaffolds, kinetic mechanisms, and self-renewing synthetic biology systems are being integrated in prototypes, exploring how these different systems might be fully integrated into new generations of buildings. Specializations are in advanced structures, mechanisms, control systems, machine learning, human-machine interaction, synthetic biology, and psychological testing. The combined expertise of the group offers unique integrated design, prototyping, and public demonstration facilities.

The partnership is structured by six discipline streams: Scaffolds, led by Philip Beesley (Waterloo Architecture); Synthetic Cognition, led by Dana Kulić (Electronic and Computer Engineering, Waterloo); Metabolism, led by Rachel Armstrong (Architecture, Newcastle); Human Experience, led by Colin Ellard (Psychology, Waterloo); Interdisciplinary Methods, led by Rob Gorbet (Knowledge Integration, Waterloo); and Theory, led by Sarah Bonnemaison (Architecture, Dalhousie).

These streams are integrated within a six-year research plan that move in cycles from experimental prototypes to integrated public scales of implementation. Growing in scale and complexity from prototype interiors to prototype envelopes, researchers will investigate how near-living architecture can integrate machine-based behaviours and chemical exchanges. In parallel, the group will investigate the cognitive, physiological, and emotional responses of occupants.

Long-term objectives of the LASG include development of advanced prototype envelopes that have achieved fully integrated self-renewing intelligent, empathetic systems, capable of functioning within existing inhabited buildings. This long-range research has the objective of finding practical strategies for achieving resilience and adaptability in states of disequilibrium, such as those currently occurring in the natural environment.

Author Biographies

Philip Beesley

Philip Beesley is a practicing visual artist, architect, and Professor in Architecture at the University of Waterloo and Professor of Digital Design and Architecture & Urbanism at the European Graduate School. Beesley's work is widely cited in contemporary art and architecture, focused on the rapidly expanding technology and culture of responsive and interactive systems.

Beesley was educated in visual art at Queen's University, in technology at Humber College, and in architecture at the University of Toronto. He serves as the Director for the Living Architecture Systems Group, and as Director for Riverside Architectural Press. His Toronto-based practice, Philip Beesley Architect Inc., operates in partnership with the Europe-based practice Pucher Seifert and the Waterloo-based Adaptive Systems Group, and in numerous collaborations including longstanding exchanges with couture designer Iris van Herpen and futurist Rachel Armstrong. PBAI/PS combine the disciplines of professional architecture, science, engineering, and visual art. The studio's methods incorporate industrial design, digital prototyping, and mechatronics engineering. Beesley has authored and edited sixteen books and proceedings, and has appeared on the cover of Artificial Life (MIT), LEONARDO, and AD journals. Features include national CBC news, Vogue, WIRED, and a series of TED talks. His work was selected to represent Canada at the 2010 Venice Biennale for Architecture, and has received distinctions including the Prix de Rome, VIDA 11.0, FEIDAD, Azure AZ, and Architizer A+.

Rachel Armstrong

Rachel Armstrong is Professor of Experimental Architecture at the School of Architecture, Planning and Landscape, Newcastle University. She is a Rising Waters II Fellow with the Robert Rauschenberg Foundation (April-May 2016), TWOTY futurist 2015, Fellow of the British Interplanetary Society and a 2010 Senior TED Fellow. Rachel is a sustainability innovator who investigates a new approach to building materials called 'living architecture,' which suggests it is possible for our buildings to share some of the properties of living systems. She collaboratively works across disciplines to build and develop prototypes that couple the computational properties of the natural world with the productivity of soils. She calls the synthesis that occurs between these systems and their inhabitants "living" architecture. She is coordinator for the €3.2m Living Architecture project, which is an ongoing collaboration of experts from the universities of Newcastle, UK, the West of England (UWE Bristol), Trento, Italy, the Spanish National Research Council in Madrid, LIQUIFER Systems Group, Vienna, Austria and EXPLORA, Venice, Italy that began in April 2016 and runs to April 2019. It is envisioned as a next-generation, selectively programmable bioreactor that is capable of extracting valuable resources from sunlight, wastewater, and air and, in turn, generating oxygen, proteins, and biomass. Her work is contextualised in her forthcoming book "Soft Living Architecture: An alternative view of bio-informed design practice" by Bloomsbury Academic, London.

Colin Ellard

Colin Ellard is a professor of cognitive neuroscience at the University of Waterloo and the director of its Urban Realities Laboratory, where he studies wayfinding, cognition, and emotion in the built environment. He has published peer-reviewed articles in visual perception, environmental psychology, cognitive mapping, virtual reality, and neuroscience in North America and Europe and has presented his work to international audiences at conferences in the areas of cognitive science, neuroscience, environmental graphic design, architecture, and planning. Ellard is interested in how the organization and appearance of natural and built spaces affects movement, wayfinding, and physiology. His approach to these questions is strongly multidisciplinary and is informed by collaborations with architects, artists, and health professionals. His current studies include investigations of the psychology of residential design, wayfinding at the urban scale, restorative effects of exposure to natural settings, and comparative studies of defensive responses. His research methods include both field investigations and studies of human behaviour in immersive virtual environments.

Ellard provides a popular account of his work in his 2009 book You Are Here, which garnered strong praise from the New York Times, PBS, Scientific American, New Scientist, and many other print and broadcast media outlets.

Rob Gorbet

Formally trained as an electrical engineer, Rob is an interdisciplinarian, a mechatronics specialist, an award-winning teacher, and a technology artist. Rob's teaching includes courses on the profession of engineering, microcontrollers, robotics, control systems, and technology art. His engineering research involves the design of actuators made of Shape Memory Alloys (SMA), for everything from car door locks to subtle next-generation actuation systems for responsive architectural environments.

Rob is a key member of Gorbet Design, a design firm and consultancy specializing in public interactive artwork and experiences, and also collaborates with other designers, artists, and architects. As a Professional Engineer and Associate Professor, Rob Gorbet chairs an innovative integrative curriculum development and technical research program in computation and mechatronics at the Centre for Knowledge Integration, University of Waterloo. An award winning teacher and artist, Gorbet's unique interdisciplinary expertise includes knowledge integration, mechatronics, and complex interactive systems. Gorbet leads the Knowledge Integration and Pedagogy research stream in developing conceptual paradigms, curriculum models, and design methods.

Dana Kulić

Dana Kulić received the combined B.A.Sc. and M.Eng. degrees in electro-mechanical engineering and the Ph.D. degree in mechanical engineering from the University of British Columbia, Vancouver, Canada, in 1998 and 2005, respectively. From 1997 to 2002, she worked as a systems engineer designing fuel cell systems with Ballard Power Systems, and developing operational control software for the CanadaArm II at MacDonald Dettwiler.

From 2002 to 2006, Dr. Kulić worked with Dr. Elizabeth Croft as a Ph.D. student and a post–doctoral researcher at the CARIS Lab at the University of British Columbia. The aim of this work was to develop a human–robot interaction strategy to ensure the safety of the human participant. From 2006 to 2009, Dr. Kulić was a JSPS Post–doctoral Fellow and a Project Assistant Professor at the Nakamura-Yamane Laboratory at the University of Tokyo, Japan. The aim of her research was to develop algorithms for incremental learning of human motion patterns for humanoid robots.

Dr. Kulić is currently an Assistant Professor at the Electrical and Computer Engineering Department at the University of Waterloo. Her research interests include robot learning, humanoid robots, human–robot interaction and mechatronics.

J.D. Talasek

J.D. Talasek is the director of Cultural Programs of the National Academy of Sciences (CPNAS), Washington, D.C., which is focused on the exploration of the intersections between science, medicine, technology, and visual culture. Talasek is the creator and moderator for a regular salon called DASER (DC Art Science Evening Rendezvous) held at the NAS and he organizes a similar salon in Austin, Texas (ATX LASER). Additionally, Talasek serves on the Contemporary Art and Science Committee (CASC) at the Smithsonian's National Museum of Natural History. He is the art advisor for Issues in Science and Technology Magazine and is currently the Art and Design Advisor for the 2015 NAKFI Conference scheduled for November 2015 in Irvine, CA. Talasek is chair elect 2016 for Leonardo's Art Education Forum.

He was the creator and organizer of two international on-line symposia on Visual Culture and Bioscience (2007) and Visual Culture and Evolution (2010). He has taught at the University of Delaware and Essex and Howard Community Colleges. Talasek has curated several exhibitions at the National Academy of Sciences, including: Imagining Deep Time; Visionary Anatomies; Absorption + Transmission: Work by Mike and Doug Starn; and Cycloids: Paintings by Michael Schultheis. At the University of Delaware, he organized and curated Observations in an Occupied Wilderness: Photographs by Terry Falke and LightBox: The Visual AIDS Archive Project. He holds a B.S. in photography from East Texas State University, an M.F.A. in studio arts from the University of Delaware, and an M.A. in museum studies from the University of Leicester.

Project Credits

Lead Collaborators

Philip Beesley, *Director LASG, Waterloo Architecture/PBAI*
Rachel Armstrong, *Experimental Architecture, Newcastle University*
Colin Ellard, *Faculty of Psychology, University of Waterloo*
Rob Gorbet, *Knowledge Integration, University of Waterloo*
Dana Kulić, *Adaptive Systems Group, University of Waterloo*

Living Architecture Systems Group/ PBAI Core Team

Matthew Chan, Electronics
Michael Formusa, Production
Mike Hu, Design
Mon Josef, Electronics
David Kadish, Electronics
Salvador Miranda, Production
Clara Montgomery, Production
Anne Paxton, Production
Thomas Noussis, Design
Jordan Prosser, Lead Design
Siubhan Taylor, Design

Sponsors

Cultural Programs of the National Academy of Sciences
National Academies Keck Futures Initiative
Ralph J. and Carol M. Cicerone
Ontario Arts Council
Social Sciences and Humanities Research Council
University of Waterloo
Catholic University of America School of Architecture and Planning
Virginia Tech School of Architecture + Design

Construction

LASG/PBAI Studio

Matthew Chan
Mike Hu
David Kadish
Thomas Noussis
Jordan Prosser

Production

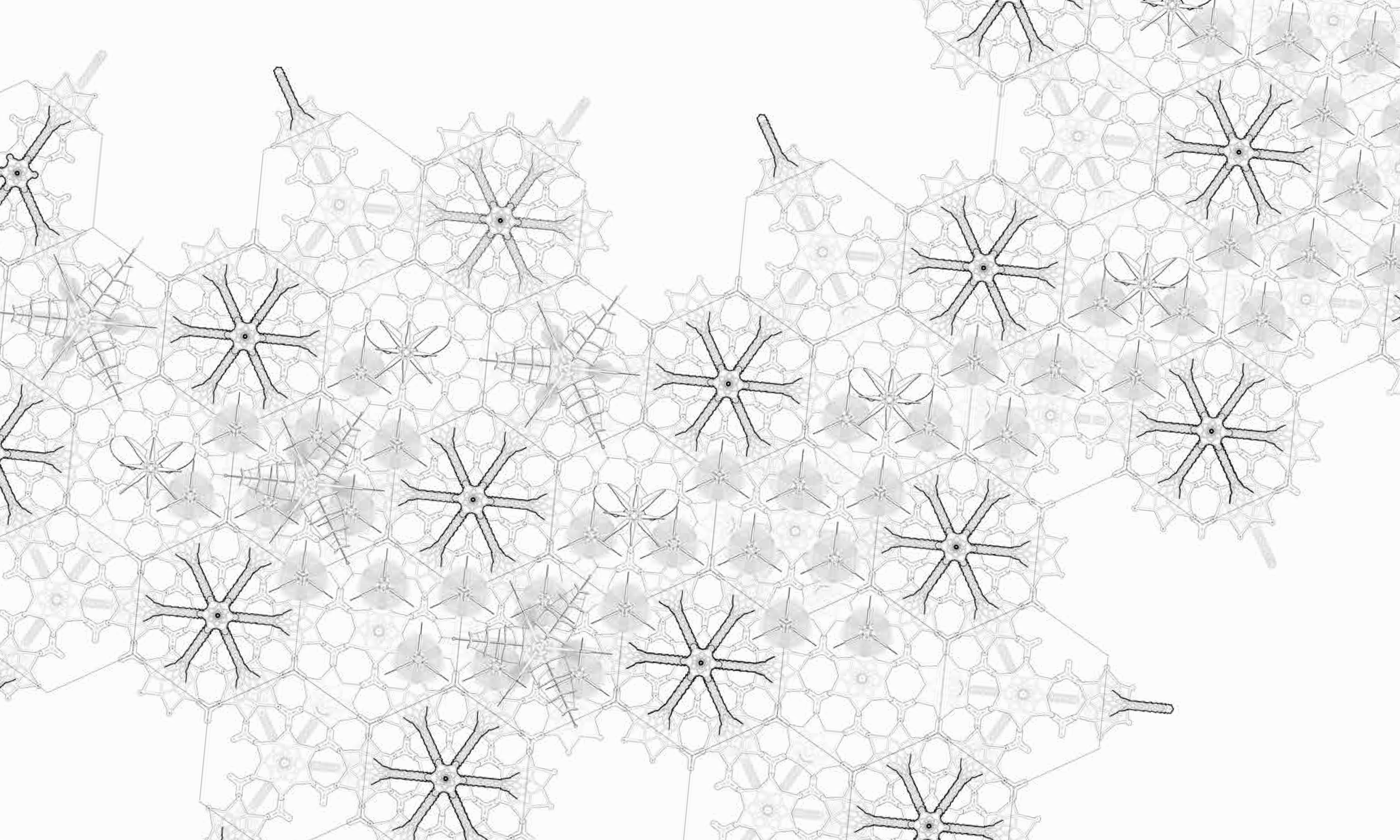
Ernestine Aying
Aishwarya Babu
Gill Baldwin
Clementine Bory
Anna Boyko
Miranda Corcoran
Sheldon DiCarmine
Supreetha Guntur
Darren Hynes
Wyran Jeong
Anna Kolesnikova
Olayide Madamidola
Francis Norman May
Shevaun Mistry
Jennifer van Overbeeke
Petar Pilipovic
Barbara Romo
Mardela Silam
Hagop Terzian
Dettia Tunga
Robin Whitteker
Jason Wong
William Yam
Zhan Zhang

Image and Illustration Credits

All images ©LASG/PBAI unless otherwise indicated

Publication Credits

Philip Beesley
Gabby Bevilacqua
Jessica Chen
Alice Choupeaux
Farzaneh Victoria Fard
Carolina Garcia
Amir Ghazanfari
Maxime Gordon
Sascha Hastings
Mike Hu
Joey Jacobson
Nicole Jazwiec
Salvador Miranda
Reza Nik
Jordan Prosser
Severyn Romanskyy
Matthew Spremulli
Ala Roushan



Sentient Chamber

National Academy of Sciences • Living Architecture Systems Group

This book documents the Sentient Chamber installation at the National Academy of Sciences, Washington. November 2, 2015–May 31, 2016

Sentient Chamber is an interactive installation exploring a revolutionary new kind of building, raising fundamental questions about how architecture might behave in the future. Might future buildings begin to know and care about us? Might they start to become alive?

The installation is composed of towering transparent acrylic arches and flexible silicon, creating quilt-like patterns. Custom glasswork vessels and translucent filtering elements expand the skeleton to form hovering surfaces that interplay with shadow and light. Distributed sensors throughout the chamber are programmed with algorithms that mimic curiosity, giving Sentient Chamber the power to sense and perceive, reacting to the presence of visitors with delicate waves of light and soft murmuring sounds.

Sentient Chamber was created by a multidisciplinary group of architects, engineers, scientists, and artists from Canada, the U.S., and Europe working within the Living Architecture Systems Group, led by Philip Beesley, University of Waterloo. The exhibition was organized by Cultural Programs of the National Academy of Sciences (CPNAS) and the National Academies Keck Futures Initiative (NAKFI). Essays, technical working drawings, and photographs of the complete installation and the process of construction are included.

ISBN 978-1-988366-05-0

9 781988 366050

Riverside Architectural Press