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Lifting the Veil

Visualizing Sentient Architecture

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***Abstract*—Increasingly, our everyday environments become more and more connected and "smart". Intelligent Interactive Systems (IIS) is an umbrella term to describe environments that are characterized by their ability to process data and generate responsive behavior using sensors, actuators, and microprocessors. Sentient Architecture generates an artful, imaginative, and engaging environment in which we can experiment with and observe human behavior and capabilities when confronted with IIS. This paper outlines a user study to test the value of a 3D augmented reality visualization which shows data flows and burst of activity in a Sentient Architecture sculpture named "Sentient Veil" in Boston, MA. Hence, our visualization is fittingly titled *Lifting the Veil*.**

Keywords—Intelligent interactive systems; engineering; information visualization; microprocessor; 3D; Internet of Things; mobile applications

I. Motivations and Aims

As the built environment becomes increasingly more complex and integrated with new technologies—including the emerging Internet of Things (IoT)—there is an urgent need to understand how embedded technologies affect the experience of individuals that inhabit these spaces and how these technologies can be most appropriately used to improve occupant experience, comfort, and well-being. In addition, the IoT provides an opportunity as well as a challenge when it comes to helping users understand how these intelligent systems gather and process information such as sensor data and how data processing results are used to drive different types of actuators.

By visualizing data streams from Sentient Architecture projects, we aim to help system architects, designers, and general audiences understand the inner workings of tightly coupled sensor-actuator systems that interlink machine and human intelligence. Our research effort aims to empower many to master basic concepts related to the operation and design of complex dynamical systems and the IoT. Specifically, we use architectural blueprints of Sentient Architecture installations together with real-time data streams to generate 3D model-aided visualizations of the operation of Sentient Architecture installations in order to improve the data visualization literacy (DVL) of visitors. These visualizations detail how sensory system input (collected via movement sensors) is processed by control circuits and used to control an array of actuators (sound, light, kinetic) within the Sentient Architecture.

The collaboration between the Cyberinfrastructure for Network Science Center (CNS) in the School of Informatics, Computing, and Engineering (SICE) at Indiana University and the Living Architecture Systems Group (LASG) as well as Philip Beesley & team from Philip Beesley Architect Inc. (PBAI) involves developing applications based on augmented-reality (AR) and other immersive media to enhance visitors' (and, some day, designers') understanding of the sculpture they interact with (or plan, design, and build). Using CNS' vast amount of expertise with data analysis and visualization as well as curation, and leveraging the efforts of PBAI and LASG to prototype, promote, and research Sentient Architecture, *Lifting the Veil* is a pioneer project for both teams. The goal is to create and test an app that helps visitors understand the internal state of the Sentient Veil sculpture, on display at the Isabella Stewart Gardner Museum in Boston, MA.

II. Prior Work

Information visualization is an established, interdisciplinary scientific field, connecting computer science, information science, informatics, data science, media studies, and psychology [6]. Its focus lies on the relationship between information, represented in qualitative and/or quantitative data, and graphic symbols. In [1], author lays out an information visualization framework that maps data to graphic variables and graphic symbols. For example, a qualitative (categorical) data variable can be encoded by the shape or color hue of a graphic symbol, whereas quantitative data such as height can be encoded by the area size or color saturation of a graphic symbol type (e.g., line, area, volume, etc.). The framework can be used to (de-)construct information visualizations systematically; it is also used to develop a visual language for the *Lifting the Veil* project. It should be noted that there are entries in the framework which are intentionally left blank to encourage further research, e.g., texture or stereoscopic depth could be but are rarely used to encode data, and thus little is known about the effectiveness of different texture or depth encodings. Plus, some graphic variables, e.g., speed or rhythm, cannot (or only hardly) be used in static, 2-dimensional visualizations for which the framework was primarily developed. Those variables offer a fertile ground for an extension of the framework. Integrating time-based, 3D, interactive, and real-time information visualizations into the framework is exactly the kind of theoretical contribution our research aims to make. The experimental framework applied to this project leverages the visualization development from prior research on Macroscopes [3]. These are setups that deploy interactive data visualizations on big-screen kiosks in museums, libraries, and other public spaces to engage the public with big data. Further research into the topic of data visualization literacy (DVL) is necessary to connect existing research on information visualization to visual perception and cognitive processing abilities of humans. Previous work has been done with regards to defining and measuring DVL [2], [5], [10]. In terms of how to use visualizations for learning, [8] and [9] detail user investigating methods to empower users to gain insights from visualizations. [8] is more focused on a special user group (young soccer players), supporting their understanding of their own performance on the field. [9] compares tutorials with various types of visualizations, finding that those presented with an interactive tutorial had a richer experience than those who did not.

III. Methods

The Sentient Veil (see Fig. 1, more photos in the Appendix) is a Sentient Architecture, creating an interactive environment for visitors of the Gardner Museum to explore. It is an array of 15 cells, organized in a grid of 3 x 5 (see Fig. 9 for a schematic drawing). Each cell contains an infrared (IR) sensor, a speaker (see Fig. 5), and a chain of LEDs (see Fig. 1, 2 and 5). Throughout the sculpture, vials (see Fig. 6) containing chemical fluids react to environmental temperature, and enable play with light. Using differently colored fluids, the designers of the sculpture create a landscape of colors (see Fig. 7 and 8). Each collection of 3 cells are locally controlled by a Teensy microcontroller as a control node. The central unit, computationally spoken, of the Sentient Veil is a Raspberry Pi that governs global actuation (i.e., light and sound emissions) within the sculpture. By using its LEDs and speakers in such a way, it reacts to movement with sounds and lights, creating a near-living environment, brought to life through the aforementioned technological organs, i.e., sensors, controllers, actuators. The Sentient Veil is able to detect movement through its IR sensors; once a given sensor is triggered through proximity of a foreign object (such as a head or a hand), the cells of the Sentient Veil emit light and sound according to an algorithm implemented in the Raspberry Pi that computes the actuation propagation for each triggered sensor. As the sculpture attracts the attention of many visitors, it is a perfect user study environment to test new visual languages that operate in highly dynamic, data-driven surroundings.

A. *Lifting the Veil App*

In order to prototype advanced 3D visualizations and to develop a visual language for the data flow in intelligent interactive systems, *Lifting the Veil* features a 3D model of the Sentient Veil and animations of data flow within the sculpture (see Fig. 3). We chose the name *Lifting the Veil* to emphasize its essential feature: to enable humans to see what is otherwise hidden behind the black box-like curtain of technology. The app features a full-screen view of a digital model of the Sentient Veil, seen from roughly the vantage point one would have if one were standing under the sculpture. Through UDP (User Datagram Protocol), the Raspberry Pi controlling the microprocessors in the sculpture sends string messages to the app, which parses them and initiates animations illustrating the data flow within the sculpture. The app implements an early version of a new visual language for IIS, where the *structure*, *dynamics*, and *state* represent three interconnected visual domains.

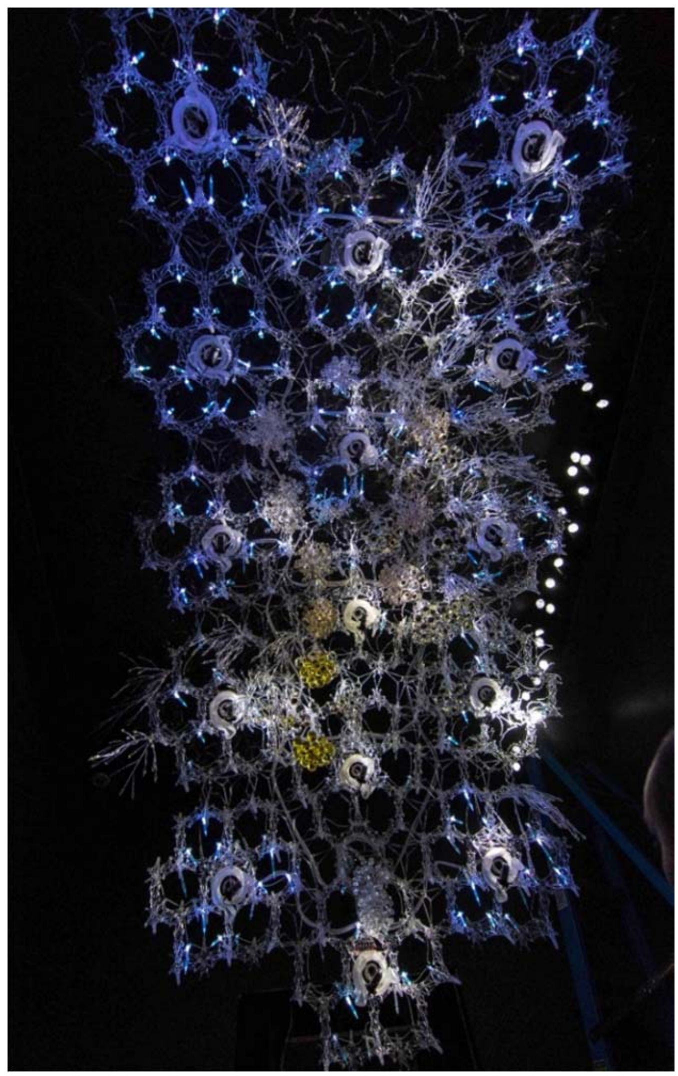

Fig. 1. Sentient Veil at Isabella Stewart Gardner Museum, Boston (MA): the sculpture as seen from the floor (see 3D model in Fig. 3 & 4).

Fig. 2. Two speakers and two arrays of LEDs (so-called “cells”).

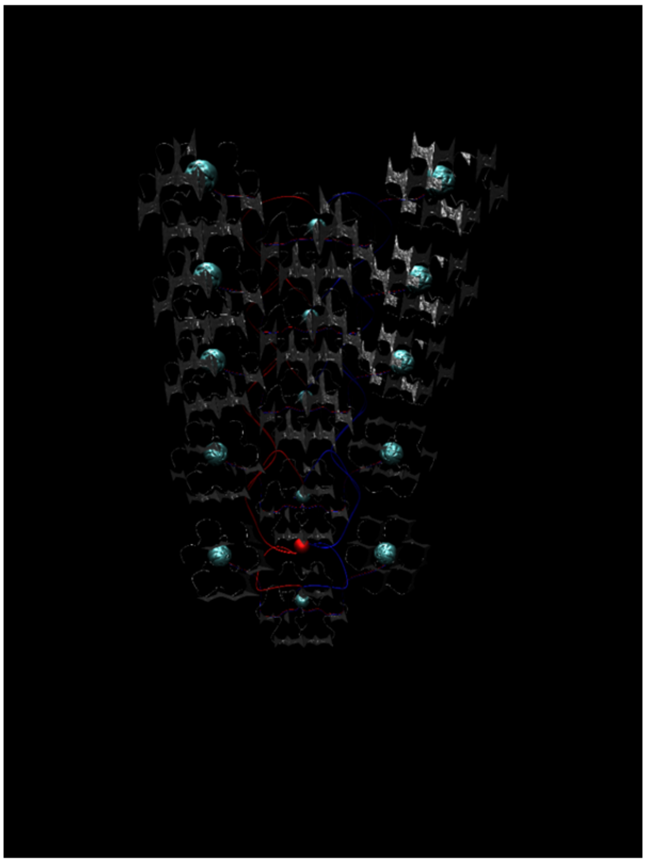

Fig. 3. Lifting the Veil in idle mode.

Structure refers to the physical parts and their position in space; for example, in Fig. 3, the 15 green spheres symbolize the device-modules through which the Sentient Veil senses its environment and actuates LED lights and speakers in response. Each green sphere represents a speaker, an IR sensor, and a device module that receives instructions from the Raspberry Pi (in red) on when to let current flow towards which actuator, depending on IR sensor input. This *structure* is rigid, and can be seen as a base map onto which information is later projected. Note that the 3D model representing the *structure* of the Veil is simplified with regards to the complexity of the physical sculpture (meaning some information has been removed), while other information has been added visually. For example, the Raspberry Pi is colored red, similar to a heart in a drawing of a human body. Also, note the blue and red colors of the communication and power cables (left and right, respectively).

Dynamics denotes the domain where the user sees the sculpture in action. Here, animations are played based on data input from the physical sculpture. *Dynamics* are invisible to the naked eye which is why this visualization project aims to illuminate these hidden processes. While actuation is perceivable by humans, current flows and data transmission are not. To implement this domain, simple animations are added to *Lifting the Veil* (see Fig. 3 and 4).

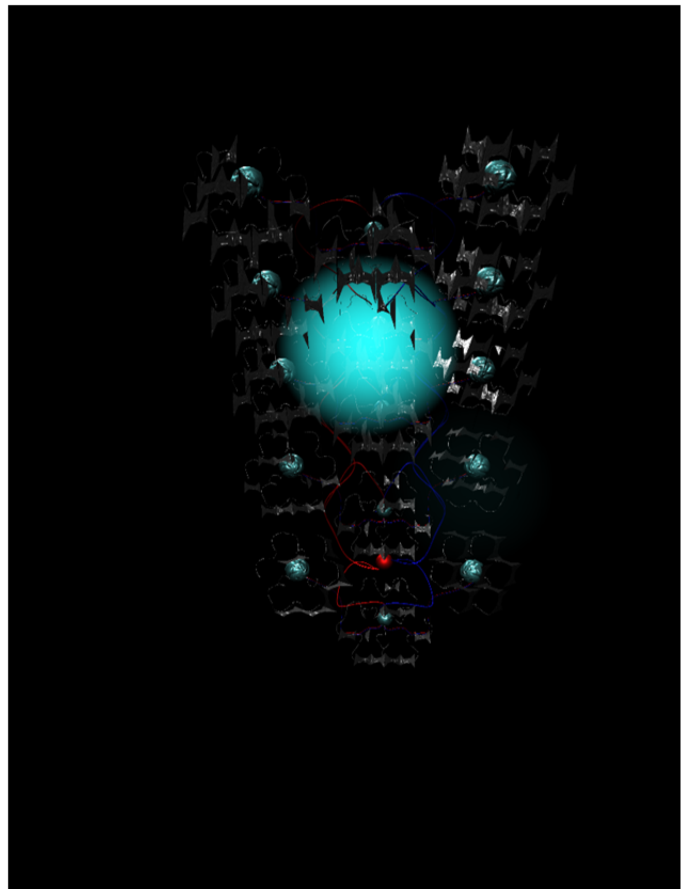

Fig. 4. Lifting the Veil playing a triggered animation.

Finally, *state* denotes a domain that has not been implemented in *Lifting the Veil*, but will be increasingly important going forward with this research and development project. *State* is conceived as the domain where we visually encode bursts of activity, distributions, and other forms of properties of aggregated data. Whether this will be visualized using standard data visualization methods (such as histograms and time series), or less accurate but more engaging ones (such as particle effects), or both, will yet have to be decided.

The user study outlined in the following paragraphs will aim to help us going forward in developing this young visual language, and will hopefully provide a plethora of data to check what kind of animations can be used to visualize the data flow within the Sentient Veil, or any IIS for that matter.

B. *User Study*

With the Gardner Museum being a prime environment for user studies, user studies could be conducted on-site. The goal is to collect both quantitative and qualitative data about visitors' understanding of the sculpture, their abilities to conceptualize its inner working, and to capture general impressions and feedback for the R&D that goes into *Lifting the Veil*. [7] details a user study previously conducted in a studio setup with elements that make up sculptures like the Sentient Veil. We aim to design a study that is to be performed in a public space.

1) *Research Design*

There will be two groups: control and treatment. Both groups will have time to interact with the sculpture, yet unknowing of the fact that they will be asked to participate in a study. After visitors have spent some time inspecting the Sentient Veil, they will be approached. Members of the control group will be asked to fill out a questionnaire (Q1, see 2) Data Collection). This will conclude their involvement. Members of the treatment group will first have the opportunity to interact with *Lifting the Veil*, and then be given an extended questionnaire (Q2), containing a section with questions about the app. Our goal is to see whether we can detect significant differences between the two groups to quantify the influence of *Lifting the Veil* on visitors' understanding of the sculpture. Our null hypothesis is that there is no significant difference in scores/answers on the questionnaire between the two groups, and the alternate hypothesis claims that there is.

2) *Data Collection*

Along with the study information sheet that features information pertaining to informed consent, there are three data collection tools to be used in this user study: the *Lifting the Veil* app and two questionnaires (Q1 and Q2, one for each group). *Lifting the Veil*, as stated previously, will only be used by the treatment group. Q1 and Q2 are similar in most regards, such as questions pertaining to the participant's interest in art, science, and math, their prior exposure to IIS (such as Amazon Echo, Google Home, etc.), as well as demographic information.

The portion of Q1 and Q2 that are the same for both groups aims to collect quantitative and qualitative data about the visitors' understanding of the *structure* and *dynamics* of the sculpture. For example, questions such as "Describe the physical parts of the sculpture" and "Draw a schematic of the electrical parts within the sculpture", through their open-ended nature, will yield data that will be harder to compare between participants than questions with right-or-wrong answers. However, we expect that because of the treatment group's exposure to *Lifting the Veil*, we will see a more complete understanding of the data flow in the sculpture on the part of the treatment group. Also, it is probable that more details will be perceived by these participants. Quantitative questions will be assigned simple scores. For example, the questions "How does the sculpture sense you?" or "How many arrays of LED lights are there?" each has one answer that is right: through (IR, or proximity) sensors, and 15. Participants should be able to figure out the answer through interaction with the sculpture; however, we expect that those who have used *Lifting the Veil* in addition to exploring the sculpture will be able to put down the correct answer more often and/or more accurately or both. It is important to note that we will not time participants.

In order to capture feedback about *Lifting the Veil*, we will include a portion in Q2 (treatment group) that will feature open-ended questions and Likert-scale items about *Lifting the Veil* itself rather than the Sentient Veil. For example, we will ask "How did you like using *Lifting the Veil*?" or "On a scale from -2 (not user-friendly at all) to +2 (very user-friendly), how would you rate the *Lifting the Veil* app you just used?". It might also be enlightening to gather data about the participant's media literacy and habits, such as "Compared to apps you use in your daily life, on a scale from -2 (not user-friendly at all) to +2 (very user-friendly), how would you rate the *Lifting the Veil* app you just used?" Then we could compare the answers to these questions for each participant.

Eventually, we hope to collect a mixed-method data set to inform the further development of *Lifting the Veil* and other IIS visualization applications.

3) *Recruitment*

Visitors in the museum space that have had time to interact with the Sentient Veil will be approached and asked to participate. In order to guarantee randomness, focal sampling will be used to make sure no bias in selection is occurring. This process will be analogous to previous work in museum settings [4]. If the prospective participant is not of age, he or she will be asked if a guardian is present. If not, he or she will not be further asked to participate. If agreeing to participate, a study information sheet will be handed to the subject, outlining the intent of the user study and the administrative background information that is typical for a study information sheet (such as IRB number, risks and benefits, and assurance of confidentiality). Additionally, the subject will read about the estimated duration of the experiment (this information will also be provided when the participant is first contacted). Then, if belonging to the control group, the participant will be handed Q1, and will be given as much time as needed to complete the questionnaire. If belonging to the treatment group, the participant will be handed a tablet running *Lifting the Veil*, and asked to explore the sculpture with the help of the app. A short oral introduction to the app will be provided by the data collector. Then, after sufficient time to use *Lifting the Veil* has been provided (probably around 3-5 minutes), Q2 will be handed to the participant, with a request for completion.

Participants will be encouraged to ask questions should they arise.

4) *Challenges*

There are two challenges for this user study: The first one is ubiquitous in user studies, and the second one is specific to a user study in a public space.

a) *Previous exposure to IIS*

If a person (let us assume she is an engineer working on autonomously driving cars) is part of the treatment group and provides mostly correct answers to the questions, it will be hard to tell whether she answered IIS-specific questions right because of her professional experience or because of *Lifting* *the Veil.* To minimize the risk of confounding variables, we include a question at the beginning of both questionnaires to inquire about previous exposure to IIS. This challenge is typical for user studies.

b) Influence of public environment

The Gardner Museum is a highly-frequented venue, and the space which is inhabited by the Sentient Veil is relatively small compared to the size of the sculpture. While there are three doors that allow visitors to enter the room, traffic through these doors to the adjacent spaces (a small room with paintings and access control through a guard, an open hallway, and a bigger room also featuring paintings) can be quite congested. This poses a challenge when it comes to creating a somewhat separated space needed for communication with the participant, and can also expose the participant to an increased risk of performance anxiety.

5) Subjects Risks and Benefits

In order to address the problem of performance anxiety outlined in the previous paragraph, subjects will be assured that they can withdraw anytime, without any ramifications whatsoever. Also, in order to facilitate the normal business of the museum, and to ensure minimum interference with the visitors' enjoyment of the sculpture, subjects will not be asked to join more than once. To protect people that are not of age, people under 18 will need parental/guardian consent to participate. In order to further reduce performance anxiety and to prevent false assumptions of duty on the side of the participants, subjects will be reminded that participation is voluntary.

IV. Future Work

The data-driven environments that take over our connected world in an increasing manner only change the way we live our every-day lives, which already creates a new need for IIS-related research projects. IIS provide a highly fertile ground for science of the interdisciplinary kind, as can be seen in this specific research project. Drawing on the data we hope to gather from this study, we hope to develop improved and more refined 3D data visualizations and applications for various IIS in a diverse set of environments. For example, we hope to also lift the veil for Sentient Architecture sculptures in spaces such as malls and university buildings. We would like to develop and implement visual languages for smart homes. There are so many possibilities, and we are excited to see the first data come in very soon to keep working on this cutting-edge research of how we engage with the systems that will guide an ever-larger portion of our lives.

V. Summary

While the challenges of this user study are rather common, the research domain itself is radically interdisciplinary and novel. It will be an essential first step to gather valuable user feedback for *Lifting the Veil* to further develop a visual language to visualize the data flow in IIS.

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Image Sources

All pictures are from the one of the following sources unless marked otherwise:

Sentient Veil, 2017, Isabella Stewart Gardner Museum, Boston, MA. Photography by Andreas Bueckle.

Lifting the Veil App by Andreas Bueckle.

APPENDIX

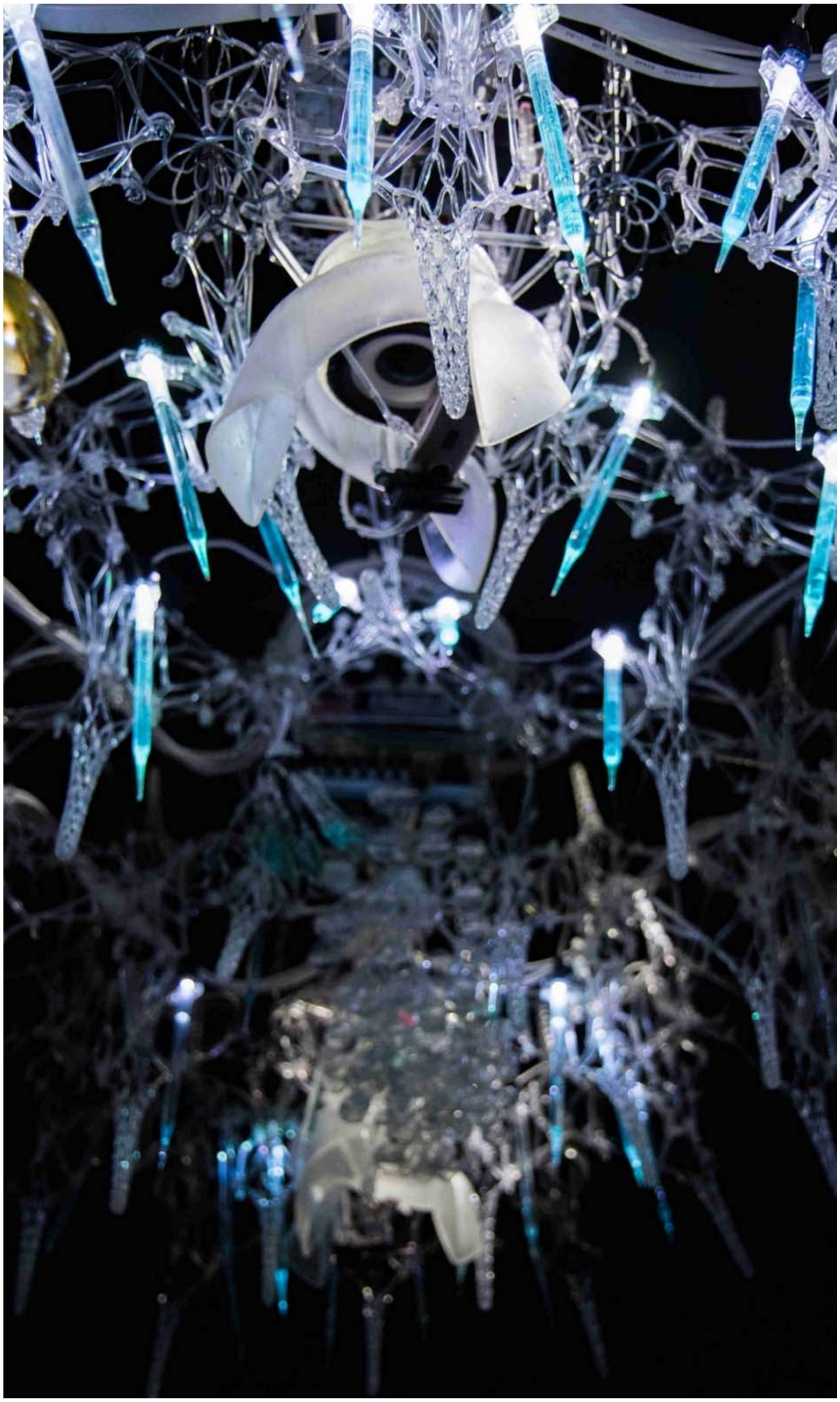

Fig. 5. Close-up of a speaker surrounded by a chain of LEDs.

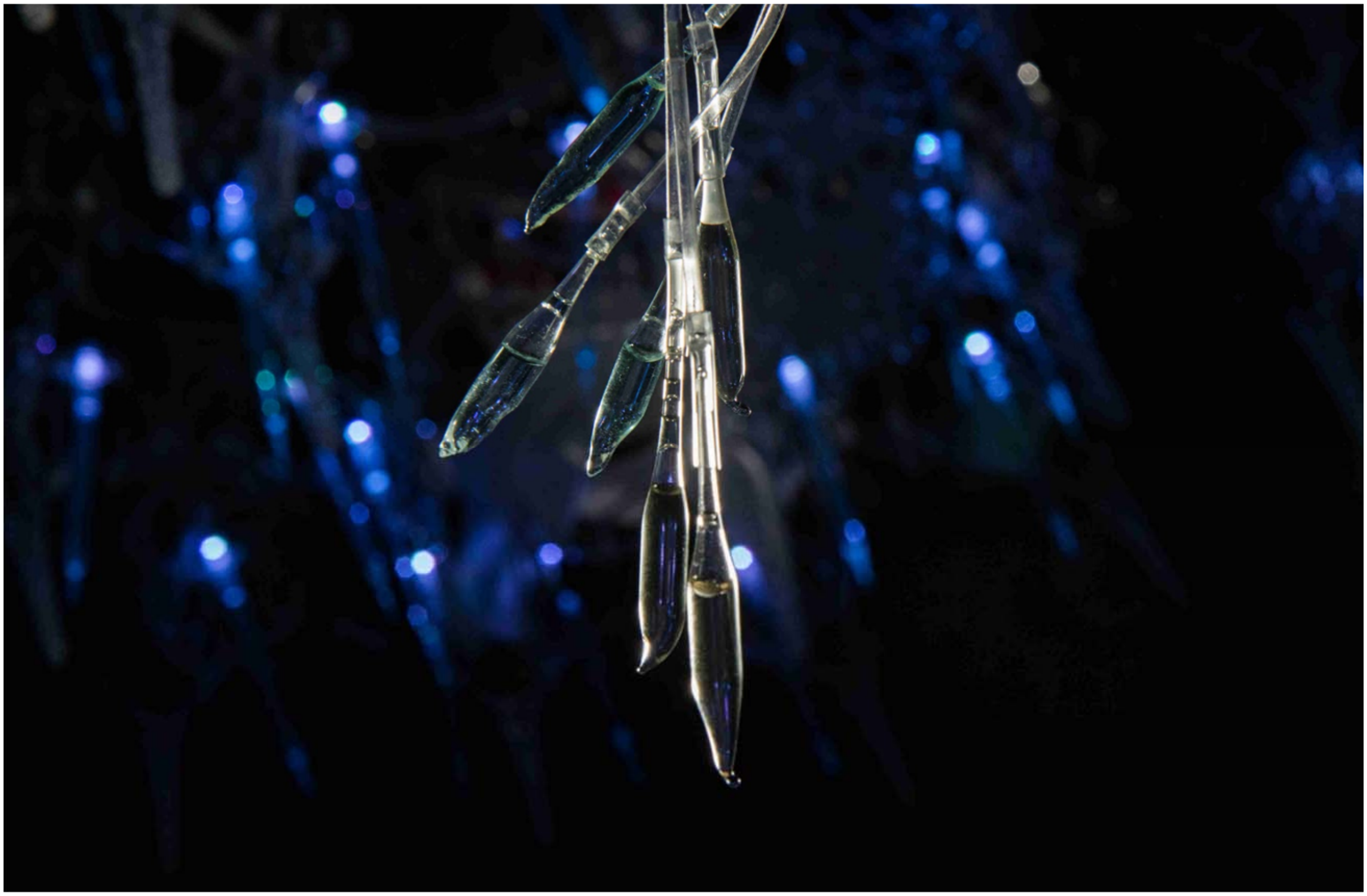

Fig. 6. Detail shot of vials with fluid.

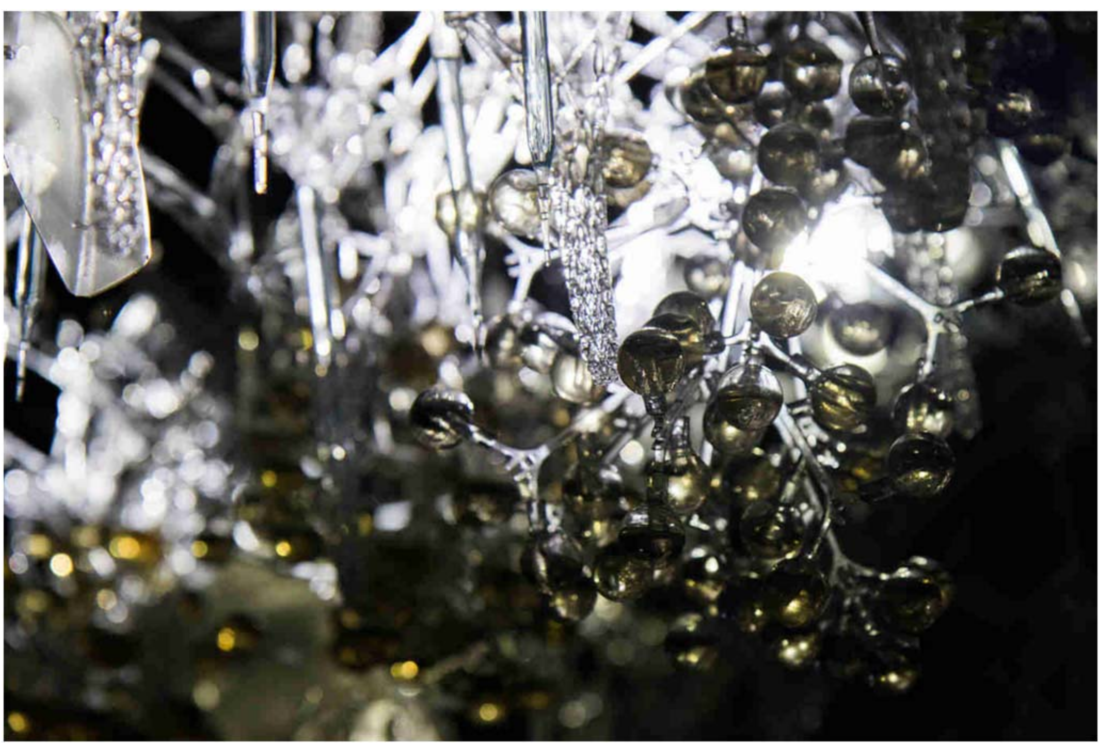

Fig. 7. Round vials in the shape of alveoli.

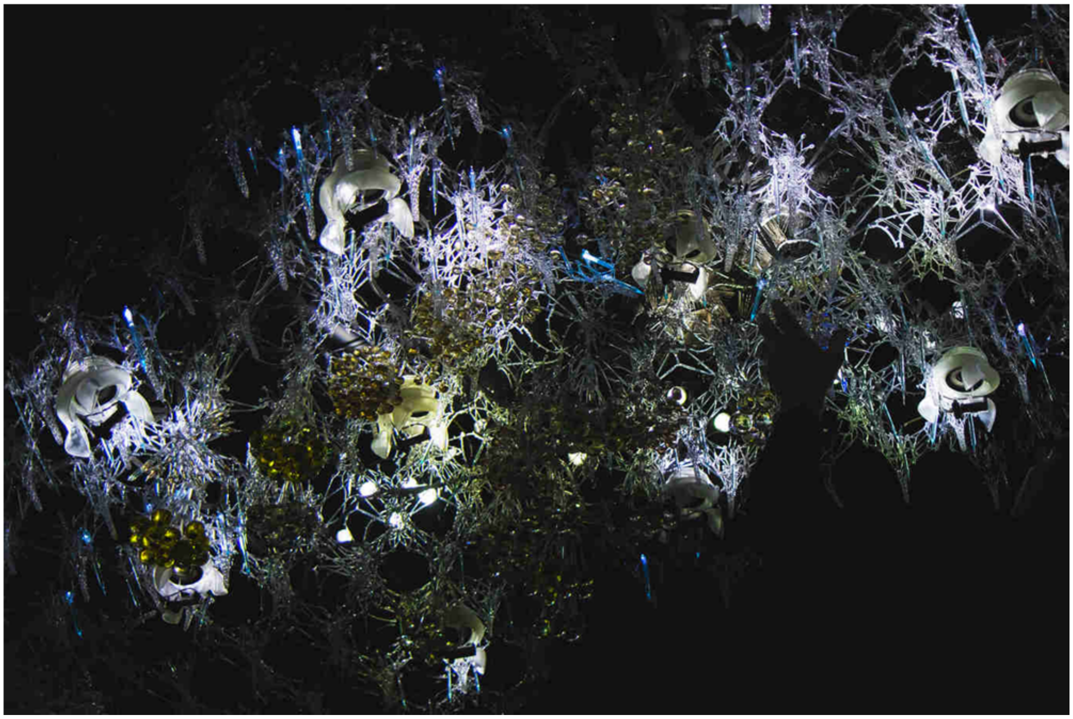

Fig. 8. Wide-angle shot of the entire Sentient Veil sculpture as seen from below.

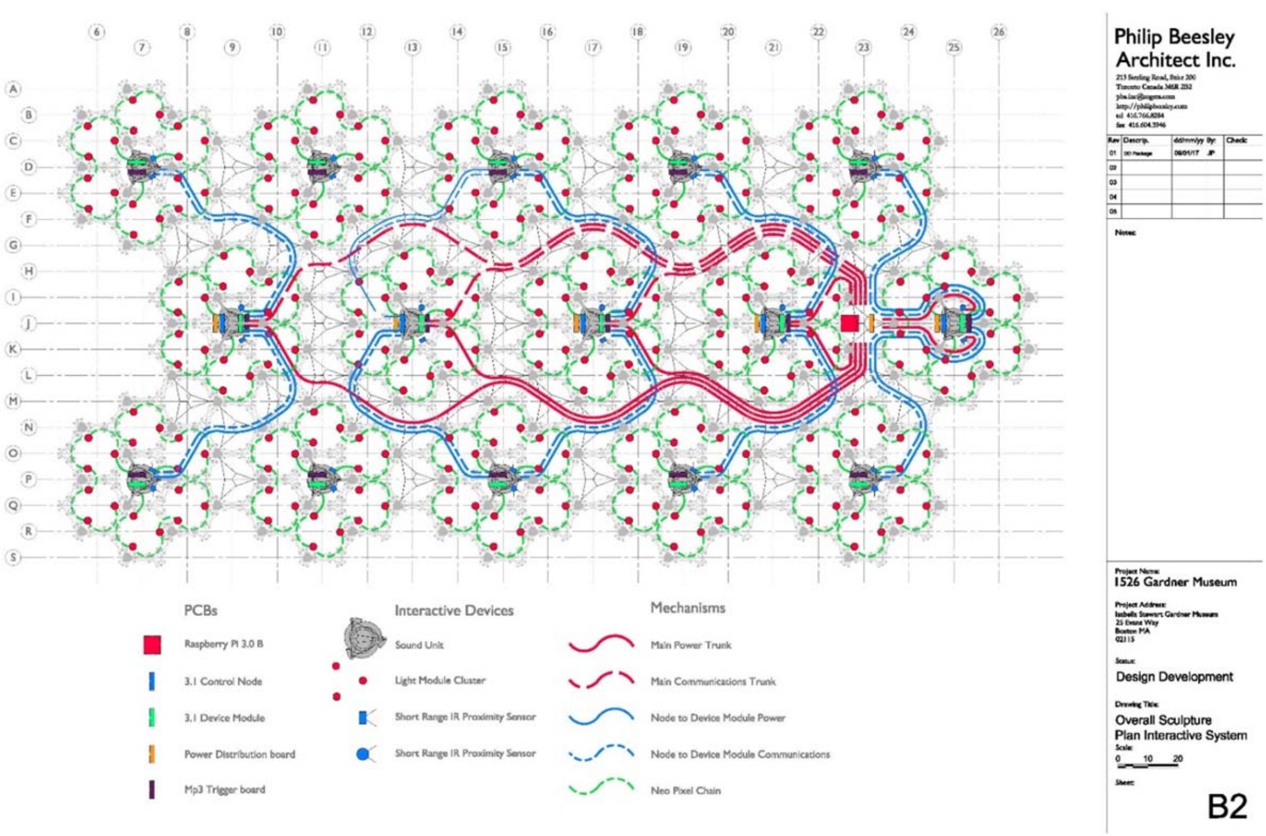

Fig. 9. A schematic drawing of the Sentient Veil.