Light Harvest: An Interactive Sculptural Installation based on Folding and Mapping Proteins

Light Harvest is an interactive sculptural installation that explores a protein called Light-Harvesting Complex II (LHCII) in the realm of materials, digital fabrication, projection mapping and interaction design. This article gives an account of the making of Light Harvest, a collaboration between an artist/designer, a structural biologist, and an interaction design technologist. The artistic concepts in material construction and digital techniques are drawn from protein folding, sophisticated mapping processes in protein X-ray crystallography, and the remarkable abilities of LHCI proteins to convert full-spectrum visible sunlight to useful energy for life. Through its interactive installation, Light Harvest engages us in an appreciation and understanding of the biological processes studied and the scientific techniques used to study them.

Keywords: protein sculpture, X-Ray crystallography, projection mapping, interaction design, paper folding, Kinect, Processing

1. Introduction

In 1951 György Kepes organized a pioneer exhibition titled "The New Landscape" at MIT, showcasing a new visual world revealed by the science and technology of the time through macro, computer images, micro photographs, and artistic reproductions. As he later wrote: "Modern physics and non-Euclidian geometry describe reality with far more subtlety and power. Interrelationships are now seen to be far more complex than we ever imagined before modern instruments allowed us to push back the limits of the very far, the very big, the very small. Behind our technical refinement is the refinement of our capacity for observing relationships in nature (Kepes 1956).” It was not until a few years later, after Kepes’s exhibition, that the world saw its first protein structure (Kendrew et al. 1958). Since then, many scientists and artists have experimented with new ways of making protein sculptures. Early protein models include Kendrew’s Ball and Spoke model (Francoeur 2017) and Byron’s Bender model (Martz and Francoeur 2017). More recently, the art of protein sculpture has been pushed further by several contemporary artists. The term “Protein Sculpture”, was most likely coined by artist Julian Voss-Andreae (Voss-Andreae 2005), the most prolific sculptor of protein structures. Artists Bathsheba Grossman (Grossman 2018) also experimented with protein sculpture. Most recently, 3D printing and other digital fabrication techniques, as well as the Protein Data Bank (https://www.rcsb.org/), have allowed artists to build physical models of proteins rapidly and accurately.

Proteins are large molecular chains with hundreds to thousands of atoms that adopt unique and perfect 3D structures through a unique self-folding process, placing chemical groups in just the right places to catalyze and build cellar functions. The process by which the atoms in a protein find their correct location to fold has fascinated structure biologists for decades, as how a protein folds and unfolds has important implications in medicine. Structural biologists use X-ray crystallography (Rupp 2010) to map the folded 3D structures of proteins through complex data collection, analysis and interpretation processes. X-ray crystallography allows the generation of very high resolution images of the molecules of life. To record high resolution X-ray diffraction images of protein crystals (Figure 1), large circular particle accelerators, synchrotrons, are used. A synchrotron emits high energy X-rays that are used to shoot protein crystals and record their diffraction images for subsequent structure determination. To study a protein folded 3D structure, hundreds of X-ray diffraction images must be collected. A typical X-ray diffraction pattern often has thousands of spots corresponding to electron locations of atoms in a protein, and each of these spots must be measured and mapped using mathematical and computational tools to calculate a protein's electron density map (Figure 2). These maps are then used to determine the 3D coordinates of each atom's positions in a given folded protein structure.

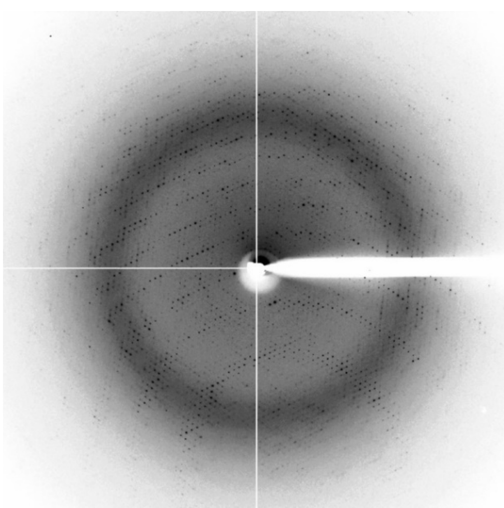

Figure 1: An X-ray diffraction image of LHCII crystallized in space group C2. Each diffraction spot is used in data analysis for structure determination (© Dr. Werner Kühlbrandt. Source: https://www.ncbi.nlm.nih.gov/pubmed/15719016)

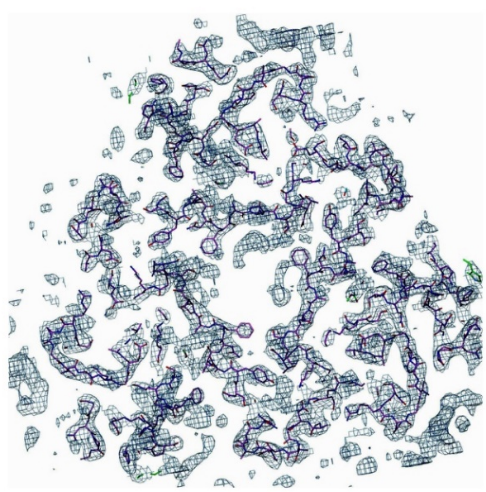

Figure 2: An X-ray diffraction image of LHCII crystallized in space group C2. Each diffraction spot is used in data analysis for structure determination (© Dr. Werner Kühlbrandt. Source: https://www.ncbi.nlm.nih.gov/pubmed/15719016)

The subject of the Light Harvest installation is a protein called Light-Harvesting Complex II (LHCII). LHCII is a vital component in the photosynthesis structures of plants and some micro-organisms that use bundled sunlight to pass it along at the correct energy to the photosystem that then together with water converts the energy harvested from the sunlight into chemical energy – sugar molecules. The fixation of atmospheric carbon dioxide by LHCII and the photosystem to generate sugar molecules together with the bi-product of this reaction, oxygen, places these proteins as the crucial players in providing the basis for life on our planet. For many years, scientists and engineers have been trying to create an artificial versions of LHCII as it presents the promise of using it as a green and renewable energy source (Chen et al. 2018). While LHCII can be assembled in a test tube and can self-organize and self-fold itself into the right form, scientists are still working on understanding LHCII in order to develop more effective solar cells in the future.

Light Harvest, an interactive sculptural installation, is a larger-than-life gallery version of LHCII that aims to draw the general public's attention to the remarkable abilities of its laboratory counterpart. While previous protein sculptures (Martz and Francoeur 2017, Grossman 2018, Voss-Andreae 2005) focused on replicating the forms of protein as object-like sculptures, Light Harvest (Figure 3), an interactive sculpture with digitally projected light, creates an experience that draws us in, transports us to the worlds of the macromolecular, and engages us in appreciating and understanding the biological processes found in the nature.

Figure 3. Light Harvest v1. Mixed media. 5’6”(W) X7’(L) X9’(H). 2016. (© Jiangmei Wu. Photo: Kyle Overton.)

2. Light Harvest Installation

Light Harvest, likes its name-sake, celebrates the remarkable light harvesting ability of LHCI proteins through an intricate display of interactive light. The artistic concepts in material construction and digital techniques are directly drawn from the folded structure of the LHCII protein, the sophisticated structural mapping process on the atomic scale in protein X-ray crystallography, and the remarkable abilities of LHCI proteins in converting full-spectrum sun light to useful energy for life. In Light Harvest, a complex folded paper structure, modeled precisely after the folded structure of LCHII, acts as a canvas for the interactive colors that are projected as light through projection mapping technology. As a large gallery installation, Light Harvest allows viewers to enter within it in order to experience its naturally orchestrated geometric folded form, its atmospheric thickening projected lights, and its intimate interaction (Figure 4 & 5). The following gives an account of the digital and material making, projection mapping, interactive color projection, gallery installation, and interaction experience of Light Harvest, a collaboration between an artist/designer, a structural biologist, and an interaction design technologist.

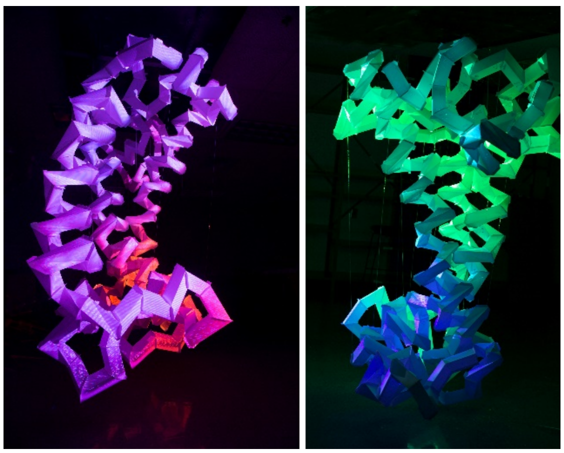

Figure 4: Various installation views of Light Harvest showing different interaction mode. When viewers get closer to Light Harvest, it will project a warm color tone.

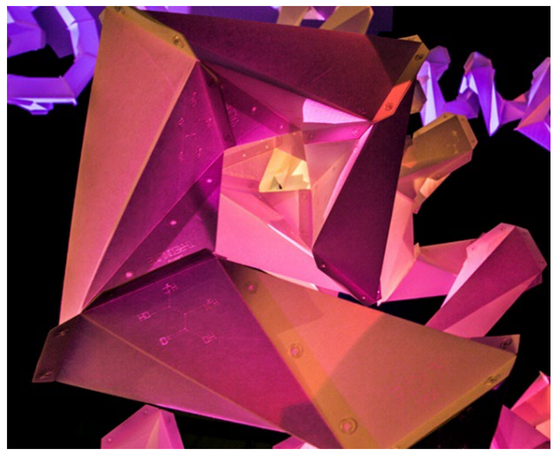

Figure 5: A close-up view of Light Harvest showing the amino acid symbols that become visible when the projected light is diffused through the material.

2.1 Digital Fabrication and Material Construction

The 3D folded protein structure, as founded in LHCII, is an intricate design of nature in six folded helices and six loops. To form a large protein compound, each of the LHCII chain aggregates in a trifold symmetry. The complex LHCII's folded and twisted backbone structure, as well as its tri-fold symmetric arrangement, provides an opportunity to create a spatial labyrinth

(Figure 6) in which its linear elements in the space no longer define a spatial boundary, but rather create a spatial flow that folds continuously and endlessly.

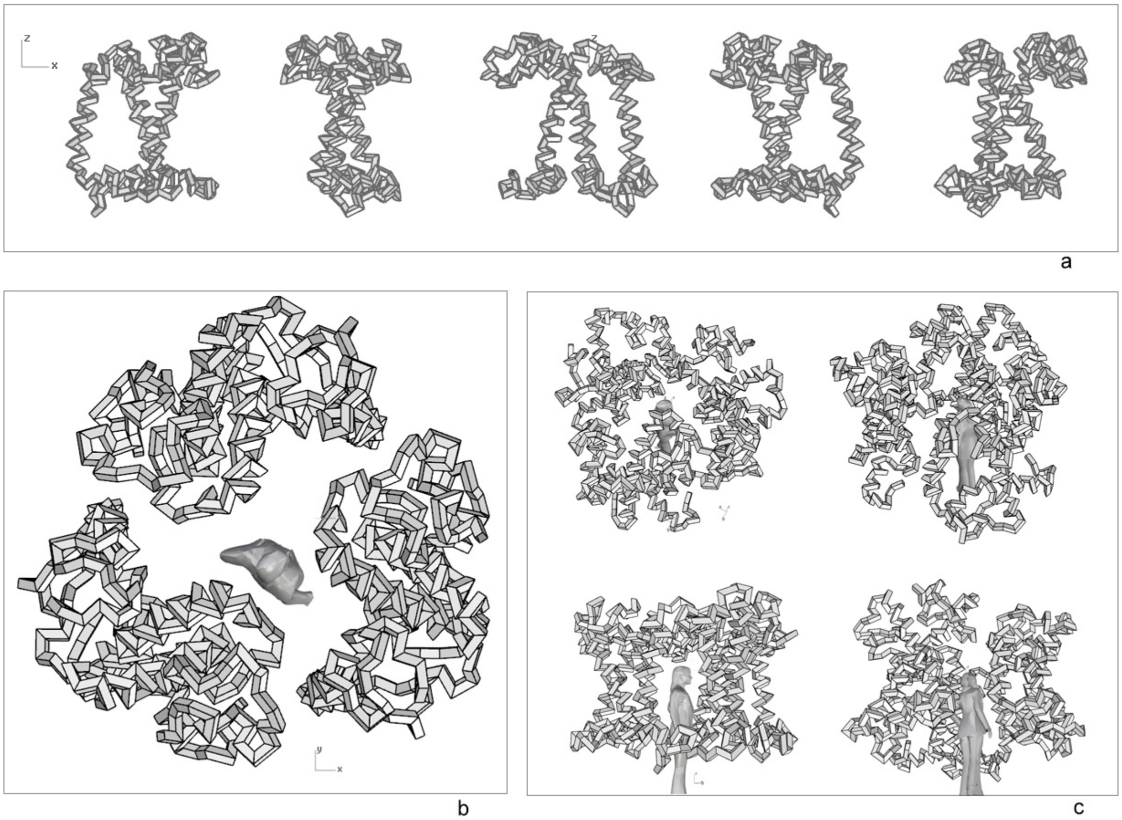

Figure 6. Schematic drawings exploring the Light Harvest installation. (a) Because of its complex spatial layout, it is difficult to comprehend its precise 3D construction from the 2D projections. (b) The spatial enclosure formed by the tri-fold symmetry found in LHCII. (c) Various schematic views of the Light Harvest installation. (© Jiangmei Wu.)

In order to accurately construct the 3D backbone folding structure of the two hundred and seven amino acids, a parametric model was created in Rhino and Grasshopper. To construct the six helixes chains as paper folds, a Nojima pattern was used. The Nojima pattern, also known as helical triangle tessellation (Wu 2018), was first discussed extensively by Taktoshi Nojima (Nojima 2003, 2007), an engineer at Kyoto University. In Light Harvest, parametric helical triangle patterns are used to mimic the helical twists in the protein structure.

Each backbone structure of an amino acid was arrayed in a set of unique 3D coordinates and then unrolled into unique 2D rollout patterns through a parametric workflow. These 2D rollout patterns were produced and sent to a laser cutter to cut and etch. A paper-like material was chosen for its aesthetic and ecological quality, allowing the projected light to pass through it, and at the same time creating an ephemeral light-diffusing effect. These paper laser-cut patterns were then hand folded and assembled in the artist's studio (Figure 7).

Figure 7. Material construction of Light Harvest at the artist's studio. (a) Laser-cut and folded paper pieces. (b) Connecting protein backbone using plastic

buttons. (c) & (d) Assembly of paper structure. (© Jiangmei Wu. Photo: Jiangmei Wu.)

2.2 Projection Mapping and Processing Technologies

Similar to X-ray crystallography, in which a highly calculated and sophisticated process is used to map the 2D diffractions patterns recorded on an X-ray detector to the 3D coordinates of the electrons, a time-consuming calibrating process using projection mapping technology is chosen (Figure 8). Projection mapping is the art of projecting 2D digital images onto real 3D environments in order to create an illusion of 3D scenes. The history of projection mapping goes back to the late 1990s, where it was referred to as video mapping, spatial augmented reality (Raskar, Welch, and Fuchs 1998), or shader lamps (Raskar et al.). In recent years, projection mapping has caught the attention of artists and has been used in light shows and festivals around the world in order to create immersive experiences.

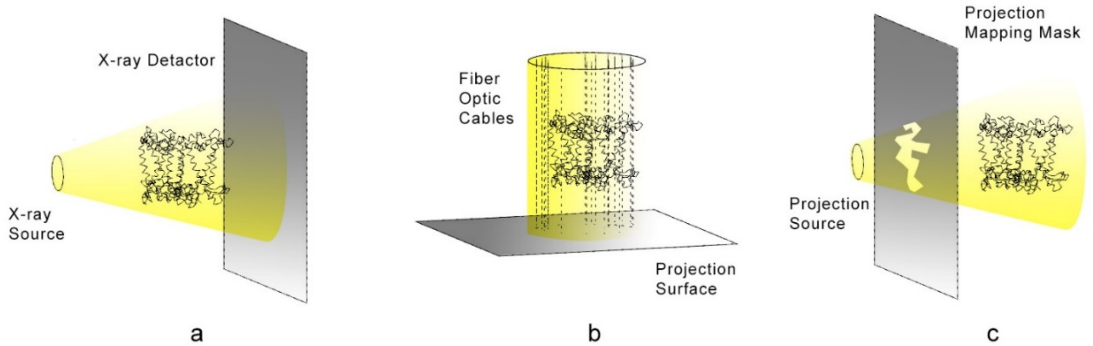

Figure 8. Schematic diagrams showing two light projecting concepts for Light Harvest in comparison to X-ray crystallography. (a) X-ray crystallography. (b) A design option using fiber optic cables that is not chosen. (c) Final design option using projection mapping technology. (© Jiangmei Wu.)

The content that is projection mapped on the Light Harvest structure is an interactive video generated in Processing, a Java based coding language. Microsoft Kinect sensors are used in order to detect people's movements in and around the Light Harvest installation. If a person moves closer to the installation, causing spatial depth data to pass certain thresholds, the projected video will be prompted with changes in colors and patterns, creating a discovery moment as viewers read the symbols of amino acids that are etched onto the structure at close-up distances. The Kinect sensors use RGB and infrared cameras that covert video feed into RGB and depth pixel data respectively. For an installation with three paper protein structures arranged in a tri-fold symmetry, three Kinect sensors, three computers running Processing, and three projectors are used to process and project the interactive videos. The area adjacent to each paper protein structure is divided into several zones that can be detected by the Kinect sensors. The depth information from the Kinect sensors in each zone is calibrated within a certain threshold. When people move in specified zones new video content is projected, with their location acting as a trigger.

2.3 Interactive Colors as Projected Light

The interactive video in Processing produces a color scheme that is in full spectrum, corresponding to LHCII proteins' diverse abilities to absorb a full spectrum of visible sunlight, from the short wavelengths of purple, blue, medium wavelengths of green, to the long wavelengths of yellow, orange, and red. Light in short wavelengths, such as purple and blue, has higher electromagnetic radiation energy than light in long wave lengths, such as orange, and red. In low light, LHCII proteins harvest every available photon in order to sustain life, while in high light they dissipate the energy absorbed in excess to photoprotect the plant (Liguori et al. 2015). Typically, in LHCII, chlorophylls absorb both short wavelength light blue and long wavelength light red, and reflect green light back to our eyes. Xanthophylls, the yellow pigments, and carotenes, the orange pigments, absorbs short wavelength light in high energy. They function as a sunscreen for the plant by protecting it from the harmful high light.

Colored light, as electromagnetic radiation energy, has tremendous effects on our perceptions. Red light waves focus behind the retina, therefore it is stimulating and has been known to raise blood pressure, and to increase respiration, and heart rates. Blue light behaves just the opposite of red. Physiologically speaking, blue has a calming effect, reduces pulse and respiration rates, and lowers the blood pressure. Green light focuses directly on our retina, and like blue, it helps us feel calm and relax (Michel 1996). The non-material colored light, alternating in various spectrum, is projected digitally onto the translucent material of Light Harvest structure. The colored light transforms the gallery environment into being sensitive to response and perception. When there are very few people in the gallery, the interactive video produces a cool color scheme, consisting mainly of blue and green colors. The cool colors emit a calm atmosphere, in a way that is similar to how LHCII proteins absorb long wavelength light and reflect short wavelength light in low energy states. As more people enter into the specified zones around the paper protein structures, the interactive video is changed gradually to a warmer color scheme, consisting mainly of yellow and orange. The warm color scheme shows an high energy state that is similar to how LHCII proteins absorb short wavelength light and reflect long wavelength light in high energy (Figure 9). And finally, when all of the specified zones are activated, the interactive video will output a finale that is celebrated with bright red and orange colors and animated patterns. For all three finales of video projections to be activated at the same time, three Kinect sensors, three computers and three projectors need to work synchronically. The finale at each installation site acts a metaphor for the molecular excitations in a photosystem in which LHCII plays a crucial role. In a biological system, molecular excitations are activated either directly from sunlight or are transferred as excitation energy via LHCII. In a gallery, the people and their locations become the catalyst for the excitement and the celebrations.

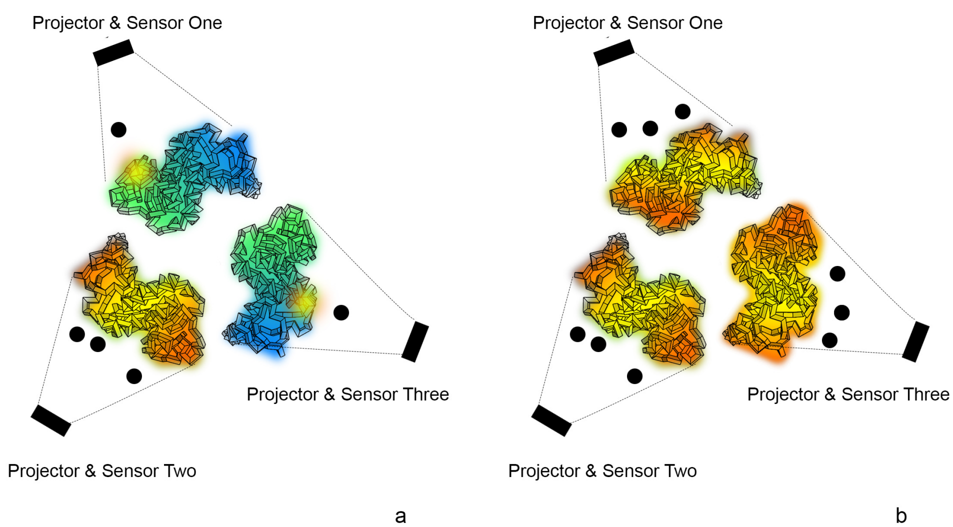

Figure 9. Schematics of Processing with the Kinect sensors used for the interactive video projection. (a) Projector one and projector two output a cool color scheme when there are few people in the specified zones detected by the Kinect sensors. Projector two outputs a warm color scheme when all of its specified zones are activated by people. (b) Three projectors work synchronically to output the finale video. (© Jiangmei Wu.)

2.4 Gallery Installation

Light Harvest has been exhibited in three different venues. To reduce discrepancies between the virtual structure and real 3D installation for projection mapping, ceiling canopies were produced at each gallery venue so that the points on the real protein chains could be measured and then hung precisely at correct 3D coordinates in the space (Figure 10a and 10b). In theory, the method of using a virtual camera taking a 2D picture from the point of view of the real projector for projection mapping works out well. Reality proves to be more difficult, especially in a structure as complex as LHCII. In order to calibrate the 2D virtual images so that points in 2D can be projected and mapped to 3D real protein structure correctly, the artist needs to hand draw the 2D images on the site from the projector's point of view at each of the installations. This hand drawn image is then used to calibrate the original digital image that is created in the virtual space (as shown in Figures 10c and 10d).

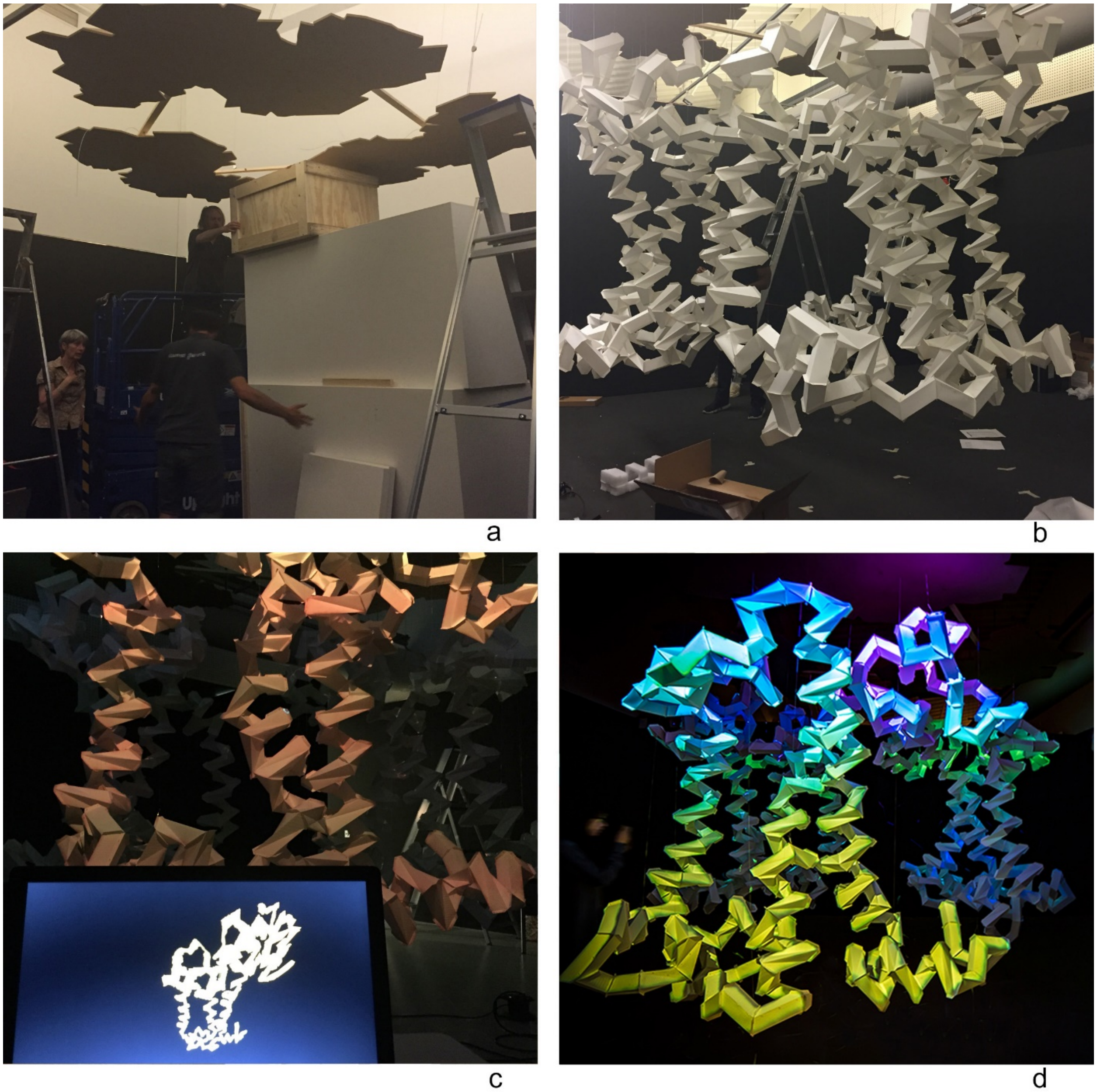

Figure 10. Light Harvest 2. Mixed media. 10’9”(W) X10’9”(L) X9’(H). CODA museum, Apeldoorn, Netherlands, 2017. (a) The CODA museum staff put up three ceiling canopies arranged in the tri-fold symmetry. (b) Finished paper structure. (c) Hand-drawn projection mask that was used to calibrate the projection mapping. (d) Real-time interaction of the installation. (© Jiangmei Wu. Photo: Jiangmei Wu and Kyle Overton.)

2.5 Interaction Experiences

In Light Harvest, the interactive video projection, using the paper protein structure as a canvas, is designed to solicit interactive experiences in a public environment. The changes in the colors and patterns in the digital projection prompt a discovery moment in a person. And for a person to discover the most exciting state, or the finale, of the video projection, other people must be present on the gallery floor. Therefore, each person becomes a performer and a spectator at the same time. The interactive experiences between a performer and a spectator in a public interface, such as in art performance or exhibition, have been studied by researchers in the past (Reeves, Benford, and Claire 2005). While a performer is often referred to as someone who explicitly stages interaction for others to view, in a public interaction setting a performer can also be someone who implicitly stages interaction without knowing or paying attention to the spectator. Therefore, a spectator can become a performer unintentionally, not merely as someone who observes others performing interaction (Reeves, Benford, and Claire 2005). According to research in interaction design, both experiences are equally valuable and should be taken into careful consideration when designing a public interface. Interaction researchers are using four different design strategies when designing spectator experiences: 'secretive,' where the performers' manipulations and effects are largely hidden; 'expressive,' where the performers' interactions tend to be fully revealed; 'magical,' where effects are revealed but the manipulations that cause the effects are hidden; and finally, 'suspenseful,' where the manipulations are apparent but effects are only revealed as the spectators take their turns (Reeves, Benford, and Claire 2005). In Light Harvest, the spectator experience can be described as both 'expressive' and 'magical' at the same time. A person can step into the specified zone and see how his or her movement prompts different colors of projected light. However, a person who sees the finale might not understand what triggers the finale as the relationship between this person and the other people are hidden, thus prompting a 'magical' discovery moment. As previously mentioned, the finale is a metaphor for the chemical reactions that happen in biological systems. In Light Harvest, orchestrated performer/spectator experiences become the catalyst for energy conversion, in a way similar to how different ingredients work together through a natural design system such as LHCII.

As an interaction design, Light Harvest generates its meaning not simply through a limited range of behaviors elicited by specific stimuli through digital interaction design, but rather, Light Harvest attempts to construct its meaning through the dynamic conditions of spatial construction and changing lighting effects. For example, between May 2017 and October 2017, Light Harvest was part of a major biannual exhibition in the CODA Museum in Apeldoorn in the Netherlands. There were about eighty thousand visitors to the exhibition, among them were students of all ages from more than eighty school classes. Light Harvest became a site of play as young children moved in and out of its paper protein structure and its canvas of light and shadows. As the paper protein structure is super light in weight, the swift bodily movements of young children caused the structure to sway slightly out of sync with the projected light, creating unexpected interplaying moments of light and shadows. These full ranges of interactive experiences in Light Harvest can only be constructed as people move into the dynamic zones that are activated by the paper protein structures, the sensors, the digital projections on the paper protein structures, the digital projections on the bodies, and finally, the unexpected digital projections on the surrounding exhibition floors and walls. It is all these experiences—negotiated between the material constructions, the digital artefacts, and the bodily effects and affects—that constitute the overall interaction experience of the Light Harvest installation (Figure 11).

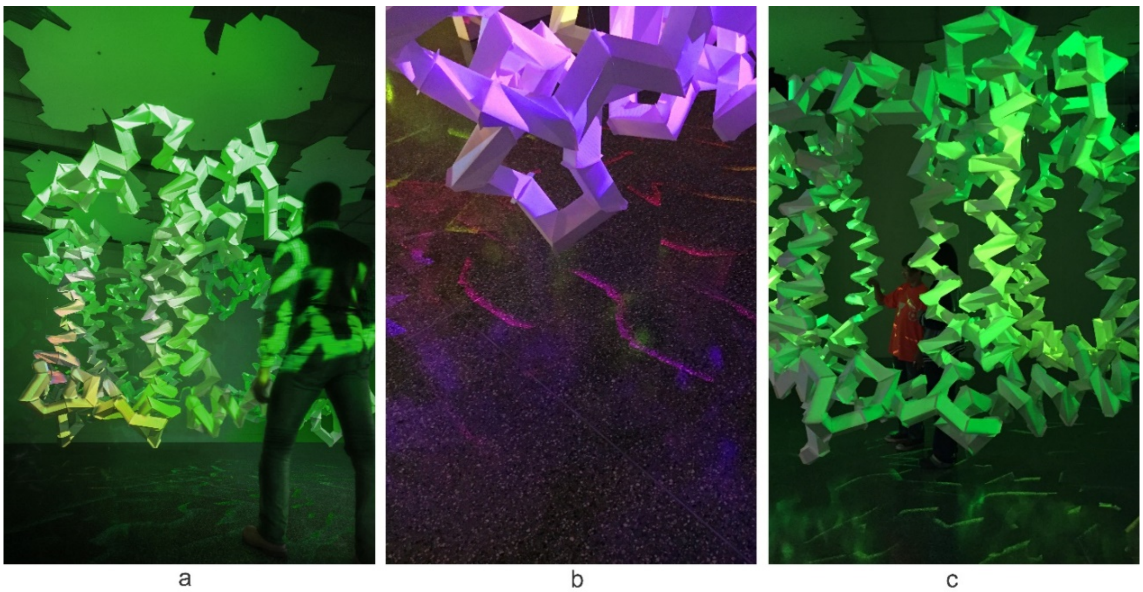

Figure 11. Light Harvest 2. Mixed media. 10’9”(W) X10’9”(L) X9’(H). Grunwald Gallery, Indiana University, Bloomington, Indiana, 2016. (a) A viewer entering an active zone, creating an embodied effect of light and shadows. (b) The ephemeral light and shadows on the protein structures and on the exhibition floor. (c) Two young children interacting with Light Harvest. (© Jiangmei Wu. Photo: Jiangmei Wu and Kyle Overton.)

3. Conclusion

Since Kepes’s novel experimentation on art through the lens of science in the early 1950s, the idea of fusing art and science, or the hybrid art-science, is no longer novel in the contemporary art world. Artists today working in the overlapping space between the arts and sciences often engage in experiments, sometimes in ways that are similar to how scientific experiments are conducted in research laboratories. Light Harvest creates a new experience not by experimenting in science laboratories, but by experimenting with new ways of making an interactive sculptural installation through custom technologies in codes and material construction, and through meaningful dialogues and collaborations between an artist, a scientist, and an interaction technologist. The work not only increases our appreciation and understanding of the biological processes studied and the scientific techniques used to study them, but also expands the cognitive experience of viewers through a full range of interaction. Light Harvest provides a model of a genomic world that we can fully engage in with our bodies and senses, but still can't fully understand and control. Such unpredictable emergence sparks us to ask these questions for future generations: Can we reengineer this complex biological structure into a new type of solar cell? Can the power of molecular biology be harnessed to address the energy and carbon dioxide problems that humankind must solve?

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