6 HyperCell: A Bio-inspired Design Framework for Real-time Interactive Architectures

“Our furniture might someday be comprised of a multitude of interconnected assemblies of robotic modules that can reconfigure themselves for a variety of desires.”

Michael Fox & Miles Kemp

“Liquid Architecture is an architecture that breathes, pulse, leaps as one form and ends as another...it is an architecture that opens to welcome me and closes to defend me.”

Marcos Novak

§ 6.1 Architecture as Body

= ideal conceptual principles of interactive architecture in accordance with a bio-inspired logic.

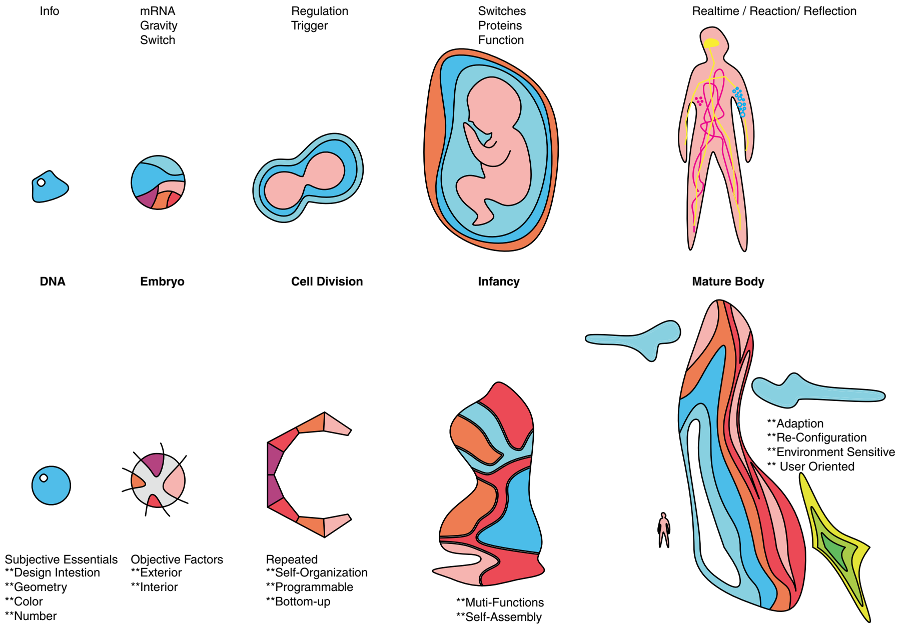

FIGURE 6.1 Diagram illustrating the analog comparison as a conceptual design idea of having an "Evolving Architecture" akin to natural growing processes. The mature architecture body would be as a human figure ultimately interacting with the surrounding environment and additionally fulfilling the user's demands as functional requirements.

This research believes that understanding the relationship between Interactive Architecture and the principles of biology will become a mainstream research area in future architectural design. Aiming towards achieving the goal of "**making architecture as organic bodies**", almost all the current digital techniques in architectural design are executed using computational simulation: digital fabrication technologies and physical computing. Based on its' main biological inspirations, Evolutionary Development Biology (Evo-Devo), this research intends to propose a novel bio-inspired design thinking wherein architecture should become analogs to the growing process of living organisms (Figure 6.1). Instead of being born from static optimization results most of the architecture seems content at aiming for nowadays, this research is looking towards designing dynamic architectural bodies which can adapt to the constantly changing environments and are thus seeking optimization in real-time. In other words, architecture should come "alive" as a living creature in order to actively optimize itself with respect to dynamic environmental conditions and user behavior' requirements in real-time. Following the notion of "**architecture as organic bodies**", six major topics were derived from the publication of "***New Wombs: Electric Bodies and Architectural Disorders***" (Palumbo, 2000). These topics are aimed at initiating critical discussions between body and space, which, are used here to re-interpret six main traits of being an interactive architecture: **Dis-measurement, Uprooting, Fluidity, Visceral Nature, Virtuality, and Sensitivity.** These six topics merge diverse key points from aforementioned chapters including outlining the vision of active interacting architecture, the transformation of human bodies under digital culture, the profound biological inspiration from Evo-Devo and the fundamental componential notion of swarm, which leads to the ultimate notion of embodying organic body-like interactive Bio-architecture.

Dis-measurement: Acknowledging the premise of "**architecture (technology) as an extension of human bodies**" proposed by Marshall McLuhan (McLuhan, Understanding Media: The Extensions of Man, 1964), it is, still difficult to explicitly define the boundary of a space, especially in the context of a borderless cyberspace (the Internet). Space in such a context expands more than ever before and thus makes traditional measurements techniques unfeasible. With cyberspace, people can be virtually present in different places at the same time, thus breaking existing physical boundaries of a space. From another point of view, space as an extension of our bodies constantly adapting to environmental conditions and user demands, creates an intimate linkage between physical bodies and spatial bodies. Interaction in such instances can be seen from a micro-scale: between biological cells and intelligent architectural components to the macro-scale: between physical organic bodies and spatial bodies/architectural space.

Uprooting: Apart from further extending the "Dis-measurement" idea by directly plugging into cyberspace (the Internet), "Uprooting" is also interpreted as adaptation devoid of any site/location constraints. In other words, the idea of "Uprooting" implies, generating an architecture that can adjust/modify in accordance with its existing surroundings by interactions between its smallest intelligent components like cells in a body searching for dynamic equilibrium. In this case, architecture has no particular reason to be designed as "rooted" on sites.

Fluidity: With the neural system inside the body, most of the messages can be transmitted, received and sent within less than a millionth of a second. To envision architecture as an information processor, which has abilities to react to dynamic environmental conditions and user demands, efficient information protocols must be built into such an organic architectural body to create seamless exterior/interior transformations.

Visceral Nature: Visceral can be interpreted in the form of an embodied organ. This implies envisioning architecture in the form of a living-entity. It is no longer the case of mimicking a natural form and thus claiming a building to be organic, but rather instigates one to look deeper into the principles of a natural form's morphogenesis and apply these to generate a truly organic space. Through the study of Evo-Devo, several principles will be applied to generate an interactive organic Bio-architecture. It is thus not an organic looking shape that matters, but the principles behind the shape, which matter. For instance, principles of self-organization, self-assembly, and self-adaptation, providing possibilities of making body-like architectures with multi-directional and multi-modal communications both inside out and outside in. An intelligent architecture, should "live" in the environment just as how the body lives with its' Visceral Nature.

Virtuality: It is impossible to talk about physical space without mentioning virtual space nowadays. From cyberspace, augmented reality to virtual reality, "Virtuality" is related to "interaction" since the beginning and has gradually become an inevitable aspect of our daily lives. In fact, virtual space has to still use constraints from the physical world to enhance experiential aspects. The ultimate goal of virtual reality here is not to end up with a VR helmet and keep constantly being stimulated by electronic messages, but to bring the physical to the virtual and in the process, attempt to search for a dynamic balance between the virtual and real by merging them together. With the assistance of virtual reality, novel unrealistic space can still be realized into creative tangible immersive and fascinating spaces, which, earlier was not possible.

Sensitivity: The notion of "**architecture is an extension of human bodies**", is crucial to embrace, if we consider enhancing the sensing abilities of the space as a body not only externally but also internally. In a digital space, active sensing can be achieved by attaching specific devices. In an interactive space, like an organic body, the sensing capabilities of the space have to be fast, accurate, intuitive, and predictive. The sensing system should thus not only work externally to sense the surrounding environment but also internally in order to fulfill the users' demands in time. With such a connection between human bodies and spatial bodies, it should become relatively understandable for the space to know the requirements of the users by means of hand gestures instead of verbal cues. The sensitivity, in this case, should rely on local information distribution as a bottom-up system rather than a top-down centralized demanding structure.

§ 6.2 The Integration of Digital Architecture = Living Interactive Architecture = New Organic Bio-Architecture

In contemporary architecture, the growing fascination with formal exploration supported by the increasing sophistication of computer aided design (CAD) software has led to misuse and misinterpretation of the term organic and bio-inspired architecture, wherein mimicking of formal attributes has taken center stage. A plethora of form-finding algorithms are now easily accessible on-line to the young generation of designers, who, have no idea what about the principles of morphogenesis behind such algorithms and are thus mostly utilizing them for the sake of generating sophisticated organic shapes. Besides Form, there should be a lot more intriguing inspiration which can be derived from nature. For instance, while an organism is growing, the material system actively cooperates with its structure and functional systems in an integrated growth process, which barely takes place in architecture design, in which construction systems are always separated as a post design attribute. Similar to the developments in digital architecture, through bio-inspired architecture, the diversity of individual experiments run into different paths that never converge. Therefore, this research believes that such separated development in digital architecture should come to an end via a convergence of digital techniques, material performance, and fabrication methodologies in order to become performative akin to a living organism. The former section gives a conceptual picture of how an organic body-like interactive Bio-architecture in accordance with bio-inspired principle could be. Here, this research attempts to point out the current developments of digital techniques in architecture from the **3F** aspects: **Formation**, **Fabrication**, and **Fluidity** to propose an integrated design thinking under the premise of becoming an organic body-like Bio-architecture.

Formation: As mentioned before, computational technology in digital architecture is quite commonly utilized with the goal of form generation. Most current digital formations within the bio-inspired domain only address shape without further understanding the principles behind it. By following applied algorithmic or parametric principles, the formation process is crystallized in a certain moment, resulting in static/rigid shapes, which lose the intimate connection between the form and the dynamic environment. A reversal of such a formation methodology can be achieved by following D'Arcy Thompson's (Thompson, 1992) well-known research, which proposes looking at resulting formations in accordance with surrounding forces. This triggers form to actively interact with the environment. In other words, the formation process using computational technologies should not only be executed for generating an ultimate static form, but, should be utilized to make form flexible enough for maintaining a constant dynamic balance externally and internally between the environment and users via real-time adaption of the form. In order to reach this state, it is thus recommended that Form should not only follow the crucial modular/componential idea proposed by this research but should also adhere to constraints from a fabrication viewpoint.

Fabrication: Digital Fabrication has been developed for decades, not only in the form of using the current trend of utilizing robotic arm assisted manufacturing and 3D printing technologies, but also earlier with conventional CNC (Computer Numeric Control) milling and laser cutting machines. Architects are thus able to learn from manufacturing processes and experiment with a series of design development iteration from conceptual development till the final production stage. Most digital fabrication projects are initiated using parametric or algorithmic design techniques in order to become more precise and efficient regardless of them being carrying a bio-inspired or purely fabrication focused research component. By gaining inspiration from natural organisms, some architects have started using digital fabrication techniques in combination with compatible material systems in order to re-create structural principles extracted from living organisms. However, such projects mostly tend to remain static in a so-called optimized phase, which, is in direct contrast to how animals adapt in time. From the technical perspective, it is known that there are physical constraints in all machines in terms of their size and applied materials. And this particular point gives this research a perfect reason to operate at a modular pre-fabricated alternative. Moreover, it makes it perfectly fit in the logic of all complex living animals that are composed of single and similar elements from the biological point of view. In this case, it is **not** the top-down thinking of having the holistic form and **post-subdivision** of the form akin to the process of tessellation, form, in this case, should be approached in a **bottom-up** fashion. In other words, each single architecture component should have a certain degree of freedom for morphing physically together with the chosen digital fabrication process and associated materials.

Fluidity: Fluidity, is akin to focusing the argument of movements in architectures. Since micro-controllers, such as Arduino, were invented, numerous architects have dedicated themselves to the kinetic, dynamic, interactive space field. Quite a number of architects took inspiration from living organisms in nature and attempted to re-generate a similar effect in architectural design to enhance the sustainability of the buildings. However, such mimicry was limited to certain mechanics of an animal's movement and also constrained the potential of the kinetic/interactive design. The crucial point here is not literally re-presenting the reified mechanism into architectural design, but from a bottom up observational principle of morphogenesis to study how a living organism is built with inherent kinetic abilities. The other crucial aspect of **Fluidity** pertains to local communication protocols. As a modular system like cells in a body, the communication is set up locally between cells as a distributed system to improve the efficiency and precision of passing messages in order to achieve their tasks.

Under this premise of "**following an organism's morphogenesis principles**", it is impossible to discuss **Formation**, **Fabrication**, and **Fluidity** separately, because this is how natural organisms grow: while generating the form (formation), it is necessary to think of how to physically fabricate and assemble the parts to achieve the overall body and to even further consider how this ultimate form will eventually have the ability to move as a living organism. At present, most bio-inspired architectural designs work in separate ways. Regardless of developing complicated form generating processes, or re-presenting organic structures cooperating with digital fabrication techniques, or extracting kinetic mechanisms from animal movements, all of these developments are in opposition to how natural organisms grow in an integrating fashion. From the bio-inspired design point of view, "**Integration**" should be the center stage of developing living-creature-like architectures which take the material, fabrication, assembly, and movement system into account as a whole. From the perspective of digital techniques applied in architectural design's, to build up a living-creature-like Interactive Architecture can create an opportunity to implement digital tools and techniques in architecture design and take them to the extreme to create a type of innovative and authentic intelligent organic architecture for the sake of convenience, comfort, and sustainability.

§ 6.3 Translating Principles from Evolutionary Development Biology to Organic Bio-Architecture Designs.

Translating Useful Principles from Evolutionary Development Biology to Rules for an Organic Body-like Interactive Bio-Architectural Design Framework.

Through years of exploration, digital architecture has gained vast inspiration from nature, especially with the assistance of computational techniques. Unfortunately, too many designers claim their projects deserve the banner of organic architecture, owing only to the increasing sophistication of the architectural appearance which misused the inherent meaning associated with the terminology of "**Bio-Inspired**" or "**Organic**". Unfortunately, this has become the current prevalent wave and has taken the lead in the digital architecture realm. Therefore, the research attempts to take an opposite strategy to search for useful inspirational principles from the intriguing evolution of morphogenesis and translate them into primary design logic instead of directly applying them only for mimicking appearances. Evolutionary Development Biology (Evo-Devo) is the essential subject of this research owing to its contribution to discovering how all organisms work under the condition of sharing the same gene toolkit while still ending up as different species due to gene switches and regulation from the embryologic phase. As mentioned at the end of Chapter 5, three major traits have been extracted from Evo-Devo by this research, namely, "**Simple to Complex**", "**Geometric Information Distribution**", and "**On/Off Switch and Trigger**" which will be further translated into preliminary principles for body-like interactive architecture.

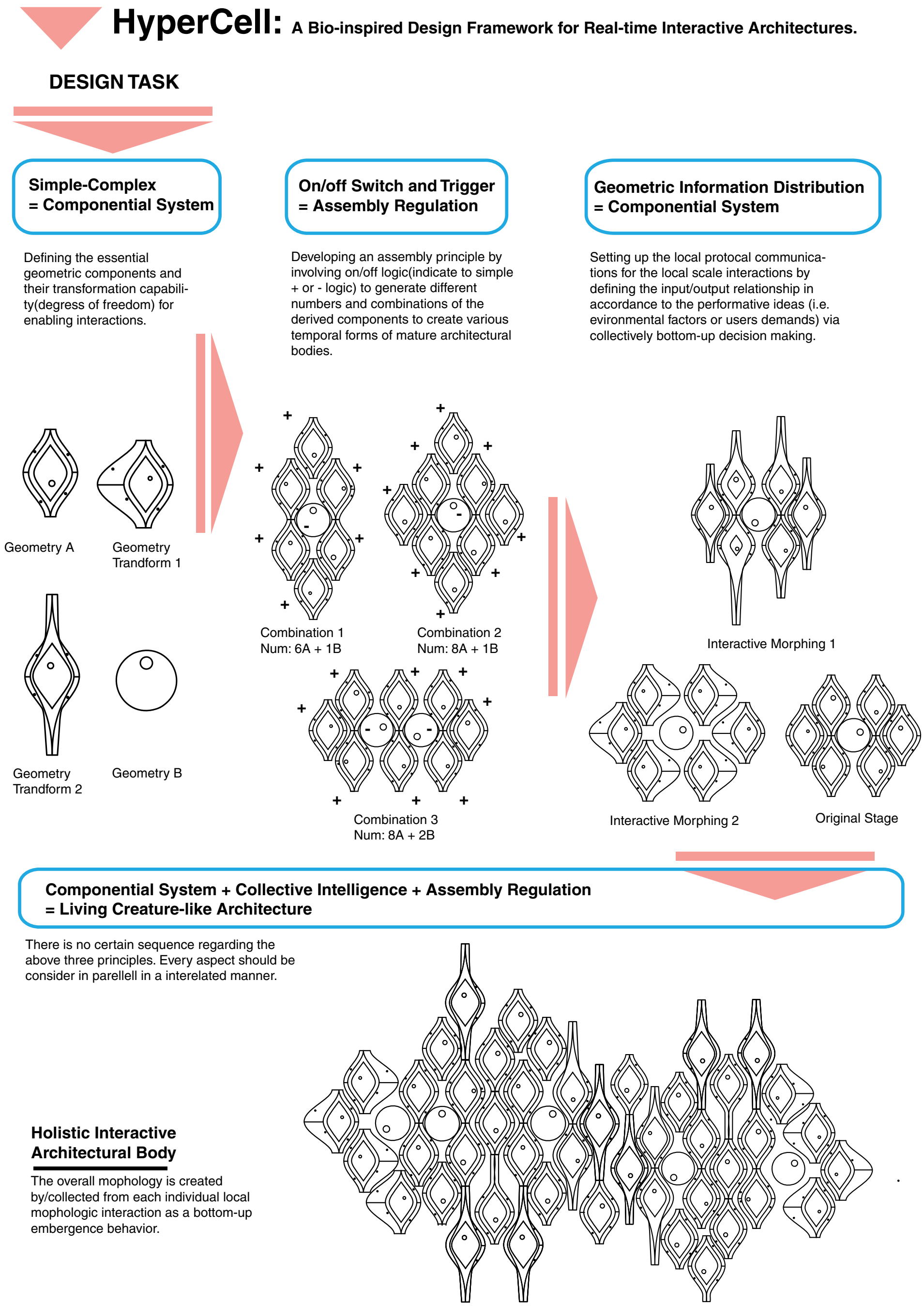

FIGURE 6.2 Diagram detailing the generic idea of HyperCell: A Bio-inspired Design Framework for Real-time Interactive Architectures.

§ 6.3.1 From "Simple to Complex" to "Componential System"

= Defining the basic geometric component.

The principles behind the "**Simple to Complex**" logic of Evo-Devo can easily be observed while studying an organism's body parts, such as the vertebrate's spine structure. Each complex organic body is composed of numerous amounts of simple and self-similar elements, which are repeated with variations in scale of the same component. This biotic principle can be translated into a "**Componential System**" in accordance with a natural bottom-up logic. Cellular and modular components with a certain degree of differentiation should be taken as essential elements for building up a mature architectural body akin to the cells in animal bodies. With certain physical constraints, such as degrees of freedom of transformation, these components can operate in a parametric fashion and be divided into different types of components to develop cellular differentiation. In other words, it implies that with different regulations (referring to the assembly regulation extended from the logic of On/Off Switches and Triggers) of a parametric combination of genes, different types of components and their performance can be defined. "Cells" should be the ideal objects to be studied, especially while dealing with a "componential" approach. In nature, cells are the essential element of any animal body which have basic intelligence and internal communications, and some of them can even generate energy to support their own life and movement.

§ 6.3.2 From "Geometric Information Distribution" to "Collective Intelligence"

= Setting up local information protocols and individual interactive transformations.

In "**Geometric Information Distribution**", the emphasis is on local signal induction outlining the manner in which cells are to be assigned different typologies alongside diverse tasks assigned to them. Besides this, at a local level, propagating signals to their neighboring cells akin to a distributed system instead of receiving one-to-one assignments from a central commander, is a trait embedded in the cells. This kind of information distribution system inside an animal body tends to be more precise and faster in both sensing, sending, and receiving of data. Strictly following this natural bottom-up principle from a "**componential system**" logic, implies any formation process or an interactive reaction should be decided via a process of "**Collective Intelligence**" which takes place between the components in accordance with the sets of parametric transformation rulesets. It is this phase wherein bottom-up information protocols between components is set up and at the same time constraints of the individual kinetic mechanism per component are initiated.

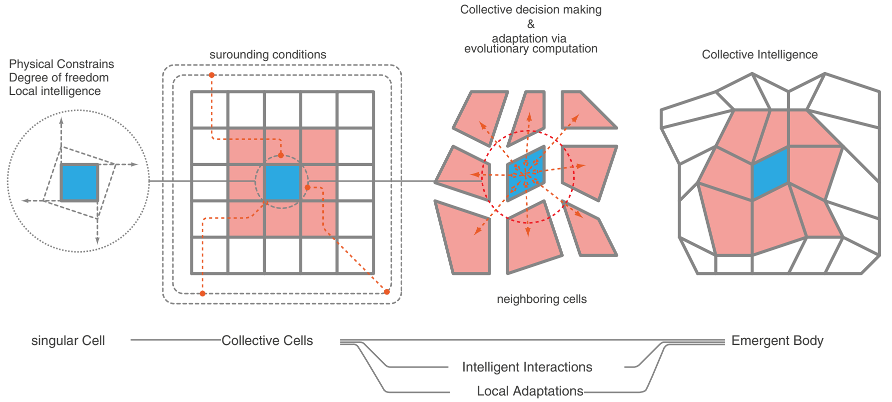

FIGURE 6.3 Process of collective decision making through local level adaptive components to the emergent optimized body for the information distribution idea within the logic of self-organization and swarm intelligence.

§ 6.3.3 From "On/off Switch and Trigger" to "Assembly Regulation"

= Specifying the rules of assembly with different degrees of freedom for kinetic transformation using simple logic.

Rather than addressing production processes, while addressing the principle of "Growth", this research instead focuses on defining assembly logic. The morphologies of animals are well defined by the mysterious and relatively complex layers of on/off triggers, which result in simple output commands. The research attempts to follow a similar, yet, simplified version of using on/off triggers to generate an assembly logic for interactive architectures. Even with the degrees of freedom to transform, it is necessary to define the generating rules for resulting bodies according to certain principles, which include the on/off makeup, extracted from Evo-Devo. As the notion of all animals sharing the same gene toolkits but only with different numbers and regulation of the genes turns out to have a diversity of species in nature, the research tests the idea

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of having self-similar geometric components cooperating with different numbers and combinations of the "On/Off" regulation. Multiple resulting forms can thus be generated according to environmental conditions or user based demands. Once the basic geometry of the components is defined, the simple logic (on/off) can be applied to further construct the assembly logic in this phase of design.

§ 6.3.4 Living Creature-like Architecture = Componential System + Collective Intelligence + Assembly Regulation

In brief, this research would like to propose a design framework, "**HyperCell**" for generating living organism-like interactive architecture by following the above translation principles from the Evo-Devo Biology. The "**HyperCell**" design framework works in a fashion such that the essential geometric components and their transformation capability for enabling interactions can be defined. After this, the simple on/off logic will be involved to develop an assembly principle to be followed for creating different numbers and combinations of the derived components to create various temporal forms of mature architectural bodies. Meanwhile, the local interactions shall imply physical morphing of each constituting component via collectively bottom-up decision making (Figure 6.2). Janie M. Benyus who coined the term "**Biomimicry**" (Benyus, 1997) once stated that there are three phases of learning from nature in order to improve our technology: imitating the form, learning about natural processes, and getting involved with natural systems[57]. Since there are a plethora of explorations which have taken place in the domain of form mimicry in architectural design, it is now time to dig deeper into the study of the **natural processes**, one of the core ideas of the "**HyperCell**" research. Unlike most so-called bio-inspired architectural research which focuses narrowly on the organic formation process, **HyperCell** intends to focus on setting the rules/principles of generating the architectural body in accordance with the idea that organic architecture should operate as a living organism and thus emulate the ultimate form of the interactive architecture (Figure 6.3). Meanwhile, the componential idea within the simple but highly-interrelated relationship of **HyperCell** fits perfectly with either the Swarm Behavior principles that this research has heavily relied on, or the philosophical ideas of Deleuze

57 Janine Benyus, a biologist, who coined the term, "biomimicry", has once stated in her TED lecture that there are three different levels of learning from nature: one is to mimic the natural form of organisms; second is to study and apply the natural process of organisms; the last is to fuse into the eco-system of the nature. The TED lecture can be found here: https://www.ted.com/talks/janine_benyus_biomimicry_in_action

and Guattari's Body Without Organs (Deleuze, G., & Guattari, F., 2003) and Gottfried Leibniz's Monadology (Leibniz, Monadology, 1714). All the above conceptual logics are narrowed down into individual entities with embedded capabilities/intelligence to set up intimate relationships in between each other and based on this intimacy, operate as a whole, like an organic body. This is to a certain extent the ultimate goal of this research by which, it attempts to push interactive architecture to the next level of becoming an organic entity.

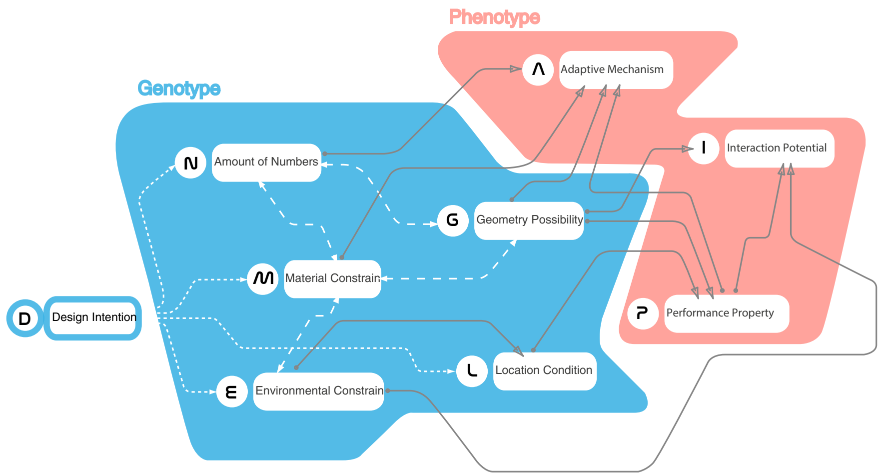

FIGURE 6.4 Diagram portraying possible DNA logic implemented in architectural design as a set of relationships instead of parameters merely for form generation.

A little reminder about the conceptual design concerning the translation of DNA.

It has been observed that genetic processes and evolutionary strategies in natural systems are easily misunderstood and misused by designers in architecture. Geometric form-finding processes are at times deduced by considering a DNA code as a metaphor for fixed formal attributes while completely ignoring the deeper relational processes that exist between encoded genetic information and the resultant phenotype. This dissertation categorically opposes the much-simplified literal translation of A-C-T-G sequences within the DNA into datasets of spatial vertexes, edges, transformation factors, and other geometric relationships for deriving a shape. On the contrary, the research premise establishes that all genes in cells should unavoidably interact with each other as a relational system in a non-linear process in order to successively grow an organism using cellular differentiation and specialization-based tissue formation into a holistic body. This necessitates a systematic relationship between genes as a vital

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area of research in order to extract rules for generating information driven performative form. In other words, the research proclaims that designers should build bottom-up spatial formations by setting up genetic rule sets within the design process. These will be inherited within the smallest unit of the proposed space; the spatial component (similar to the cells in organisms). The number of such cells, their material make-up, their communication protocols and data exchange routines (gene expression and signal processing) while interacting with their immediate context in order to arrive at individual cell specialization (in terms of form and ambient characteristics) result in the generation of emergent morphological phenotypes (Figure 6.4).

§ 6.4 The crucial and immediate demands of developing real-time re-configuring space as a living creature

= taking the users' requirements as a fundamental variable for real-time spatial re-configuration in a proactive manner.

With the development of advanced medical science and technologies, human life extends much longer than before, which causes a population growth problem. The population projections for 2050 show that there will be 9.2 billion people in the world and 66 percent of the population will be staying in urban areas[58], which rapidly increase urban density and enormously influences daily lives of humans. The price of real estate is also extremely high due to the immense spatial demands in urban areas and the lack of equal supply of the required space, and this naturally results in various economic and social issues. Therefore, the real-time adaptive spatial formations, which this research proposes, will in their own smart way aim to enhance customizability and thus enhance adaptive re-use possibilities of architectural space. In other words, this kind of real-time re-configuring space can remove the redundancy of unused space by only using a specific footprint of size and yet fulfill essential usability of space in daily life. Therefore, the design experimentations with the Hypercells in this research mainly focuses on residential space with a focus on providing early career professionals and students with affordable smart living solutions. However, it can also serve as an experimental case within the domotics sector in order to aid elderly people in their daily activities via intelligent spatial adaptation.

58 Please check the United Nation's webpage for more information about population projections for 2050: http://www.un.org/en/development/desa/news/population/2015-report.html.

This research would like to place a major emphasis upon users demands as a major factor to be considered for real-time spatial interaction. On one hand, as the aforementioned discussion said, it is advantageous to reduce the redundancy of unused space but meanwhile be able to fulfill the essential requirements of the user's. On the other hand, "to fulfill" would mean "to customize the spatial requirements".

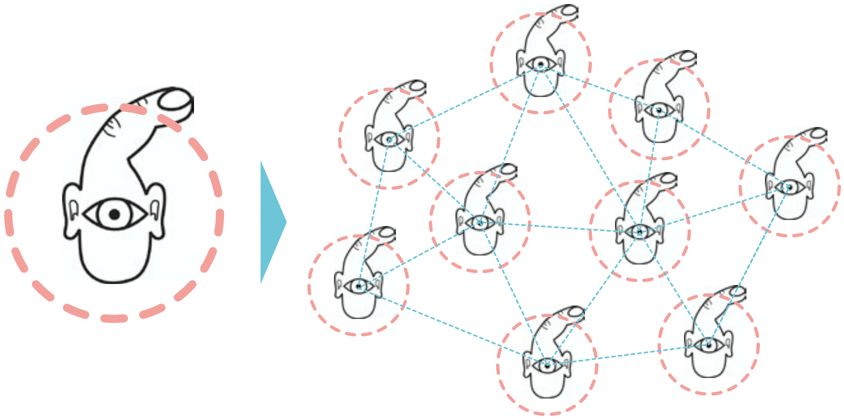

FIGURE 6.5 Diagram illustrating how the computer sees us from the left derived from the publication of "Physical Computing: sensing and controlling the physical world with computers", and on the right-hand side exhibiting how this research would like the HyperCell components to possess essential intelligence.

"**The kinetics for spatial optimization systems are generally described as how systems can facilitate flexible spatial adaptability. Multifunction designs differs from spatial optimization system, because these systems specifically provide the means for a plurality of optimized states to address changing use,"** as noted in "***Interactive Architecture***" (Fox, Michael, & Kemp, Miles, 2009) by Michael Fox and Miles Kemp, re-defining the term "optimization" with multifunctional space from a user centric perspective is quintessential in Interactive Architecture rather than adhering to conventional interpretation of optimization in terms of structure or material optimization. This reconfigurable space idea can be traced back to Cedric Price's "**Fun Palace**", which, operated as a constantly shifting structural framework in accordance with the spatial usage of the space at that moment in time. More recently, Greg Lynn proposed an egg-shaped housing called the RV Room[59], which can be physically rotated with electric motors to reveal different spatial configurations to fit the user's

59 Please see Greg Lynn's FORM website for more information about the "RV" project: http://glform.com/buildings/rv-room-vehicle-house-prototype/.

spatial demands. Other solutions like Gary Chen's transformable impact furniture piece (Extreme Transformer Home)[60] which can turn into almost all the functional furniture imagined fitting into a single box by manually pulling, pushing or sliding...etc. or "cityHome"[61] project done by MIT Media LAB which brought Gary Chen's manual transformable furniture idea even further by contributing to the hi-tech developments of Human Machine/Computer Interface with freehand gestures' controls.

In another project by Cedric Price, "**Generator Project**", he stated that "...**Instantaneous architectural response to a particular problem is too slow. Architecture must concern itself with the socially beneficial distortion of the environment. Like medicine it must move from the curative to the preventive** (Price, 2002)". This further gave rise to the issue of intelligence embedded in architecture. Again, from the book "***Interactive Architecture***" (Fox, Michael, & Kemp, Miles, 2009) which foresaw the interesting applications based on users' requirements, some interesting ideas, can be further traced; "**Adaptive control methods offer a means to revolutionize plants and process efficiency responsive time, and profitability by allowing a process to be regulated by a form of rule-based artificial intelligence, without human intervention**" and also "**Recently processors and sensors have shifted from strictly looking at environment conditions outside the building and performance-based aspects of the building to include predicting and reacting to information inside the building, which includes understanding and monitoring the changing needs to the users of space**". These, illustrate not only a shift in focus from external to internal environments in interactive architecture but also point towards a key factor; "**the intelligence of the building**". Unlike direct interpretations of developing a powerful intelligent centralized system, following the componential system logic from biology and the agent-based swarm behavior, this research rather relies on multiple relatively simple but intelligent entities instead. In the publication, "***Physical Computing: Sensing and Controlling the Physical World with Computers***" (O'Sullivan, Dan & Igoe, Tom, 2004), there is a diagram illustrating how a computer sees a human which has only an index finger(clicking) with ears on both sides of the face, and an eye in the middle (Figure 6.5, left). But this research would like to reverse this notation and thus embed each of the "**HyperCell**" components with essential but crucial intelligence in order to collectively operate as a holistic intelligent entity (Figure 6.5, right). To have no human intervention and yet to be able to predict the changing needs of the humans inside, the space has to turn itself into a living entity with active behavior with the aid of computational technology.

60 Please refer to https://www.youtube.com/watch?v=WB2-2j9e4co for a video regarding the "Extreme Transformer Home"

61 Please refer to https://www.youtube.com/watch?v=f8giE7i7CAE for the video regarding cityHome.

§ 6.5 A Series of Experiments with the HyperCell System:

HyperCell, in this section, no longer implies a design framework for bio-inspired interactive architecture but turns into a design project in itself, attempting to embody intriguing principles from Evolutionary Developmental Biology. In other words, here, the term of "**HyperCell"** is not only representing the methodological framework of organic body-like interactive architecture owing to the componential system but is also the name given to the prototyped intelligent component system. "**For many applications ranging from exploring space to household cleaning, designers are moving away from figural humanoid robots to transformable systems made up of a number of smaller robots,**" (Fox, Michael, & Kemp, Miles, 2009) said Michael Fox and Miles Kemp, and this perspective almost perfectly fits in the philosophy of "what **HyperCell** is". Moreover, from the same book, "***Interactive Architecture***", the quote regarding "**…Current advancements in metamorphic, evolutionary, and self-assembling robot, specially dealing with the scale of the building block and the amount of intelligent responsiveness that can be embedded in these modules, are setting new standards for the construction…"** indicates precisely to central notion of developing an intelligent and transformable "**robotic building block**" like The HyperCell. This **HyperCell** research insists on utilizing the principles extracted from the study of Evo-Devo in the following manner: Apply the "**Simple to Complex**" principle to develop a modular system for the cell, Utilize the "**Geometric Information Distribution**" principle to develop the idea of collective intelligence by means of real-time communication between the cellular components, and lastly use the principle of "**On/Off Switch and Trigger**" as a logic for deriving assembly regulations of the cellular components. The **HyperCell** research was initiated by aiming to begin with a small-scale idea but having a big impact via a transformable spatial system in the form of a furniture system; the **HyperCell** furniture. As a transformable block with certain degrees of freedom, it allows users to initiate diverse functions by combining a different number of Hypercells together and customizing different nature of the output. These re-configurable functional variations can fulfill the essential user demands throughout time. At another level, these components can also be seen as agents of a swarm keeping constantly regulating their emerging shapes by shifting their positions in order to achieve dynamically occurring goals. In the following sub-sections, this research proposes the possibilities of using the **HyperCell** furniture system and emphasizes upon its development owing to its basic geometric principles, the technical protocols via a series of experiments catering to varied experiential tasks. Once again, the **HyperCell** components here are not exhibited as the ultimate solution but rather provide a potential possibility to stimulate the development of similar design ideas.

§ 6.5.1 HyperCell[62] Geometric Principles and technical interpretation:

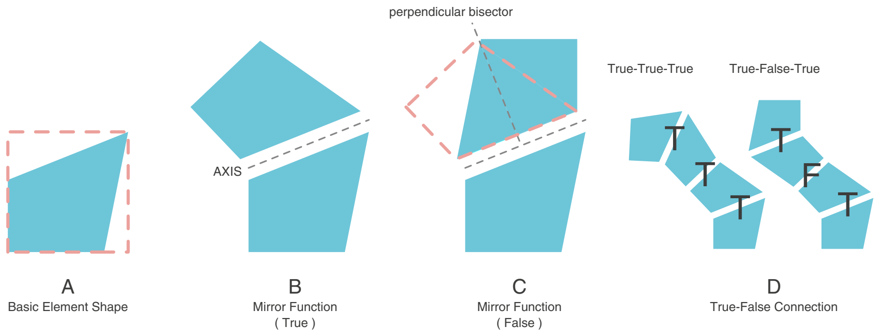

FIGURE 6.6 A) Degrees of freedom in terms of dimensions. B) True mirror function. C) False mirror function. D) An Example of True & False regulation between cells.

The fundamental geometry chosen here is a regular "Hexahedral(cubic)" shape, which, in real-time adapts and transforms its geometrical shape in response to contextual factors and user-based activity requirements to generate feasible topologies. The initial research phase employs a 2-dimensional quadrangle-based structure as the fundamental element of the **HyperCells**. From a parametric design point of view, the coordination and controls of the constituting four vertices of a single quadrangle shape contribute towards attaining geometric variability and transformation possibilities for the **HyperCells** (Figure 6.6A). In other words, different lengths of a basic quadrangular element's edges (= basic componential module) define a repeated geometric shape in order to compose a **HyperCell** by following the "mirror" geometric transformational function. The mirror function in the mathematical definition is called a reflection transformation based on a mirror (a line for 2D space or a plane for 3D space as an axis of reflection) to map a specific figure to its opposite position creating symmetry. In this

62 Please refer to the following papers of the authors for more detailed information:
Biloria, Nimish & Chang, Jia-Rey. (2012). HyperCell: A Bio-Inspired Information Design Framework for Real-Time Adaptive Spatial Components. Proceedings of the 30th eCAADe Conference (pp. 573-581). Prague: eCAADe and Czech Technical University in Prague, Faculty of Architecture. (http://papers.cumincad.org/cgi-bin/works/Show?e-caade2012_5)
Biloria, Nimish & Chang, Jia-Rey. (2013). Hyper-Morphology: Experimentations with bio-inspired design processes for adaptive spatial re-use. Proceedings of the eCAADe Conference Volume No.1, 2013 (TU Delft) (pp. 529-538). Delft: eCAADe and Faculty of Architecture, Delft University of Technology. (http://papers.cumincad.org/cgi-bin/works/Show?ecaade2013_023)

research, two different mirror functions have been applied as "**True and False**" logic while composing the **HyperCell** organ as their gene switch (= assembly regulation).

The "True mirror function" adheres to the general reflection idea to create a symmetric figure based on one of the original quadrangle's edges (Figure 6.6B). The "False mirror function" adds one step after getting the reflected figure by the True mirror function. Instead of using the quadrangle's edge as an axis of reflection, the "False mirror function" makes another reflection based on the first reflected shape's perpendicular bisector (Figure 6.6C). This "**True and False**" combination logic is a crucial mechanism of forming a single **HyperCell** component by connecting the quadrangular cells together. This can be interfaced with the switch and trigger mechanism derived from Evo-Devo Biology: for example, if we connect four quadrangular **HyperCells** components, first we have to decide the True or False sequence, such as TTT or TFT (T = True and F = False) as the connecting regulation between cells (Figure 6.6D). This simple regulation of True and False (= On/Off switch) sets up the basic formation of the **HyperBody** parts similar to the gene switches controlling the regulation process of living creatures, which define their body parts. Besides this, it strictly follows the fundamental critical logic that all animals share the same gene toolkits, but within the variation of combination numbers and regulation, it is allowed to form different animal forms. This idea has been translated by taking each hexahedral (cubic) **HyperCell** as the basic element and the TF logic as a gene switch re-configuring to generate different body parts or even diverse holistic **HyperBodies** composed of **HyperCells**. But how these **HyperCells** know what types and tasks they will eventually perform, operates pursuant to the "**local protocol**" under collective intelligence which makes the idea achievable.

This collective decision-making protocol triggers numerous autonomous components (**HyperCells**) with material limitation driven local degrees of freedom referring back to cells in an organism. Based on local adaptation routines stored within each component's DNA, efficient negotiation scenarios between immediate neighboring components are structured in order to collectively decipher performative morphologies in accordance with user requirements as regards the activities they wish to perform. This collective decision-making scenario applies to diverse set-up of the components with differing material and geometric make-up in the form of variable gene regulation akin to cellular differentiation mechanisms in the natural world. In other words, instead of a centralized command, through the local communication protocol, within physical constraints of the **HyperCell**s, the **HyperCell**s will either change their assembly regulation or make new transforming mechanisms and evolve a new global morphology bottom up. Particularly in this case, once a specific quadrangular cell gets its dimensional information from the system to change one of its edge's lengths, it will pass this information to its neighboring cells in order to do the same transformation so that the overall **HyperCell** components can make different bending formations in real time for different usages. This data transmission is related to the information distribution between cells. Furthermore, by extruding the 2D quadrangular cells of particular lengths as 3D-Hexahedral elements, the transformation mechanism can still be embedded and applied to build a 3D **HyperCell** component (Figure 6.7).

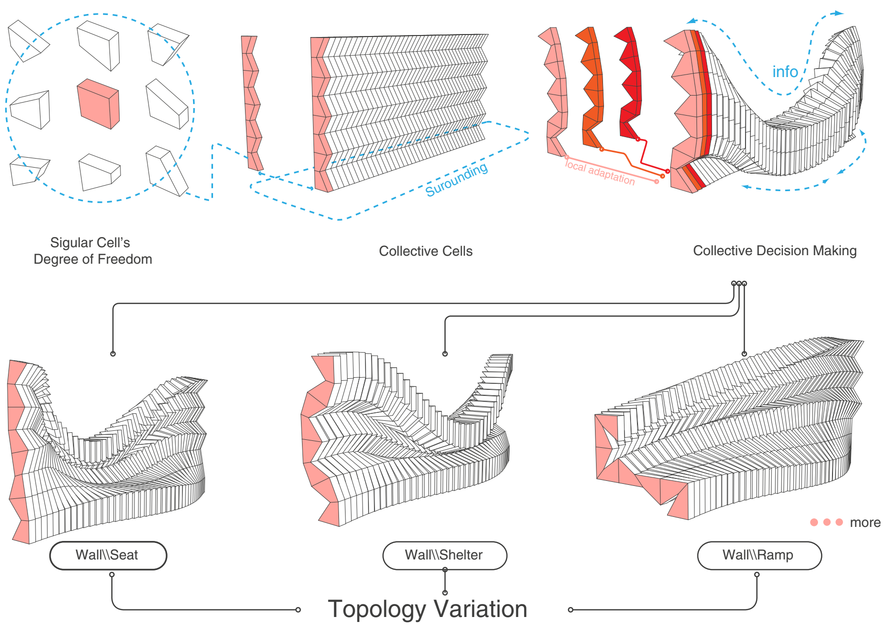

FIGURE 6.7 Diagram illustrating the bottom-up communication protocols and how it influences the real-time morphology of the architectural element (wall in this case) owing to users' demands using the swarm intelligence logic.

§ 6.5.2 The Applications of a HyperCell Furniture System and Future Evolution

After having a general picture of its geometric transformation principles as well as how the HyperCell can compose a **HyperBody's** parts, it is time to discuss the applications of the **HyperCell** in terms of a furniture system. The phrase "**Our furniture might someday be comprised of a multitude of interconnected assemblies of robotic modules that can reconfigure themselves for a variety of needs or desires**", as quoted from "***Interactive Architecture***" (Fox, Michael, & Kemp, Miles, 2009) explicitly illustrates the kernel vision of the **HyperCell** furniture system. Instead of directly implementing the HyperCell as real building blocks in construction within an architectural scale, this research attempts to create variations of the furniture functions to achieve the required usages within the same footprint of adaptable space. It aims to take transformable robotic elements as basic components to be self-assembled as real-time re-configuring space(body) to fulfill users' demands through time slots, which can also work in existing buildings for re-use purposes or serve to reduce the re-construction cost of an old building. With these goals, multi-functional **HyperCell** furniture can, owing to their adaptation/transformable possibilities, minimize each person's genetic spatial volume for daily living. Two sets of parameters, Logic-DNA(L-DNA) and Dimension-DNA(D-DNA) drive the main furniture (trans)formation composed of **HyperCells**, such as chairs, benches, tables, desk, bed, partition walls...etc., with different types. With the numbers of the components defined, these two sets of parameters are associated with the aforementioned transformation logic while defining the basic quadrangular shapes and the manner of connecting them. **L-DNA** is the logic extending the "**True/False**" mirror geometric transformation determining the assembly regulation, while **D-DNA** is the logic of defining the basic component's shape as well as the degrees of freedom concerning the physical constraints of the component in order to interact with the users and make the transformation as a bottom-up emergence behavior.

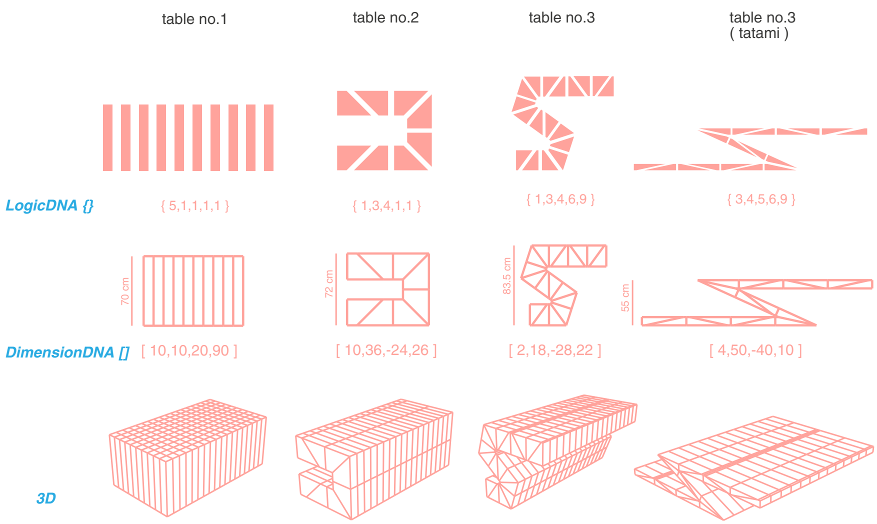

FIGURE 6.8 Diagram showing types of table variations also as an example for forming the furniture in accordance with the logic of Logic-DNA and Dimension-DNA as this research developed.

Apart from applying principles of cellular differentiation, the idea that all species share the same gene tool-kit, involves simple operations to produce complex outcomes and attain morphological variation via simple switch and trigger mechanisms which are perfectly experimented with in this research. Although all cells (**HyperCell**s) share the same degree of freedom (**D-DNA**), they have different amounts (**number**) and geometric regulation (**L-DNA**), so they create various functional furniture formations to fulfill different spatial and usage based topological requirements. This on-going research subsequently aims to develop and market the **HyperCell**s as flexible and transformable furniture pieces apt for adaptive reuse. In other words, a set of **HyperCell**s bought by customers, can be assembled differently by using different D-DNA and L-DNA to attain specific furniture functions, or enable the embodiment of different transforming abilities to existing functions in order to suit the customer's spatial requirements in time as regards the active reuse of space (Figure 6.8) Metaphorically speaking, if each of the **HyperCell** furniture in the space is taken as a body part of an organism, different configurations of the **HyperCell** furniture will metaphorically represent a specific spatial species (Figure 6.9).

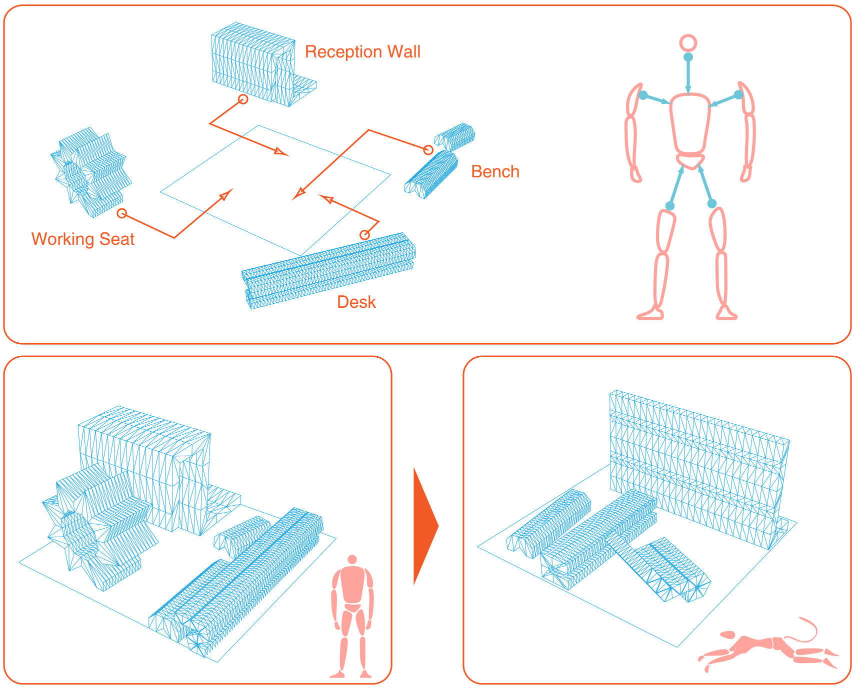

FIGURE 6.9 Diagram illustrating the conceptual idea of having different reconfiguration and combinations of the furniture system as various spatial usages metaphorically representing different species. (I.e. From left to right: private working space to office space; Human being to Panther).

“**In the future, users will be able to purchase these robotic parts with the capability of adding their own intelligent, customizable setting** (Fox, Michael, & Kemp, Miles, 2009)”, explicitly outlines the kernel idea of the **HyperCell** furniture system. Imagine a scenario, where you go to a shop like Ikea, and you purchase numbers of these **HyperCell**s, once you get home, you are able to assemble them as a default setting following the instructions and eventually enjoy the transformable feature with multiple functions. In other words, customers just need to purchase these transformable yet programmable cubes with instructions, and they can have multiple furniture functions with these cubes and furthermore customize their own creative furniture where the “**EVOLUTION**” enters. Therefore, the evolution process of the **HyperCel**ls will mainly come from the end users. Although several default settings of the **HyperCell** furniture and configurations will be given while users start using it, the users are not forced to stay with these settings. In other words, users are allowed to create their own customized furniture or spatial usages by modifying the two sets of the aforementioned **HyperCell** parameters (**D-DNA** & **L-DNA**). This evolution idea can reflect the idea that every natural species are sharing the same gene toolkits from the principles of Evo-Devo Biology. Similar to LEGO bricks, the **HyperCell** components will also have the potential to generate various results to challenge the conventional ideas of furniture and space. Moreover, because of the transformable feature of the **HyperCell** components, more flexible spatial ambiance and practical usages will be more suitable to the users according to their spatial requirement through time. It perfectly fits this research’s interpretation of taking users’ demands in real-time reconfiguring space as the environmental factors as in nature which can heavily drive the force of evolution as customized but also optimized solutions.

Google, is working on a similar idea on a relatively smaller scale with an exciting project: ARA[63]. ARA is a smartphone device with individual units which are called “Phone Blocks”.
These can be assembled to suit a users’ own needs. The framework of the phone provides a basic platform for operating, but the inserting units can be purchased individually and defined by the users.

63 Please see the webpage of “Google ARA” for more details: https://atap.google.com/ara/.

§ 6.5.3 A Series of Developments with HyperCell

1 HyperCell: Geometric Experiments:

Following the geometric principles, several experiments have been conducted with the assistance of computational tools. The series of experiments started with exploring the essential modular components. This research selected the hexahedral(cubic) shape as its version of **HyperCell**'s essential geometry as modules for further experiments. In the very beginning, the first version of **HyperCell**s, "**HyperCell 1.0**", gathered series of hexahedral HyperCells by only regulating each length of the shape's edges to figure out the variations using the fundamental principles of sharing the same modified elements to produce the diverse results. Fortunately, even without implementing the "**True and False**" switches, it resulted in the production of numerous outcomes in terms of geometric transformations and produced various visions of practical spatial applications[64] (Figure 6.10, up). Later on, this "**True and False**" switch was applied as a reflection transformation function for the first time not acting as a form regulation factor but rather a reaction/interaction of an experimental project called the "**Duchamp Wall**", exhibiting the fluidity of a wall which can interact with the users by changing the length of the element's edges (Figure 6.10, bottom). In "**HyperCell 2.0**", the "**True and False**" geometry reflection transformation has been implemented as a role of gene switch in the **HyperCell** assembly regulations (the Logic-DNA), and with numbers of **HyperCell**s components, it can create almost an infinite set of results. The transforming degree of freedom (the Dimension-DNA) in addition to the True/False switches generates the interactive morphology of the overall shape to provide the flexibility and multi-functional usages. As a result, multiple furniture or architecture elements such as desks, shelters, seats, or ramps can be realized based on the geometric assembly and transformation principles owing to the Evo-Devo based biotic inspirations. The research utilized digital tools from 3D modeling software with its parametric plug-ins, "Rhinoceros+Grasshopper", to the open source visualization program, "Processing", for the purpose of real-time simulation. Through Processing simulation, more real-time responsive reactions designed for **HyperCell**'s applications, like walls with doors, walls with seats, or façades with penetrating light/wind openings, can be much more precisely exhibited[65] (Figure 6.11). To further confirm the feasibility of the **HyperCell** furniture systems, a catalogue with default settings of these **HyperCell** cubes following the assembly and transformation principles were made to prove not only that the natural principle of all

64 Please see the video for more details: https://vimeo.com/55289946.

65 Please see the simulation for further understanding: https://vimeo.com/61828421.

animal sharing same gene toolkits which can be applied and can work perfectly but, it also shows the incredible diversity and functionality the cubes can provide. Numerous sets of furniture, such as chairs, sofa, tables, beds, partition walls…etc. were generated with the parameters of the amount of HyperCells, L-DNA, and D-DNA. The L-DNA basically defined the category of the furniture, and the D-DNA managed to transform interactive physicality of the furniture owing to its specific utility. For example, by the definition of L-DNA (which is the True and False mirror function), the object can be categorized as a chair, and following the D-DNA (which is the interactive transformation), the resulting sofa (under the chair's division) is able to follow the user to generate a comfortable sitting area (Figure 6.12, the detailed settings of the L-DNA and D-DNA of the furniture applications will be exhibited in Appendix i). Nevertheless, if envisioning each furniture piece as a particular body part, then all pieces together in a footprint of space can be metaphorically interpreted as a specific animal body or a species. Through different time slots of spatial requirements, the combination of the **HyperCell**s must re-self-assemble and evolve from one to another species for the sake of meeting user's demands (Figure 6.9). In spite of the originally extracted biotic principles, after translating, the applications of **HyperCell** appear to be not only theoretically meaningful but also practically feasible and have high-potential for further development of the current technologies.

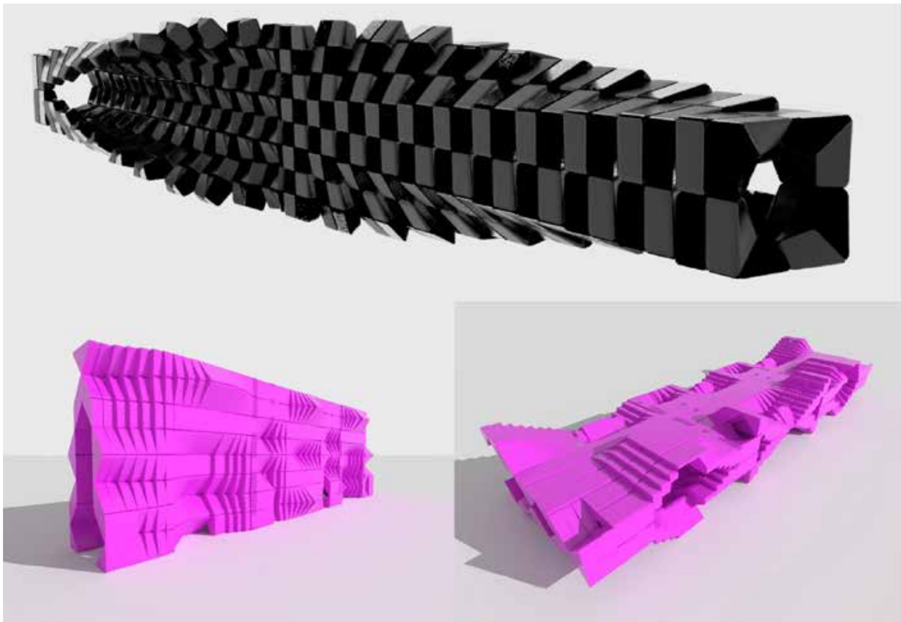

FIGURE 6.10 The first generation of HyperCell component on top, and a Duchamp Wall project following the same logic with more diversity of the morphing patterns.

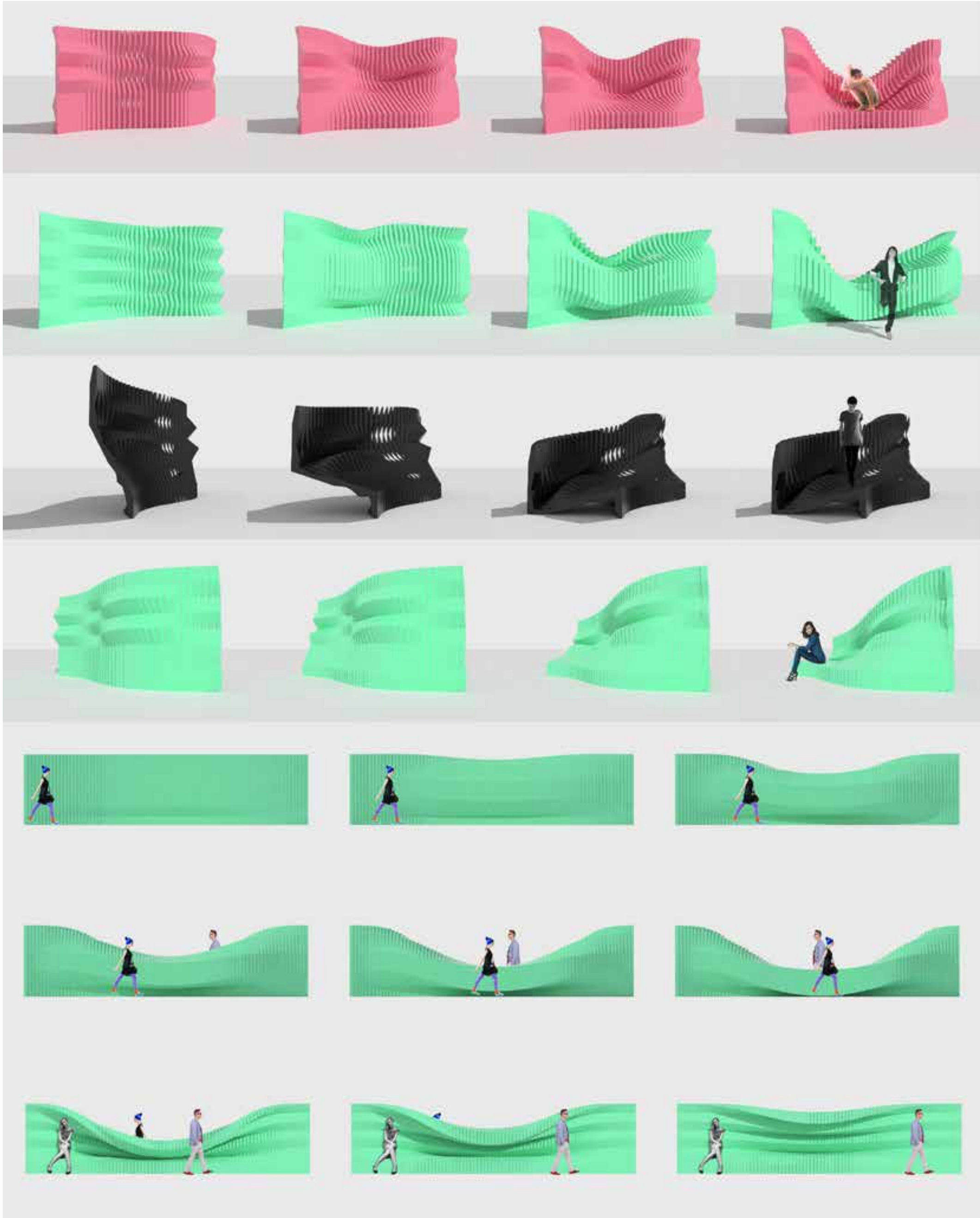

FIGURE 6.11 HyperCell 2.0 Furniture applications such as HyperCell Walls that can reconfigure (transform into) Seats, Counters, Ramps, Waiting Partitions, and Encountering Meeting Spots as multi-functional partitions owing to diverse time slots and users' demands.

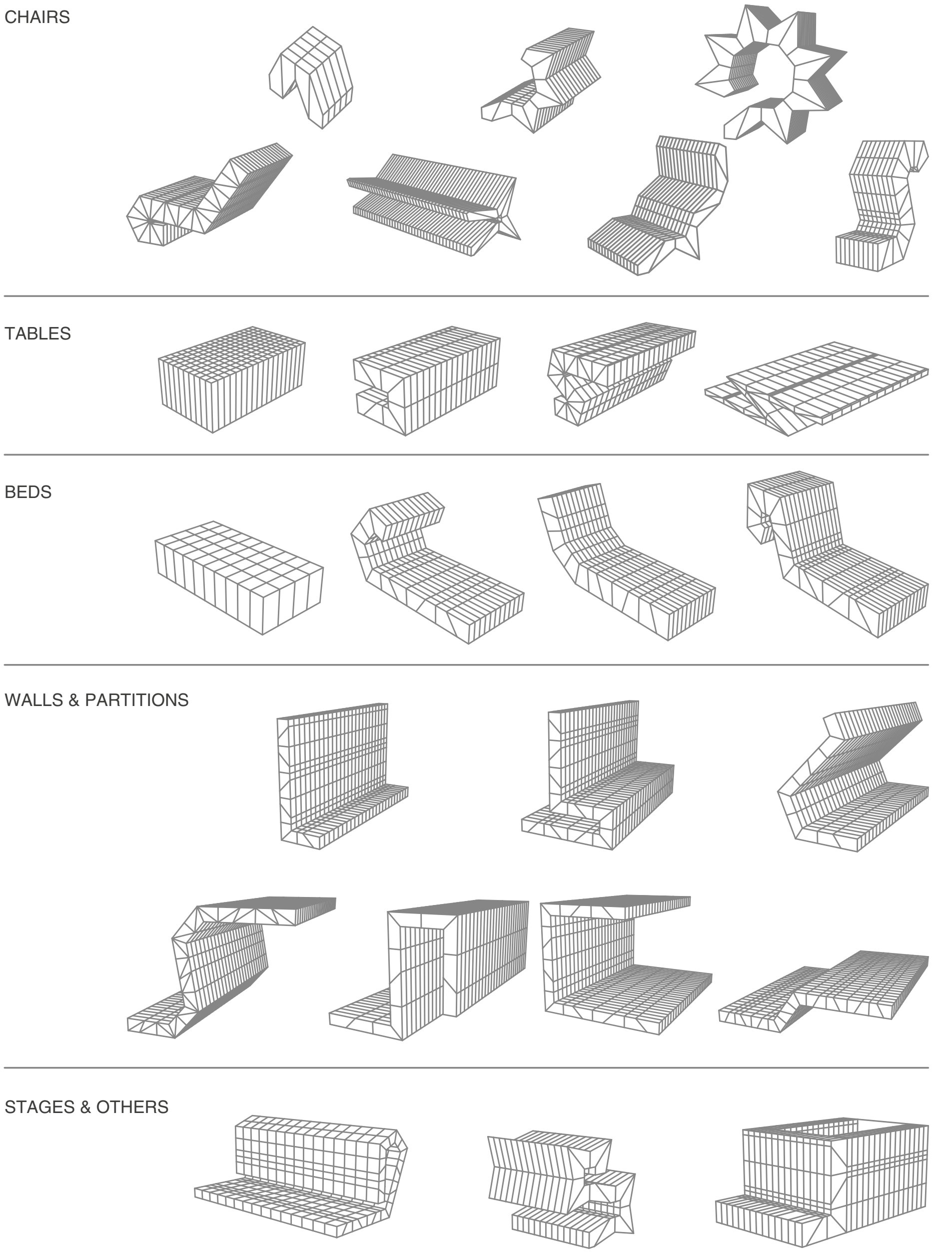

FIGURE 6.12 A 3D Diagram exhibiting the collections of the transformable furniture system made of "HyperCell" components as a catalog. These are variations but can include more diversity in terms of form and usage. The catalog with L-DAN and D-DNA is found in Appendix i.

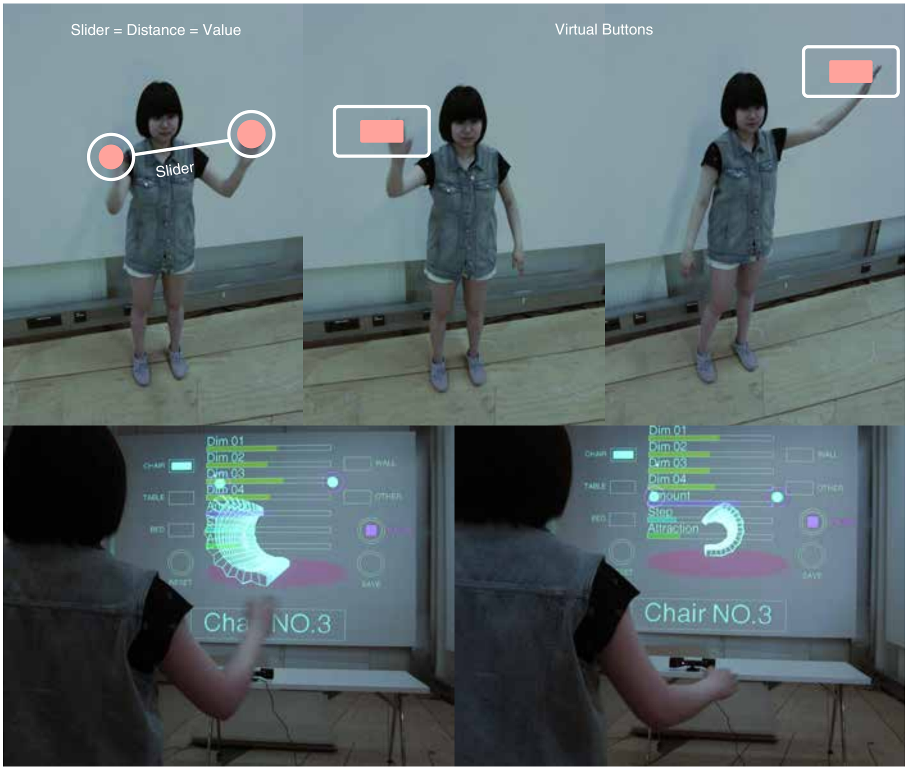

FIGURE 6.13 Top image shows the concept of virtual slider and button in accord with hand gestures. Bottom image records the utilization of the HyperCell interface in real physical space (see the video here: https://vimeo.com/68836252).

2 HyperCell: Intelligent Free-Hand Gesture Graphic User Interface (GUI)

With the availability of motion tracking technology and devices like Microsoft Kinect, it is possible to create a graphic user interface (GUI) in order to control the transformations of the **HyperCell**s. Resisting utilizing common gadgets like keyboards and a mouse to send messages to a computational device, the goal of this experiment intended to employ free-hand gesture (Body movement) to control the transformable **HyperCell**s. Each single hand acts as a cursor that can browse and push the pre-set buttons of the UI (User Interface) to accomplish simple selecting tasks. Besides, this, for detailing the input value on the UI, the distance between two hands will be remapped and defined relatively as an input value generating the resulting output. Here in the HyperCell interface, both hands can be used as cursors to select the furniture typologies from chairs, tables, beds...etc., and after picking up a certain category, the chosen furniture can be further detailed with the parameters manipulated with the distance between hands as sliders. The original vision with this GUI system was to make each **HyperCell** have the possibilities of reconfiguring by free-hand gestures without driving them always with a set of devices like a desktop computer with conventional gadgets[66]. Furthermore, just as PC stands for "Personal Computer", HyperCells furniture system can be regarded as "PF" standing for "Personal Furniture" named after the intellectual communication process in between the **HyperCell**s. As concerns the interactive intention between objects and users in the future developments, this UI system be translated and utilized as a visualizing software to generate customized furniture pieces. Using freehand gestures defining the furniture types and parameters, it is possible to export the digital files by simply pushing the "**Export**" button on the UI to create a 3D digital model for further detailing developments which can be available as a producing process for users to design their own style. To envision a network of communication protocols amongst each **HyperCell** as well as between each **HyperCell** and users, **HyperCell** is just an initial phase of non-verbal communication with expectations for future enhancements along with technological improvements (Figure 6.13).

3 HyperCell: Turns Simulation into an Immersive Virtual Reality Experience[67]

After exploring the geometric developments of **HyperCell** with several computational simulations and setting up the GUI as manipulating protocols with each **HyperCell**, the research decided to take the whole simulating space composed of the **HyperCell**s to an immersive spatial experience. The Microsoft Kinect device here is used for tracking the 15 joints of a human body but is implemented differently to arrange a setting to remap and rebuild the AVATAR onto the virtual reality world. A series of furniture functions and architectural elements were applied to be experienced from single user to multiple users with their intuitive reactions in schematic scenarios: a dynamic landscape will expand the space for a person presenting underneath; a sensitive wall will open to let a person pass through; a transformable shelter to provide people with seating as and when needed...etc. Realizing the installation through projections in an extremely dark room, people can easily experience tangibly the general idea of how these interactive **HyperCell**s would operate in real life as a virtual rehearsal. Technically speaking, only one Kinect device was used in this installation and all the computational calculations were done using Processing with a specifically designed library, simpleOpenni,

66 Please refer to the video for details of HyperCell Interface: https://vimeo.com/68836252.

67 Please refer to the video to see the HyperCell Virtual Reality application: https://vimeo.com/78387283.

to cooperate and collaborate with Kinect for tracing the body joints moving in 3-Dimensional space. Through the experience, the skepticism about the feasibility of **HyperCell**s can be rapidly eliminated. During the experience, people learned how to release and freely manipulate their body and initiate non-verbal communication with this reacting space (Figure 6.14).

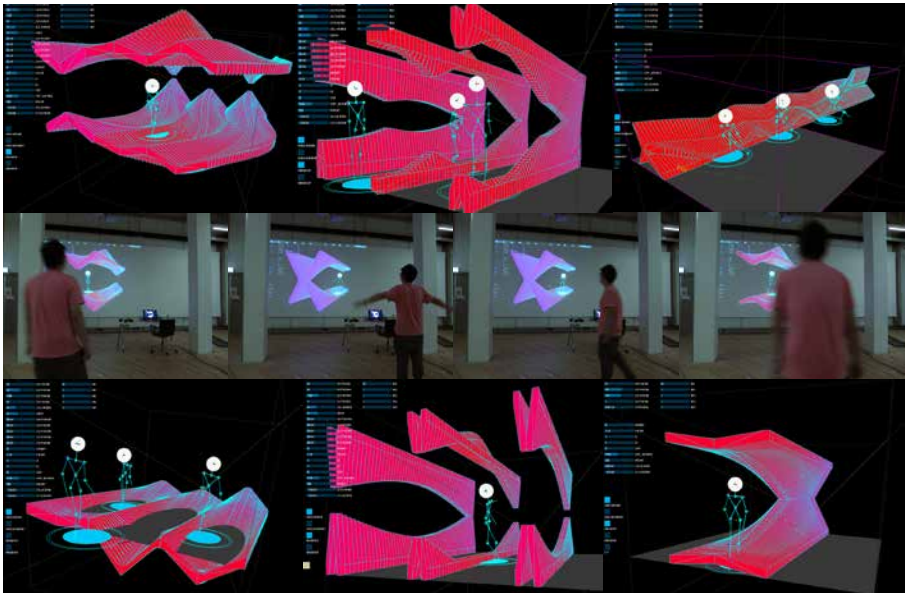

FIGURE 6.14 Images exhibiting the Virtual Reality Space built up by transformable HyperCell components which is able to interact with the users in real-time as an immersive spatial experience by utilizing the Processing real-time simulation and motion tracking technology cooperating with Microsoft Kinect (Please check the video for more understanding: https://vimeo.com/78387283).

§ 6.6 Brief Conclusion

In brief, the research so far illustrated the ideal features of the body-like interactive Bio-architecture (as new organic architecture) which has borrowed the six points from Maria Luisa Palumbo's viewpoints of "***New Wombs: Electronic Bodies and Architecture Disorders*** (Palumbo, 2000)**"** but re-interpreted them as a summary including the key points of each former chapter as "**Dis-measurement**", "**Uprooting**", "**Fluidity**", "**Visceral**

Nature", "**Virtuality**" and "**Sensitivity**". After that, it explained the reason why to treat the organic body-like architecture as an integration of all digital technologies that are applied in architectural design by the supporting argumentations titled as **3F**: **Form**, **Fabrication**, and **Fluidity**. Moreover, this lead to a proposal of a design framework: "**HyperCell**", for developing bio-inspired interactive architectural design by extracting biotic principles such as "**Simple to Complex to derive Componential Systems**", "**Geometric Information Distribution to derive Collective Intelligence protocols**", and "**On/Off Switch and Trigger to develop Assembly Regulations**" to generate organic body-like architecture. From a sociological perspective, the research pointed out the advantages this kind of reconfigurable space can offer to everyday users. In the last section, the research eventually took the **HyperCell** design frameworks into account to develop a series of experimental projects, especially the furniture systems, showing the potential possibilities and applications for user centric real-time spatial reconfiguration. In the end, the **HyperCell** is not only the title of the design framework but also a representation of each intelligent component exhibiting the architectural applications, GUI communication interface, and the immersive VR experience. The transformable cubic shape serving as **HyperCell**'s essential geometric module for furniture systems here is not claimed as an ultimate solution, but rather as an example showing the resulting variations and possibilities within this modular system by following simple logic like swarms. However, until now, this research has always taken the users' demands as a critical factor for this active transformable space supposing that the goal of this robotic re-configuring space is to fulfill the user's demands. Artistically, however, it implies questioning oneself at another level: how to think of space as a living entity, possessing its own intelligence and behavior, and how people will interact with such a space? This is a crucial topic discussed in the following section in this chapter.

§ 6.7 Living creature-like space with its own intelligence and behavior

In fact, the argument of "**Living Creature-like Space with Its Own Intelligence and Behavior**" has already been visited in one of the previous chapters. However, here, the user demands are no longer the first priority for such kind of an intelligent space. Instead, the discussion pursues the relationships and communication between humans and space. In other words, space is a living object that people have to get to know/understand and get along with, rather than, in a top-down commanding fashion instruct it about your wishes. Of course, this kind of "**Space with Intelligence**" has not only been discussed in architectural design but has also sparked interest in other fields of research, such as electronic engineering, computer science, and robotic development. Douglas Engelbart in his article "***Augmenting Human Intellect: A Conceptual Framework***" (Engelbart, 1962) has envisioned an intellectual space which he called "**augmented architecture**" as a working space for architects. But it is more akin to a Sci-Fi movie imagination, the description of his imagination was mainly addressed on high-technology gadgets, such as touch screens, holographic display systems, and how the architect in the narrative uses a pointer and collects data for improving design, which basically illustrates a scenario in which the intelligent space itself acts like a huge computer device. Certainly, the space should have the ability to act as an intelligent computational device to deal with all kinds of occasions but it should perform not only as a tool or device for people to develop "**living creature-like architecture**". The vision that "'**IA' system will disappear into our buildings and become the architecture itself** (Fox, Michael, & Kemp, Miles, 2009)" clearly outlines how the intelligence of a space shouldn't be embodied only as a top-down commanding computational device but should be fused within the space itself. "**Liquid Architecture is an architecture that breathes, pulse, leaps as one form and ends as another…it is an architecture that opens to welcome me and closes to defend me…**" (Novak, 1991), argues Marcos Novak's Liquid Architecture which eventually illustrated a vision of intra-active architecture with intelligence and free-will for interacting with users in multiple ways as a living creature. Unlike the one-directional interaction operating as a switch to turn a device on or off, **Liquid Architecture** has various sensors omnipresent on its skin, which filters data to make resulting moves in accordance with the emerging input values from all sensors. In the research, the componential idea is retained since the beginning, the intelligence of the space here should come as a collective intelligence emerging from bottom up. This collective swarm idea cooperating with intra-active architecture can be observed in the theory of "**HyperBodies**" of Kas Oosterhuis. "**True hyperBodies are proactive bodies, true hyperBodies actively propose actions. They act before they are triggered to do so. HyperBodies display something like a will of their own. They sense, they actuate, but essentially not as a response to a single request**" (Oosterhuis, HyperBodies: Towards an E-motive Architecture, 2003). Both Marcos and Kas would like to envision a scenario where the space can have its own will to react with either the environmental conditions or the artificial human movements. Therefore, artistically, the critical problem raised here is to question people involved in the space as to how they will execute, conduct, react, think of, confronting such a space with its own will, and how can one set up communication protocols or networks between the human body and the architectural body.

In order to answer such questions, the author was fortunate to be a part of a European Cultural Project, MetaBody[68] in July of 2013. Media artists, digital music composers, choreographer, dancers, performers, programmers, designers, and architects from 7 different countries in Europe were brought together to cooperate and develop performances and spatial projects following the major discourse of the MetaBody. The critical idea of MetaBody is to question the homogenization of expressions in the current information and controlling mediums and to break through boundaries to release and provoke the already-formulated body movements by interacting with pro-activeness in architectural space both digitally and physically. During the participation in MetaBody, two major deliveries were contributed by the research as concerns both digital and physical prototyping. These were in the form of two intra-active projects: "**Ambiguous Topology**" and the "**HyperLoop**" pavilion. These, are described in the following sections.

§ 6.7.1 Ambiguous Topology

FIGURE 6.15 Image of "Ambiguous Topology".

68 Please refer to the links: http://metabody.eu/ or http://www.hyperbody.nl/research/projects/metabody/.

Ambiguous Topology Introduction

Ambiguous topology[69] is an installation which incorporates creatively combining dynamic movement of the human body and swarm intelligence driven generative geometry production capabilities realized by volumetric projection systems. It is a five-minute immersive light experience in which the speed, frequency, and intensity of movement of a participant's body are used as triggers for activating a swarm of volumetrically projected digital particles in space in real-time. The usage of fully immersive volumetric light projection media to visualize 3D geometric morphologies in the swarm of digital particles renders abstract 3D topological nuances within which the participant navigates. This resulted in the generation of both interactive as well as pro-active behavior from the participants as they experience new states of ambiguity and dis-alignment. A looped data driven relationship is thus successfully established between the digital, physical and embodied corporeal space.

Volumetric Projection System

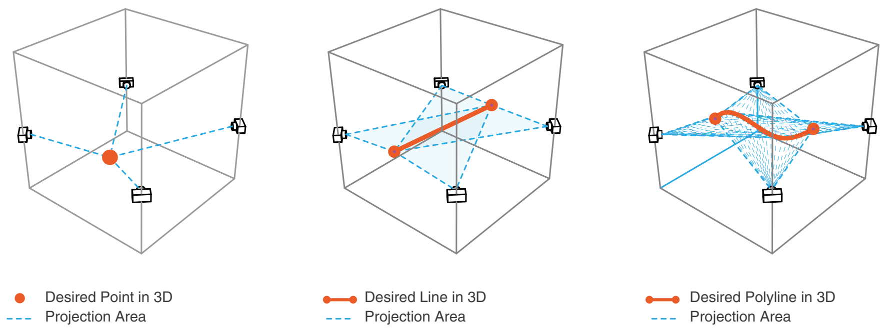

FIGURE 6.16 Diagrams showing basic principles and setup for 3-Dimensional geometry realization based on the volumetric projection system.

69 For more detailed understanding and outlines of the project, "Ambiguous Topology", please check the video here:
https://vimeo.com/105027652 , https://vimeo.com/105421757, and related paper of
Chang, Jia-Rey, Biloria, Nimish, & Vandoren, Dieter. (2015). Ambiguous Topology from Interactive to Pro-active Spatial Environments. Proceedings of the IEEE VISAP'15 Conference: Data Improvisation (pp. 7-13). Chicago: IEEE VISAP. (http://visap.uic.edu/2015/VISAP15-Papers/visap2015_Chang_AmbiguousTopology.pdf)

"**Volumetric Projection System**" is the main technique for materializing the simulated geometries in real physical space. The interpretation and production of 3-Dimensional simulated geometries using the light projection system, or in other words "**volumetric projection**", has been developed by the media artist; Dieter Vandoren (one of the team members of the Ambiguous Topology project). This involved the extensive use and customization of Max/MSP based routines. In terms of hardware, four high-resolution projectors are located in four corners of the affective space in order to attain a fully immersive interaction zone at their point of convergence. Besides this, one Microsoft Kinect device is used for motion tracking and is placed at the center (front facing) of the interaction zone. Within this physical set-up, unlike with the hologram projection, specific ways of interpreting geometries with light projection, such as points, lines, polylines etc. are developed as stated below (Figure 6.16):

1. Point: A point in 3d space is visualized by the intersection of four light beams from four projectors located in four corners of the space. As a result, participants experience this specific point as four light beams' instead of a single light pixel flying in space. This principle is mainly implemented for realizing each point's location in space using different colors.

2. Line: A line in 3d space is achieved by the intersection of four light planes from four projectors located in the corners of the interaction zone. In other words, in accordance with the projection angle, the participants would see a spatial intersection line built up in the interaction zone as four triangulated planes.

3. Polyline: A polyline in 3d space is achieved by the intersection of light planes with a curvature from four projectors located in the corners of the interaction zone. Because of the original geometry's curvature and the limitation of the projection angles, participants mostly will be surrounded in the conical shape created by the light projections.

Swarm Behavior Premise:

The particle system simulations responsible for the generation of the constantly transforming topology is essentially based on Craig Reynolds' swarm (flocking) behavior principles developed in 1986 (http://www.red3d.com/cwr/boids/) (Reynolds, Steering Behaviors For Autonomous Characters, 1999) (Reynolds, Flocks, herds and schools: A distributed behavioral model, 1987). By observing flocks of flying birds, Craig Reynolds developed a swarm behavior simulation to mimic numerous animal species, which intend to move collectively as gigantic creatures, for example, birds, fish, and bees, etc. **Separation**, **Alignment,** and **Cohesion** are the three major principles of swarm behavior determining each agent's intelligence virtually in the flock. Separation implies avoiding crowding next to each other, alignment implies steering towards the average direction of the neighboring flocks, and cohesion implies driving the agents' movement towards the average position of the local agents (Figure 6.17). Using the combination of the above simple rule sets encoded within each agent, emergent clustering formations can be derived. **Ambiguous Topology**, and its inherent drive to generate continuously transforming topologies at a global output level, harnesses these simple rules set based behaviors and embeds them within each constituting particle in the simulations. Emergent topological formation as a result of local level interactions within the swarm of particles is thus a novel attribute that is exploited within the installation.

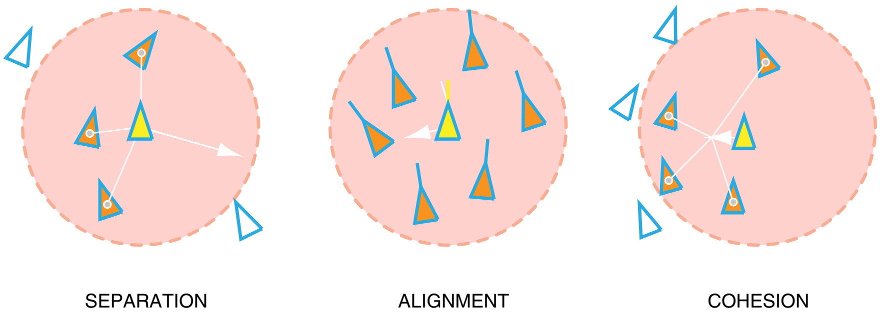

FIGURE 6.17 Diagrams of Craig Reynold's swarm behavior principles for the flocking simulation; separation, alignment, and cohesion. (http://www.red3d.com/cwr/boids/).

Furthermore, as an interactive installation, the particles/agents within the installation specifically, relate to the participant's body movements in real-time. Therefore, the propulsion of agents is not only influenced by their internally coded rule sets in accordance with the swarm behavior principles but also driven by the participant's reactions. In other words, participants can create attracting or repelling forces by propelling the agents to affect their 3d location, velocities, and accelerations through different narrative scenes in the installation. In order to communicate the state of each agent's locomotion and energy levels to the participants, color gradients within the projections are utilized as a clear visual cue. Aggressive colors, such as red and yellow indicate high value of locomotion compared to blue and green, which express relatively passive and stable agent movement. As regards the 3-dimensional projection of agents, all agents are exhibited as "**Points**" using the aforementioned projection logic with the color gradient representing their energy and movement state. These colorful light beams strongly encourage the participants to engage in the Ambiguous Topology installation without any external persuasion.

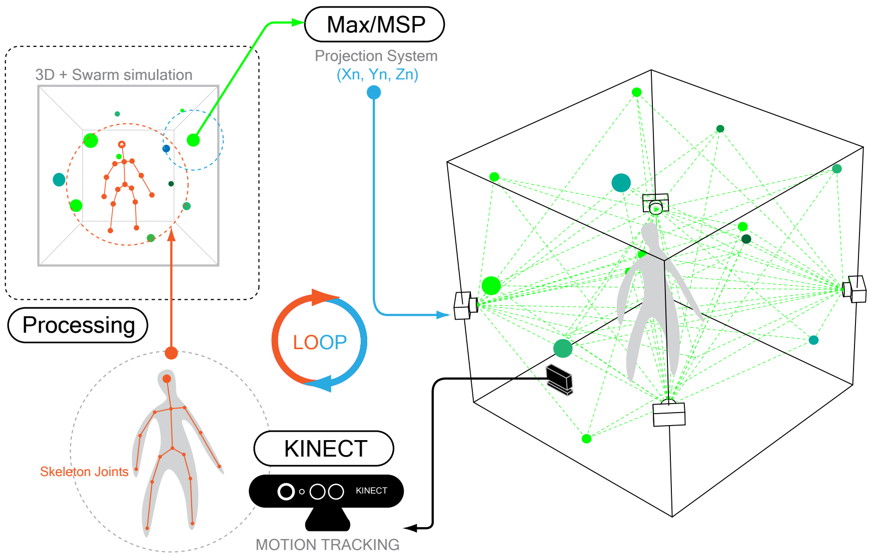

FIGURE 6.18 Diagram showing the interactive loop of data streams.

Technical Interpretation:

The agent-based simulation is created using an open-source programming language, Processing. Hardware wise, the motion tracking system in Ambiguous Topology is set up by utilizing the Microsoft Kinect device and is correlated with simpleOpenNi which is a motion-tracking library of Processing. All computational processes are calculated and simulated in Processing 3-Dimensionally based on swarm behavior principles which, were directly networked with skeleton tracking based data from Kinect. During the computational process, Processing simultaneously transmits the required data, the coordination of the autonomous particles, to a platform set up in Max/MSP through OSC (Open Sound Control) protocol. By establishing a communication protocol between Processing and Max/MSP, the X-Y-Z coordinates of each swarm agent's location is synchronized with the projection system to materialize three-dimensional geometries in space using the aforementioned volumetric projection principles. Furthermore, after receiving the input data from Processing, the Max/MSP patches are able to adequately implement it with the render mode for the HD projectors (Figure 6.18).

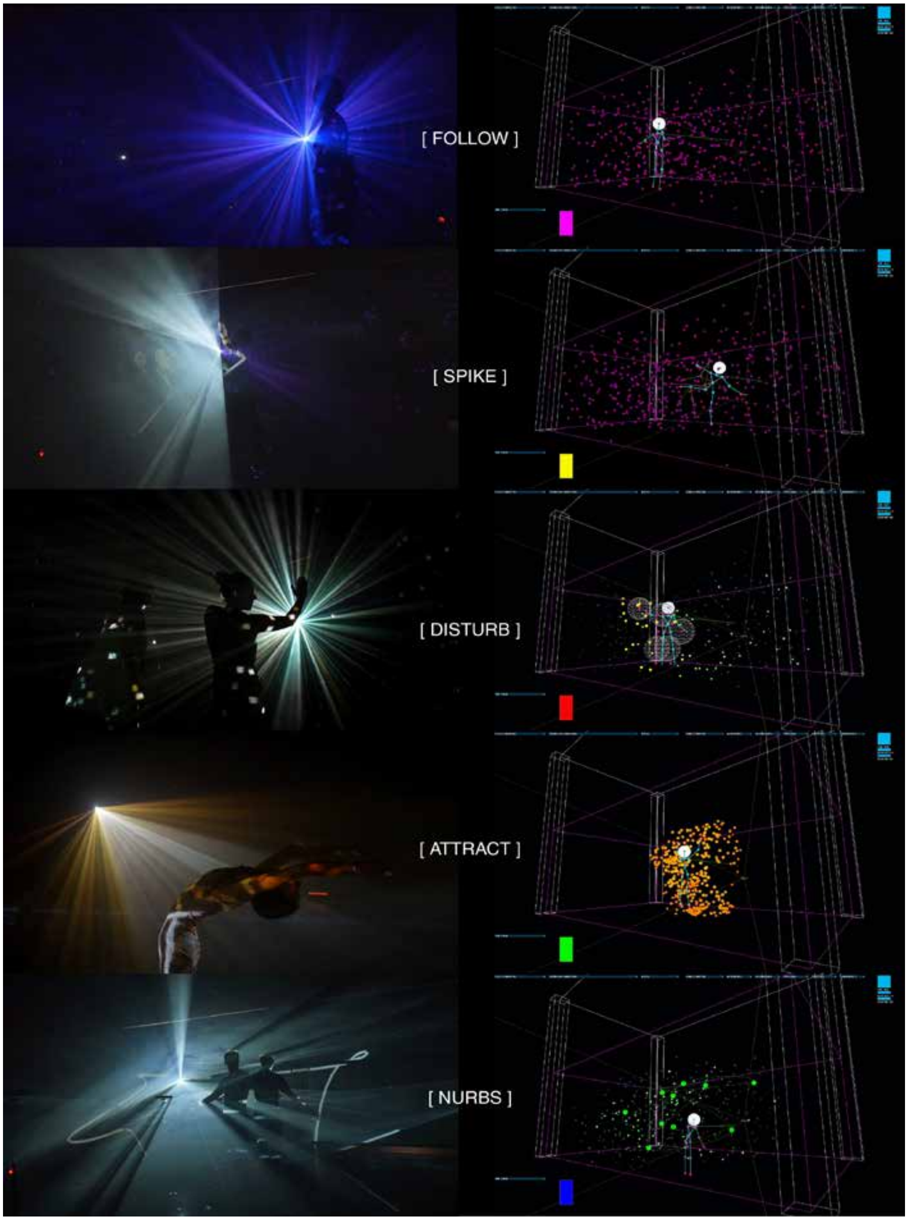

FIGURE 6.19 Images showing different modes of the Ambiguous Topology experience with scenes of "Follow", "Spike", "Disturb", "Attract", and "Nurbs" mode from top to bottom with photos taken on the left and simulations on the right side.

Settings and the Narrative:

After meticulous development and user testing, **Ambiguous Topology**, was successfully set-up as a real-time immersive public installation in Media-Prado, Madrid, in July of 2014. The site allocated for the installation allowed, an effective interaction zone (the convergence point of the four projectors) of 6 meters in width (X-direction), 5 meters in length (Y-direction) and 5 meters in Height (Z- direction). 640 agents/particles embedded in the space wait to be triggered by the influx of participants. Seven fundamental narrative modes are developed and arranged in a fluent sequence in order to facilitate a holistic experience to the participants. These narratives are sequenced as different modes in the following order: **Rain Mode, Follow Mode, Spike Mode, Disturb Mode, Attract Mode, Nurbs Mode, and Rain-Up Mode**. These are described in the following sections in conjunction with the participant's experiences.

Rain Mode:

The Rain Mode is triggered by the presence of people (tracked by Kinect) within the allocated installation space. A high-velocity downpour of 640 agents/particles constituting the installation akin to heavy rainfall is immediately set in motion. The agents gradually reduce their speed of falling and completely cease to do so in certain locations in space. This is accompanied by a change in the color gradient of the agents (from magenta to dark blue), indicating the change in the velocity levels of the agents; from high velocity to a stable and calm state.

Follow Mode:

This is the first instance that participants provide an impulse to the agents. Each movement of the participant creates a flux in the agent field (based on the aforementioned swarm principles) within which they are immersed. The swarm logic further entails that the agent propels its movement to the nearest neighbors and thus a ripple is sent through the virtual field as an emergent global outcome. It was observed that over time, the swarm of agents in space tends to follow the average direction of movement of the participants (if they move in the same direction). However, if two participants attempt to move in opposite directions, the swarm tends to remain stable. Furthermore, differential agent velocities of the entire swarm are the result of the participant's movement velocity and thus tend to speed up or slow down, with high-velocity states depicted as magenta and low state as blue. This mode thus subtly engages the participant via responsive interaction and hence provokes physical movement of the participants (Figure 6.19, Follow).

Spike Mode:

The Spike Mode involves the introduction of geometry using the volumetric projection system. In this narrative, along with all the existing colored agents, pure white lines are *exhibited (line-connections). These lines are directly connected to the distances between the nearest agents of the swarm and are specifically triggered by tracking of the participant's body joints. Both hand and feet joints of the participant's digital skeletons (as seen via Kinect) are specifically chosen. Thus, while waving one's hands and feet, any two agents falling within this waving path, which is triggered establish a connection depicted by a white line to be drawn between them. Because of numerous autonomous agents floating around the participants, they can freely and easily generate these flashing lines and start manipulating them once they unravel this simple logic. Some characteristics of the Follow Mode, such as the panning effect and color gradations are retained in this narrative and tend to seamlessly blend with the characteristics of the Spike Mode. (Figure 6.19, Spike).*

Disturb Mode:
The Disturb Mode is the narrative where a shift from responsive to pro-active interaction germinates. Participants lose the ability to influence the movement of swarm agents using their own body movements. Additionally, all the agents, as autonomous entities start losing their energy, turn transparent and become almost invisible in space. In reality, once the agents lose their momentum, they become imperceptible and acquire a state of readiness for new stimulation from the participants. By touching, pushing, swinging the invisible agents, the participants actually feed/pass the agents energy and trigger their movement again. Each participant's hands and knees, now, become activating nodes, which, in turn, influence the agents, based on the momentum produced by the movement of the participant's joints. The faster the participants move, the larger the area of influence of the agents is, and thus the impact on the agent's velocity and energy is also stronger. The swarm logic behind the scenes implies that active agents seek to influence other passive neighbors and thus set forth a non-linear movement. It was observed that the participants tend to become keen and keep trying different body postures and movements to gradually set the dormant swarm in action once more (Figure 6.19, Disturb).

Attract Mode:
The Attract Mode involves the swarm of agents to suddenly and aggressively move rapidly towards the participant. This is also accompanied by the agent's switching their color to an aggressive red and yellow gradient. In this mode, the agent simulations are programmed to be attracted towards the participant's hands and feet in order to create virtual polygonal geometries in space. Over a period of time, these virtual polygons unknowingly produced by the participants also appear in white along with other colored agents thus distinguishing the polygonal geometries the participants generate. Once the participants become aware of this game-play, they instinctively start attracting the agents via producing strange but interesting movements, such as changing moving direction rapidly, jumping up and down radically, and curling or stretching bodies oddly (Figure 6.19, Attract).

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Nurbs Mode:
In the Nurbs Mode, the participants are allowed to push, wave, and touch the agents similar to the Disturb Mode. In addition to this, a continuous transforming nurbs (spline-line) is materialized based on the agent aggregation based density in space. On an average, ten locations coinciding with ten densest locations of the agents in space are selected as control points to construct the nurbs. Since the agent densities can be impacted directly by the participant's influential movement in space, the nurbs geometry fluidly morphs from one shape to another shape (Figure 6.19, Nurbs).

Rain-Up Mode:
Before the "Rain-up Mode", the "Follow Mode" is exhibited again to gently inform the participants that the experiential installation is nearly towards the end. After a few minutes of "Follow Mode", the participants entirely lose their control over all the agent movements and only witness the agents flying back up to the sky. All the agents will fly up with high velocity and gradually slow down to cease in a certain location in space. In terms of color, all the agents start with magenta representing higher speed and become dark blue corresponding to the velocity each agent embodies. Towards the end, all the agents lose their momentum, turn transparent and tend to fully disappear. Hence, the whole space returns back into an entirely dark state awaiting the next group of participants to engage with.

Ambiguous Topology Conclusion

Ambiguous Topology is an innovative experimental installation which intends to challenge conventional modes of perceiving space as a dormant object and abolishes the subject-object relationship, which has long been associated with it. Space, in this case, acquires a pro-active character and most importantly is built up via a non-tangible entity: Embodied Visible Light. The installation also physiologically and psychologically appeals and instigates our regulated behavioral selves resulting in the generation of novel reactions and interactions. **Ambiguous Topology** thus attempts to create a fully transformable topology composed of numerous autonomous agents to achieve a unique e-motive spatial environment. Different geometric instances of the fluid environmental topology are generated via the interplay between the participants and the conceived system and are materialized via the immersive light projection (volumetric projection) system as a meta-narrative. As a result, an intimate relationship between the overall environment and participants naturally appears during the experiential phase. Meanwhile, an information feedback loop is at play, which binds the physical interactions of the participants, with soft simulation and computation processes to ultimately impact and influence the participants' behavior in real-time. During the interaction process, novel movements, group dynamics, and gestural novelty came to the fore. The research was thus able to address an individual's innate bodily and mental experiences. In this five-minute immersive/interactive environmental experience, **Ambiguous Topology** gives the participants opportunities to introspect, engage, influence and explore their perception and inner creative instincts in an engaging experience. As aforementioned, in **Ambiguous Topology**, one of the main characteristics is to utilize the non-tangible entity: light, to create an immersive dynamic environment. But in the "**HyperLoop**" pavilion, the research attempts to develop a physical interactive dynamic space made with real materials so as to be truly tangible.

§ 6.7.2 HyperLoop, an Intra-active Pavilion

The preliminary idea of the **HyperLoop** pavilion[70](Figure 6.20) is to create a transformable, portable, mobile space as an interactive environment with abilities to physically morph akin to a creature with its own will. It is a large-scale real-time interactive structure which is in a constant state of flux. Once again, it is similar to how Marcos Novak outlined his "**Liquid Architecture**" and Kas Oosterhuis outlined his "**HyperBodies**": the architecture has embedded emotions and its own behavior which help it to react in different contexts. **"…it is an architecture that opens to welcome me and closes to defend me**" (Novak, 1991) and "**…they sense, they actuate, but essentially not as a response to a single request**" (Oosterhuis, HyperBodies: Towards an E-motive Architecture, 2003). In this sense, the architecture from the users' point of view is never a controllable space which can fulfill their requests. On the contrary, the user has to find ways to cooperate with this gigantic holistic sensible body by setting up a relatively intimate relationship with it. This research envisioned this dynamic interactive space would induce or evoke common people to get out of their comfort zone to react in unusual/unconventional ways with their body gestures. This is one of the main goals of the pavilion. The pavilion practically speaking, would also be used as an interdisciplinary laboratory for scientist, programmers, artists, biologist, performers, choreographers, designers, architects…etc., who are interested in experimenting with reversal of homogenization of expression caused by current information technologies and surveillance mediums.

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70 Please refer to https://vimeo.com/117388146, http://www.hyperbody.nl/research/projects/the-hyper-loop/, and http://re.hyperbody.nl/index.php/Msc2G7:Frontpage, for a detailed description of the development process of HyperLoop and the related video.

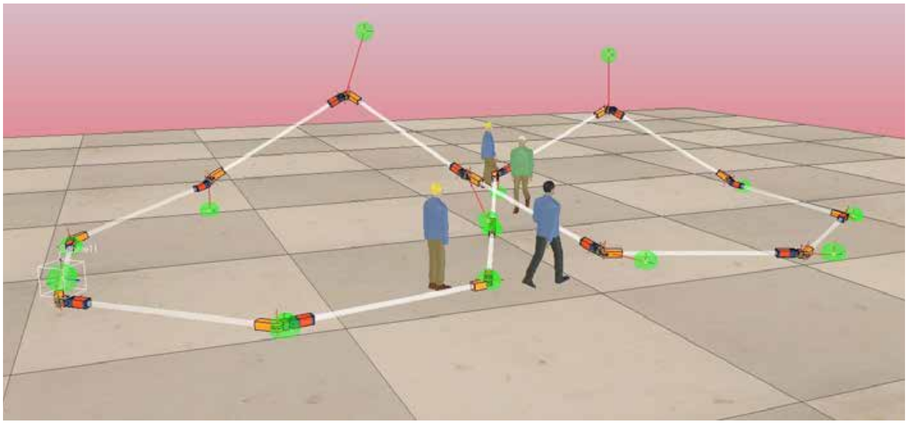

FIGURE 6.20 HyperLoop pavilion simulation by V-Rep.

For executing this interdisciplinary project, the research cooperated with Delft Robotics Institute to have professional support from their Mechanics, Electronics, Systems and Control faculties. This research mainly focuses on the multi-directional development of the large-scale dynamic structures and intends to realize it and experiment with it in a scaled-down prototype. Practically, this large-scale structure is composed of 12 distributed joints with various degrees of freedom, and geometrically takes the form of an infinite loop (it can also be in a sense seen as an 8-shape Mobius ring), which can fully re-configure its constituting components in real-time (Figure 6.21). Therefore, the joints of the Hyperloop play extremely crucial roles from both the design and engineering points of view. Each joint acts as an independent agent in its own right and hosts **micro-controllers**, attached to **motors/servos** in addition to **sensing systems** (which can track the proximity of people) and local sound and light emitting sources. In other words, the joint with the structural tube should be seen as the "**HyperCell**" component in this case which has basic intelligence with degrees of freedom to physically transform to enable multiple interactions. Each joint is thus an agent of the holistic swam: the **HyperLoop**'s body. In terms of interaction scenarios, the makeup per joint is aimed at generating a fully kinetic and sonic real-time interaction with people approaching or leaving the structure as well as moving within the structure itself. The entire loop is thus being a fully dynamic structure akin to an exploratory robot, which harnesses different capacities of movement, sound, and light as an active medium of communication with its visitors.

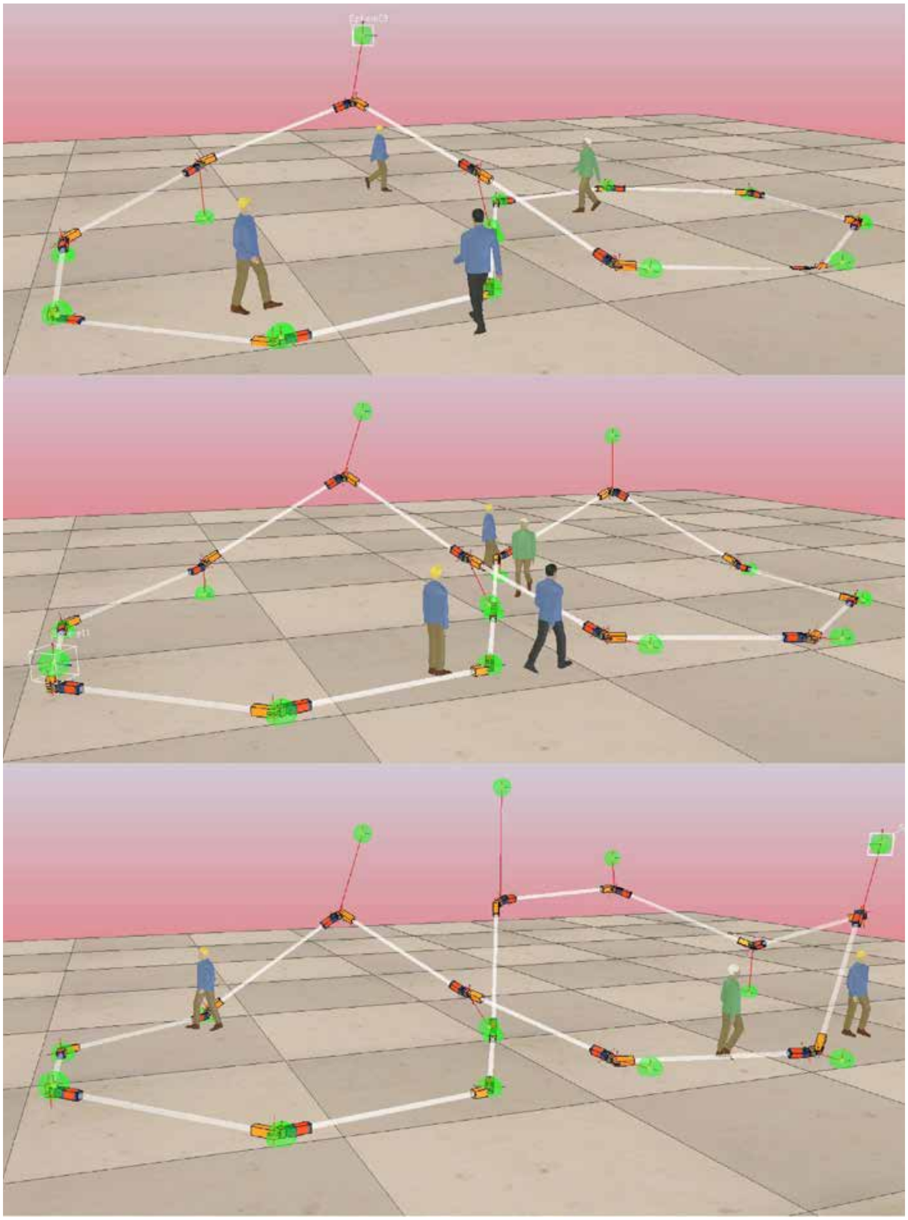

FIGURE 6.21 The real-time morphology simulation of HyperLoop acting by embracing and repelling movement among the people surrounding it by V-Rep.

HyperLoop Simulation, a mere step before physical prototype

= Mechanical Make-up + Consensus Algorithm

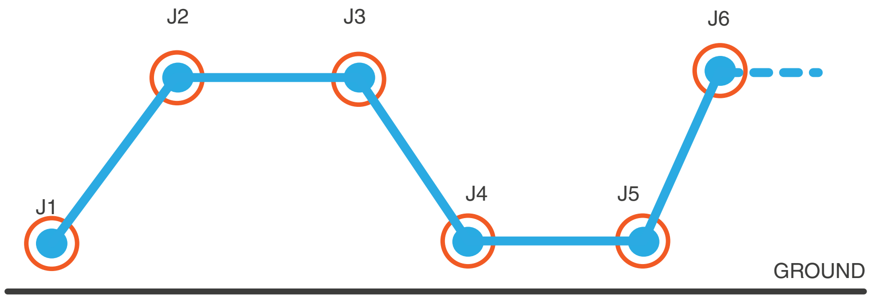

FIGURE 6.22 Diagram explaining the mechanical loop structure concerning the capability of the joint against gravity: NO.1 joint staying on the ground can possibly hold NO.2 and NO.3 joints in the Air but NO.4 joint would have to stay on the ground in order to support the structural stability.

In order to precisely realize the actual conditions of the **HyperLoop** structure, this research had to rely on professional mechanical engineering software, "V-Rep" (Virtual Robot Experimentation Platform) based on a distributed control so that each object/model can be individually controlled via an embedded script, a plugin, an ROS node, a remote API client, or a custom solution within the software operation. As a loop-shaped structure, the crucial mechanical task is to retain the connectivity of the structure keeping the enclosure condition as a chain-like polyline. The key point in making this task happen also relies heavily on both the mechanical design of the joints and the mathematical algorithms keeping the overall shape constantly unbroken. Within the V-Rep simulation, it can be relatively easy to represent all the different conditions and configurations of the real dynamic structures but the most important bit is to embed the limitations/physical constraints, such as gravity, motor torque, and the mechanical degrees of freedom. The research was able to import the 3D model of the **HyperLoop** structure and examine real-time manipulation of mechanical simulations virtually within V-Rep. One of the crucial mechanical constraints in the design of **HyperLoop** is that any one joint can at a maximum support 2 neighboring joints in the air. In other words, if there are labels tagging on each joint, the J1 joint staying on the ground can possibly hold J2 and J3 joints in the air but then J4 joint would undoubtedly have to stay on the ground in order to support the structural stability (Figure 6.22). Certainly, the torque of the joint should be taken into account while simulating the transformations of the **HyperLoop**. The **HyperLoop** transformation depends highly on the interaction scenarios triggered by the data gathered from the embedded sensors which are fed to microcontrollers mounted onto each joint. Therefore, it puts more load on the computational calculation for searching for a dynamic homeostasis or balance condition. Nevertheless, the V-Rep software can provide a 3D platform for robotic simulation, but the calculation of torques, physical constraints as morphological principles, the interactive reaction driven by the data coming from pre-set sensors, and the communication protocols amongst each joint in order to balance the overall **HyperLoop** body, require advanced programming tools to conduct such heavy calculations. This is done using two software suites, "MatLab" and "Mathematica".

"MatLab" is used initially following all the above constraints and principles to program suitable algorithms mainly for mechanical examinations. "Mathematica" then takes the algorithms in and sets-up the control system and communication protocols as a test model meanwhile sending the resulting outcomes for visualizing simulations under the V-Rep's environment, confirming the feasibility of dynamic stability of this large-scale transforming structure. The complexity of the **HyperLoop's** movements comes from the real-time calculation since each moving step will result in disrupting the balance of the entire loop instantly and thus requires an immediate response to gain back the balance. This results in a relatively complicated situation waiting to be solved owing to the resulting torque and driving angles of the joints. Once this particular angle is decided, the rest of the HyperLoop's joints have to respond in order to maintain the balance of the overall body while maintaining the closed loop condition. To keep the balance while simultaneously deriving and communicating the new adjustments/positioning of the joints, the development of a "**Consensus Algorithm**" is critical. **Consensus Algorithm** works on the basis of distributed communication that calculates an agreement/consensus among a number of processes to obtain a set of data values, in time, which drive the **HyperLoop**'s joints. For instance, once one of the active joints, `joint_1`, receives a value(`V1`) from the attached sensor for driving this specific joint to move to a certain angle(`A1`), this angle value(`A1`) will pass through to inform all the other joints. After all the rest of the joints have been informed, they will decide to agree or disagree with this change. If in agreement, `joint_1` will move to the angle `A1`, and the rest of the joints will follow a balancing equation accordingly to change/or not to change their positions; if in disagreement, `joint_1` will propose another relatively minor angle value(A2) and once again pass it through the rest of the joints to search for a possible agreement. The process goes repeatedly until all the joints entirely agree, and they will eventually follow the decision and make the resulting movements. Thus, every time there is a sensing value coming in, all the joints mounted on **HyperLoop** will run the whole process again and again until they reach a consensus. As mentioned before, the task of "MatLab" and "Mathematica" are mainly to examine the overall computational calculations virtually and later on input this into "V-Rep" to simulate various morphing conditions in the real physical environmental settings to prove the correctness, precision and the feasibility of the sophisticated mechanisms and network protocols. Once the applied mechanisms are proven, both MatLab (in terms of mechanisms) and Mathematica (in terms of internal communication) algorithms are translated into a programming language in accordance with the applied microcontroller, which is an Arduino in this case, in order to develop a scaled prototype.

Joint Design Developments

Before having a strong support from the Delft Robotic Institute, this research was dedicated to the crucial development of the joint's design both in terms of its form and in its mechanism. After the Delft Robotic Institute joined the project, they gave professional suggestions and re-designed the joint from the sense of efficiency of the mechanics points of view. Several motorized propulsion mechanisms were considered, such as Mechanical, Hydraulic, Pneumatic, and Electrical. Hydraulic and Pneumatic are both powerful and controllable but not accurate enough for the **HyperLoop**; Mechanical methods use fuel which makes it heavier to lift as a joint needed to be in the air within **HyperLoop**; Electrical was then deemed as the ideal choice, which is easily controlled with accuracy and is light weight enough to attain flexible positions. Three phases of developments listed as "**Initial Thought**", "**Idea Proposal**" and "**Physical Prototyping**" will illustrate the evolution of the joint design both in terms of form and mechanic composition.

Initial Thought:

This is the phase before having the contribution of the Delft Robotic Institute.
To make an enclosure loop and at the same time provide the joints can be freely 3-Dimensionally posed in different overall morphologies, the idea was to have 3 servo motors which were in charge of 3 different axial rotations to complete the tasks (Figure 6.23). As for transportation, it has to be easy to be delivered and assembly on site. This specific transportation idea drove the joint design to be easily assembled and de-attached. Therefore, all the electronic devices, such as microcontrollers, motors, and sensors, were designed to be impacted and embedded inside the joints for quick and easy assembly. In this phase, the research set up general principles for the joint design, and also brought out the confronting problems to be solved by numerous experimental examinations either with simulations or physical prototyping.

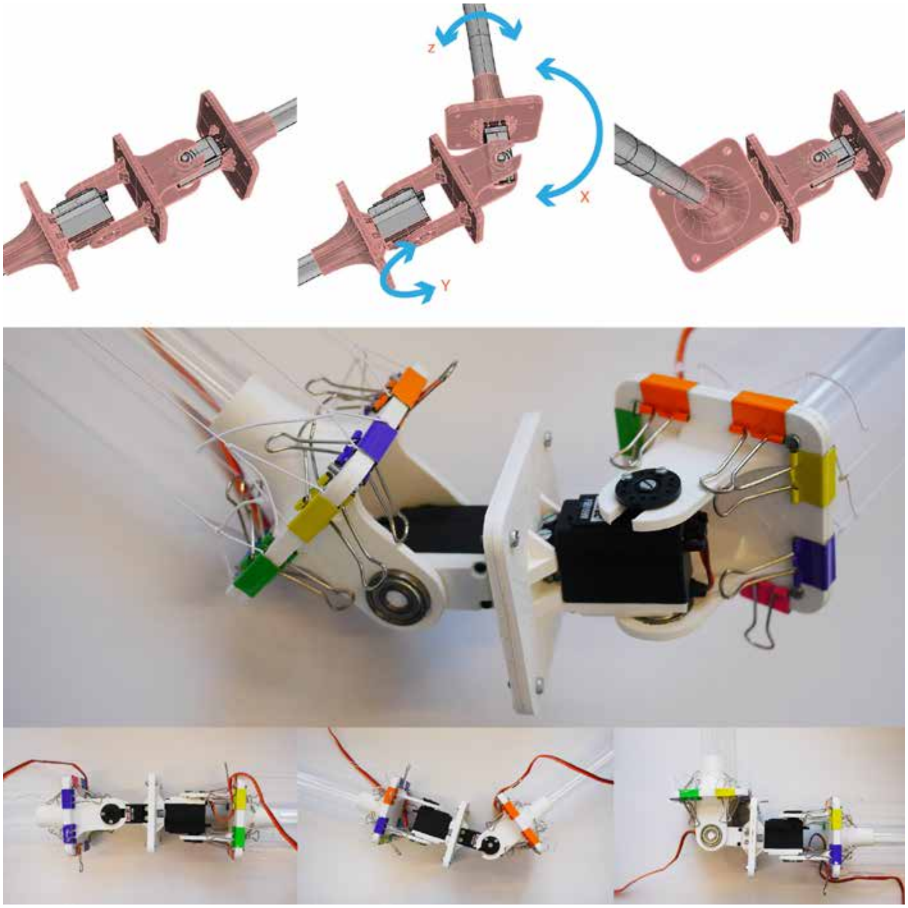

FIGURE 6.23 Diagrams illustrating the flexibilities and the rotation axis of the joint design at the initial experiment stage. The bottom is the photo of the 3D printing prototype embedded with 2 servo motors as the rotating actuators.

Idea Proposal:

Along with the consultants of the Delft Robotic Institute, several undergraduate students joined the team and made the project a collaborative effort enjoying their professional contributions. In this phase of design, the motorized devices were reduced to only two servo motors to keep the same performance, but mechanically simpler and lighter weight for the sake of lifting the joints as one of the major tasks. Mechanically, two directional rotations are controlled by two motors in a set of joints. By inserting the structural tube inside the controllable joints, the **HyperLoop** can complete exactly the same motion as with the three motors version proposed in the initial phase (Figure 6.24). The structural tube should be at least 2 meters in length as a hollow tube not only for the sake of light-weight but also for the convenience of putting the required electronic wires inside as connections and for system protection. The joint was designed as a ball (sphere) shape in order to reduce the friction while touching the ground which might be taken as extra opposing forces and at the same time protect the crucial electronic devices inside the joint.

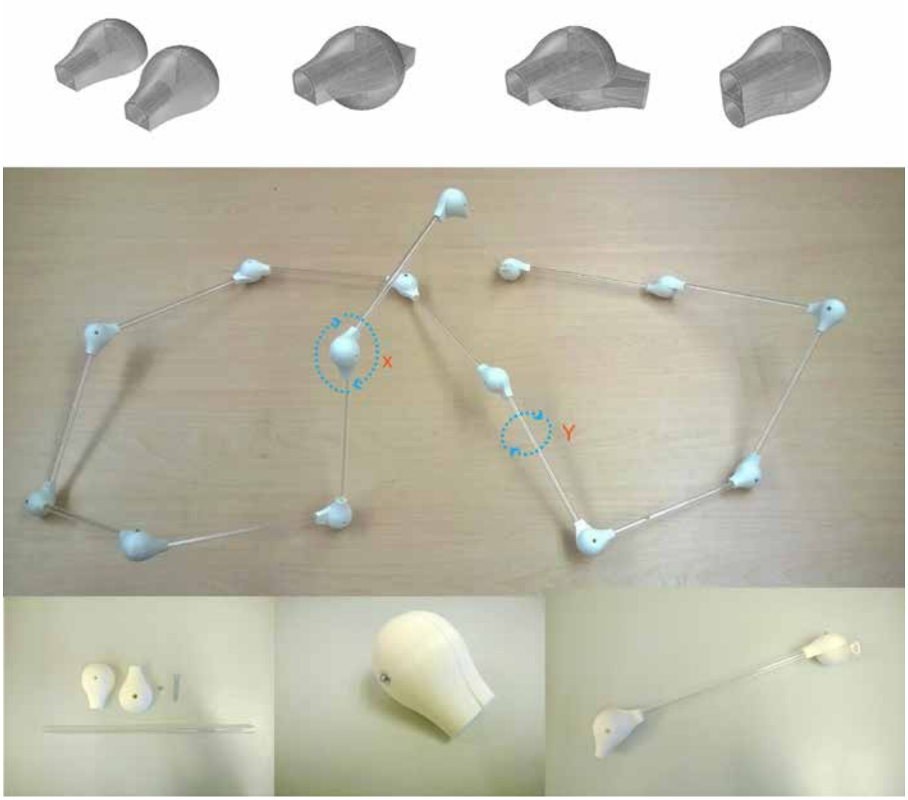

FIGURE 6.24 Images exhibiting the simulations and the photos of the 3D printing joint as scale models for examining the flexibility of the pavilions. The sphere shape of the joint reduces one directional rotation to make it functionally more impactful and efficient and also relatively more protectable for the device when embedded into the joint against the friction while making the morphology of the whole structure.

Physical Prototype:

In order to be examined in a short period of time, the joint was design as a simplified version without having a ball shape yet. The goal with the physical prototype was to prove the actual mechanisms work properly. Two servo motors in charge of two directions

(X-Axis and Z-Axis) were mounted onto one side of the joint, and the other side of the joint mainly harnessed the rotation angle by the assigned motors. Several modification steps had to be done before assembly of the servo motors into the joint. The “mechanic stop” inside the regular servo motors had to be removed in order to make more rotational angles than the default constraint by 180 degrees. In terms of control, the potential meters inside the regular servo motors had to be taken out and a knob-like gear added for harnessing the precise angular rotations. A warm gear was required for each servo motor to have more torque power driving the mechanism (Figure 6.25). After the motors’ modifications, by placing them into the proper positions and assembly with the structural tubes and connecting the wire for signal induction from each of the related Arduino boards with Ethernet cables, it was able to drive the **HyperLoop** prototype to life.

HyperCell = HyperLoop? How Does HyperLoop Design Fit in the HyperCell Framework?

There is a question if “the **HyperLoop** does not look like a componential system in terms of its appearance, how could it fit in the framework of ‘**HyperCell**’?”. This question emerged from a stereotypical view of how a “cell” should be defined. Is it necessary to be a cube, a sphere, a bubble, or a blob-like shape to be claimed to be a “Cell”? any form as long as it has the componential idea should be able to be treated as a “**HyperCell**”. That’s why a building block can also be seen as the “Cell” of a building, as does an aluminum tube even though they are all static elements. So, the difference of the “**HyperCell**” component is that it should have the ability of morphing its own structural makeup. In the case of **HyperLoop** pavilion, the joint with tubes **IS** the form/shape of the Cell. With the 2 variables of rotations, it creates the morphological transformations of the cells but at the same time affects the overall shape in the end (Figure 6.21). Not to mention the internal communication setup in between which makes it a perfect case study not only as a representation following the swarm behavior logic but also the expression of the **HyperCell** design framework. The joints should be taken as the agent of the swarm which has basic intelligence encoded in its microcontrollers. Although the intelligence of the microcontrollers is coded, the resulting outcome works via collective decision-making in a bottom-up fashion by the joints. This gave it free will and made it impossible to be predictable with respect to its next moves. Therefore, the **HyperCell** should be seen as a design framework rather than an object akin to a transformable primitive geometry as a box or sphere in terms of design thinking to increasingly evoke intriguing **HyperCell** typologies.

FIGURE 6.25 Images exhibiting the simulations, the prototype scale model of the HyperLoop pavilion, and a closer look at the joint design and prototype.

§ 6.8 Conclusion

"**If a building could change its posture, tighten its muscles and brace itself against the wind, its structural mass could literally be cut in half,**" said structural engineer, Guy Nordenson. The quote describes a vision that "**a building could have its own behavior and will**". This chapter is the summary of all preceding chapters attempting to propose a new kind of Organic Bio-Architecture which can interact like an organic body. As a bio-inspired design, unlike conventional ways of implementing the mimicry of natural shapes or the existing algorithms generating the natural forms and claiming them as organic architecture, several useful principles have been extracted from the fundamental research of the Evo-Devo Biology perspective and have been translated into crucial design rules to be followed. The principle of integration is the key not only for translating natural principles but also for potentially applying digital tools and techniques from the digital/parametric field of architecture.

A "**HyperCell**" design framework embeds such principles and logics to evoke a new kind of design thinking intending to showcase the value of componential systems, collective intelligence, and assembly systems following the fundamental rules for morphogenesis in animals. With these principles, one is able to create organic body-like architectural designs which can adapt and interact with user demands in real-time. In this chapter, the researcher not only indicates the design framework for organic body-like architectures but also the title of the **HyperCell** is also used to represent a transformable component in a reconfigurable furniture system which implies more efficient and novel usage of space. Multi-functional furniture and space would be the next prevalent step from the research point of view. Until the discourse of the **HyperCell** furniture system, the focus of this chapter still remained with taking care of the users' demands. But the second half of the chapter started raising critical questions pertaining to new relationships which would need to emerge between human bodies and spatial bodies **if space had its own behavior and will**". This is an artistically and theoretically intriguing topic to think of especially in today's time as we head into a new era of AI (artificial intelligence). In the not too distant future, people will confront the issue of intelligent robots regardless of them being shaped as a human figure or like the HyperCell furniture. "**Ambiguous Topology**" was exhibited as an experimental installation under the European Culture Project, MetaBody, for encouraging people to manipulate their body's in unconventional ways by using immersive light projections as a medium of non-verbal communication. "**HyperLoop**" pavilion was exhibited as an interactive structural system in the form of an infinite loop shape which can embrace people within or repel people based on its physical reconfiguration. The **HyperLoop** also serves as an example to break the stereotypical idea of a cell and its shape.

This research also does not claim that projects like the **HyperCell** or **HyperLoop** pavilion should become the ultimate goal for all designers to follow. On the contrary, the research aims to provide a design thinking direction in order to truly follow natural principles to develop interactive Bio-architectures. From this research perspective, the novel Organic Architecture should embody interaction as a generic modality, which makes such architectures actively confront dynamic contextual conditions via dynamic optimization processes akin to an organic body.

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