2 From Interactive to Intra-active Body: Towards a New Organic Digital Architecture

"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."

Kas Oosterhuis

§ 2.0 Background: The Origin of Interactive Architecture

The 60s was the age of freedom and boldness. According to John Lennon, the legendary singer-songwriter, who said in his last interview for RKO, "***The thing the sixties did was to show us the possibilities and the responsibility that we all had. It wasn't the answer. It just gave us a glimpse of the possibility***".[10] Various technologies and cultures were developing boundlessly at an unprecedented speed during this time. Movements for civil rights due to racial discrimination, movements for women's rights due to feminism, liberation movements for bodily autonomy, and student movements

10 This interview was done with the interviewer, Dave Sholin of RKO radio, which is the last one John Lennon did to promote his new album "Double Fantasy" before he got murdered on the same day. Please refer to http://www.thenation.com/article/lennons-last-interview-sixties-showed-us-possibility/

(Mai 68) in France due to the education system, influenced and challenged the conservative thought and systems in the society which people were used to. With the flourishing development of high-end technology, during the cold war period, the US and Russia were still competing to be the world leaders in technological development. The battlefields of the well-known space race included not only the terrain of the earth but also the surface of the moon. For the general public, the impact of rapid technological development, plus the discovery of chaos theory in Science and the gradual advancement of computer technology, opened the door towards all kinds of imagination about how the future world will look. The influential pop art movement, gave new birth to art which was no longer bigwigs' assets hung on the walls of a royal palace and high-end art galleries, but relatively closer to people's daily lives by using common substances and materials for creating art pieces. In addition, with the growth of the underground hippy culture and rock 'n roll music, it was the golden age when people gradually had the courage to explore, to experiment, to express personal opinions, and dare to imagine and expect a future life of their own. And this was also the time when Archigram was born.

FIGURE 2.1 Archigram has published several pamphlets about its design ideas and ideals. Their concepts are often expressed through very stylish collages. This picture here is titled Tuned Suburban, showing the urban design concept for the Triennale di Milano in 1968. In this image, the spatial units of architecture are designed by pre-cast mass production which can be purchased in advance and attached to the existing building to perfectly complete users' requirements (source: http://balticplus.uk/tuned-suburb-c5797/).

Archigram was founded by Peter Cook (1936-), David Greene, (1937-), Mike Webb (1937-), and Dennis Crompton (1930-1994) in London, UK. It had swept across the architecture field like a rock 'n roll band, leading a new direction of architectural design through a series of pamphlets published regarding their visionary architectural design ideas (Crompton, D., & Archigram (Group)., 2012)(Figure 2.1). Besides unrestrained imagination and the corresponding inspiration with the combination of architectural design and technology, the main values that Archigram brought to architects was to challenge the virtues of architecture, "Utilitas, Firmitas, and Venustas", written by Vitruvius in "De Architectura", which had been strictly followed by professional architects since the 1st century BC. In a sense, Archigram seemed to find possible ways to release architecture from these constraints by relating architectural design to the rapid development of aerospace and other hi-end technology to create avant-garde architectural fantasies, which perfectly fit into the vigorous wave of liberal society at that time. For instances, their large city-scale design concepts such as Walking City which can find its optimized environments through mobile migration like animals (Ron Herron, 1964) (Figure 2.2, left); or Plug-in City (Peter Cook, 1964) where they proposed an idea of capsule-like dwelling units which can be plugged/replaced into a Mega Infrastructure to form an economical efficient recycling process for a Circular Economy; to body-scale ideas such as Suitaloon (Mike Webb, 1966), which intended to be a wearable and portable space to explore the intimate relationship between body and space; and another experimental project, Cushicle (Mike Webb, 1966) (Figure 2.2, right), within the spirit of nomad living which can be compressed and inflated to fit in different environmental indoor/outdoor conditions. All the aforementioned cases are a part of Achigram's visionary projects, but they strongly impacted people's typical impressions regarding the fundamental definition of what architecture should be. Overall, Archigram's design philosophy can be shortly interpreted here in its three major emphases of "**non-permanence**, **non-immobility**, and **non-standardization**". Being non-permanent means being temporary or instantaneous, which means architecture no longer has to exist externally. Instead, architecture can perform temporarily on demand and then be removed, and be mobile to respond to requests elsewhere. Non-immobility refers to the idea that architecture can be portable and perform as a nomad living space. Non-standardization expands/blurs the standard definitions of architecture as it can be defined as including wearable devices, be transformed as transportation, and even be performed as spaces.

These definitions are no longer constrained by conventional concepts of Architecture but rather motivated and inspired the development of an embryonic stage of interactive architecture, namely kinetic architecture[11] back in the 60s.

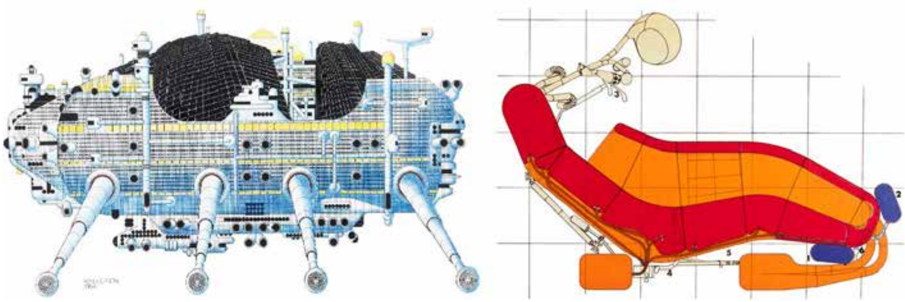

FIGURE 2.2 Left: Walking City (1964) (source: https://www.archdaily.com/tag/archigram) and right: Cushicle (1966) (source: http://archigram.westminster.ac.uk/project.php?id=92).

Besides the UK, other European countries had, under this innovative wave, developed various architectural design experiments to challenge the conventional/essential notion of Architecture as well. For example, Villa Rosa, designed by an Austrian architecture team, Coop Himmel(b)lau in 1968, is an inflatable installation space which can be adjusted in accordance with different interior/exterior spatial conditions. Another Austrian architecture team Haus-Rucker-CO designed Oase No. 7 in 1972, attempting to challenge classic architectural facades by attaching inflatable spherical spaces out of them to express their weariness. In addition, just to name a few, projects like New Babylon (1959-1974) by a Dutch architect, Constant Nieuwenhuys, Continuous Monument (1969) by the Italian architecture team Suprastudio, and Ville Spatiale (1960) by Czech architect Yona Friedman, are all inspiring experimental designs revealing a new-generation of architectural conceptual ideas in the urban domain with characteristics of high convenience, promptness and immediacy (van Schalk & Macel, 2005). One of the most innovative and interesting visionary projects is this paradigm, Fun Palace (Figure 2.3) designed by Cedric Price in 1961, is an initial architectural experiment endeavoring to create an adjustable/adaptive space which can be re-configured through time and functional requirements by employing the

11 As for interactive Bio-architecture, there are more detailed distinctions and definitions. The kinetic architecture mentioned in this research is purely based on space transformation. Adaptive architecture is space with transformable façades that make-up or undergo re-configuration which can adjust according to time or environment. Besides the above elements, spatiotemporal interactive architecture also stresses the links and perceptive associations between space and space and between space and body.

combined technologies of computational programming and architectural design. This idea basically revealed the now prevalent definition of an adaptive architecture, which made Fun Palace one of the primary and iconic interactive/adaptive architectural experiments in the early years. During this time, Cedric Price sought to cooperate with John Frazer, one of the pioneers of digital architecture in the UK, facilitating the opportunity of merging information science, digital technologies, and interactive architecture.

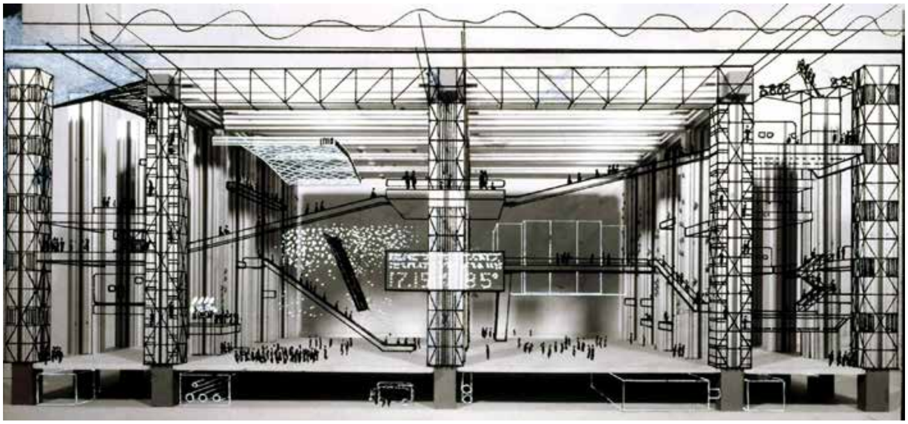

FIGURE 2.3 The perspective drawing of Fun Palace (1966), proposed by Cedric Price in 1961 (source: http://www.cca.qc.ca/en/collection/283-cedric-price-fun-palace).

Although none of these avant-garde architects and teams were able to carry out their wild visionary designs in reality, their experiments still have had a great influence on later generations, extended the scope and horizon of contemporary architectural design, and even opened the gate towards the uncharted territory of interactive Bio-architecture. The design of Centre Georges-Pompidou, Paris project was developed by Peter Cook's students: Richard Rogers and Renzo Piano, at the Architectural Association (AA), with an initial intention to introduce Archigram's concept of dynamic floors within the Centre Pompidou. Unfortunately, the idea of the movable floors based on time and functional requirements was not realized due to that era's technology constraints. A few years later, Rem Koolhaas, another Dutch architect, who graduated from the AA, implemented the idea of dynamic floors while designing a residential project of Maison À Boraudeaux for a client whose lower body was paralyzed after a serious car accident (Figure 2.4). To complete each floor's function as a dynamic floor plate, the center zone of the house is a massive platform which can be elevated and descended, like an open elevator, to connect to different floors. Rem Koolhaas, on one hand, fulfilled the requirements requested from the clients to create the spatial complexity of this residential project; on the other hand, the architect cleverly resolved the issue of accessibility for his disabled client. In Rem

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Koolhaas' project, we witnessed an evolving progress from a pure kinetic architecture to an adaptive architecture for functional purposes. And at the same time, the project showed the pragmatic potential of interactive architecture to solve complex and multiple functional spatial requirements.

FIGURE 2.4 The Bordeaux House Plan by Rem Koolhaas with an elevator in the center for the owner who was unable to move freely to go to any floor at will which completed the functions of each floor as it reached that floor (source: http://www.oma.eu/projects/1998/maison-%C3%A0-bordeaux/).

In addition, from the other side of the globe, in Japan, the Metabolism movement in Architecture led by Kisho Kurokawa brought forth another modern innovative design idea in an attempt to conceive an organisms' metabolism into both urban and architectural design concepts. One of the representative projects, the Nakagin Capsule Tower built in 1972, was coincidentally almost the thorough realization of the ideas hinted upon by Archigram's Plug-In city. Regardless of being damaged or in case a tenant moved out, the former residential unit of the Nakagin Capsule Tower can be taken out and be replaced immediately by inserting a new pre-fabricated unit to the main infrastructure of the tower. The concept of Metabolism in Architecture based on organisms happened to be consistent with the ideas of visionary architecture by Archigram and other European avant-grade architects who were looking for inspirations from innovative technology. This coincidence seemed to be a clue to predict a corresponding possibility of bridging kinetic architecture and organic architecture together for developing a new kind of interactive organic Bio-architecture in the near future.

§ 2.1 De-Skinning of Interactive Architecture

FIGURE 2.5 A scene from Blade Runner (source: Blade Runner, a 1982 movie directed by Ridley Scott).

With the popularization of computers and applications of computer-aided design, architects have become interested in the appearance of the form of architecture and are mainly focused on the external skin of their designs. No longer limited by simplifying designs under the global trend of modernism, they started to use computer-assisted modeling software to create higher fluidity and for sculpting free-form appearances. With the rapid growth of new media technology, and not being satisfied with only the fancy forms created with the computer, some architects eventually started focusing on new media and eventually started to apply information technology onto physical architectural skins. All along, the purpose of the architecture façade is to express architects' subjective aesthetics, decoration, and unique architectural language. The fluidity of multimedia screens with real-time information enhanced the potential of architecture as a vehicle not merely to deliver visual information but also to send messages. These kinds of programmable walls with dynamic information for highly interactive social exchanges made it possible for architecture to communicate with its spectators. Moreover, the influence from Sci-Fi movies on architecture can be traced back to Ridley Scott's well-known film, "Blade Runner" (Figure 2.5), in which the main character flew his flying vehicle amidst high-rise buildings with multimedia screens. This tremendous scene was a shock to many people's imaginations, including architects, as regards potential cities of the future, and in terms of further enhancing their desire and craving for implementation of interactive architectural skins in the form of digital building façades.

In terms of theoretical aspects, architects also witnessed a shift in their philosophical interests; from the concept of heterogeneity and deconstruction based on the theory proposed by French semiotician, Jacques Derrida to the "smoothness" of surface theory from "**A Thousand Plateaus**" (Deluze, G., & Guattari, F., 2004) by Gille Deleuze and Felix Guattari. This philosophy shift indeed resulted in a deep impact on architecture, not only in terms of liberating form, with respect to its geometry but in terms of enhancing it by implementing an additional interactive layer between building skins and the users. Furthermore, Deleuze and Guattari's notions of the Fold inspired topological innovation wherein a flat skin surface could be converted into a 3-Dimensional space. To this space, the addition of the dimension of time, in the form of real-time immediate information, converts it to a so-called 4D space (Imperiale, 2000). When seeing the multimedia screens on Time Square in New York, what people perceive is not just plain colorful skins of the buildings, but rather a vivid space with variable depths caused by the commercial or animation running behind static skins. That unprecedented scene in Blade Runner with multimedia building façades has now come to fruition in mega cities around the world and has now become quite common as information propagators. In the meanwhile, Marcos Novak proposed the concept of "**hypersurface**" expressing his idea that a computer screen could be considered as an intelligent surface, and can even be extended via the Internet to visualize fluid space (Palumbo, 2000). Thus, in practice, architects have indeed been exploring more exciting possibilities for architectural skins and are not only constrained within the boundaries of media façades. For example, Jean Nouvel designed the Arab World Institute with delicate camera-lens-like mechanical devices on the surface of the building to adjust the light penetration patterns in real-time. In this case, the skin of the architecture acts similar to a living creature, which can adapt as a response to its surrounding environment. Furthermore, not only being a carrier to perceive information (intensity of light), this skin of the architecture is also a feedback actuator responding to those input information (hole size adjustment). Although these kinetic facade devices Jean Nouvel created fall completely under the mechanical paradigm, he managed to embody the architectural skin with an organic sensing/actuating capacity. Another interesting case is The Tower of Winds in Yokohama, Japan by Toyo Ito. The project is near a subway station, with its external skin having the ability to change its color in accordance with the amount of surrounding air pollution. The amount of air pollution is thus delivered indirectly and an invisible dialogue is initiated between the building and the passersby, thus converting an otherwise inert building entity into a dynamic information vehicle. Some design projects, such as The Al Bahar Towers in Abu Dhabi by AEDAS and One Ocean Thematic Pavilion EXPO 2012 designed by SOMA carry on such innovative trends. These innovations have not only been treated as information carriers through the idea of media façades but have managed to convert architectural skins into smart surfaces with real-time adaptation possibilities (Figure 2.6).

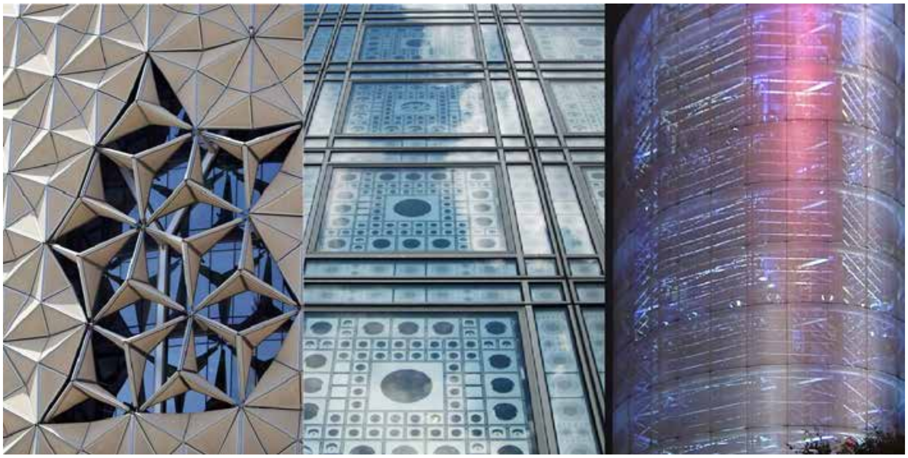

FIGURE 2.6 From left to right: Al Bahr Towers in Abu Dhabi by AEDAS (source: http://www.thenational.ae/business/property/in-pictures-international-property-awards-success-for-uae-developments), Arab World Institute in Paris by Jean Nouvel (source: http://www.archdata.org/buildings/12/arab-world-institute), and Tower of Winds in Yokohama by Toyo Ito (source: https://en.wikipedia.org/wiki/Toyo_Ito).

However, as regards interactivity of architectural space, the aforementioned projects hardly provide the users with actual physical/tangible interaction abilities with their immediate spatial surroundings. Reasons such as the economies of scale may possibly be the reason why the current development of interactivity in buildings is at a relatively smaller scale or is mainly limited to certain parts of a building, such as façades. The purpose of interaction in such cases is mostly limited to environmental response, such as light and air flow, and thus do not touch upon issues of spatial re-configuration. It was only in 2003, that deCoi led by Mark Goulthrope collaborated with the MIT Media Lab to develop the HypoSurface (Figure 2.7) project, giving people direct and tangible impact from an architectural space interactively.

FIGURE 2.7 HypoSurface designed in 2003 by deCoi, let by Mark Goulthrope (source: https://www.cca.qc.ca/en/events/3425/archaeology-of-the-digital-media-and-machines).

The original concept of HypoSurface was inspired by Aegis in Greek mythology which means being under the protection of a powerful all-knowledgeable source. Each unit comprising the HypoSurface is made of triangulated metal panels combined with a linear actuator behind them. The operation of the linear actuator can trigger a 3D morphological change of the corresponding triangulated surface. When people touch this morphable wall installation, they can literally feel the actual thrust of the actuation on their body. This programmable skin system strongly achieves tangible interactions and delivers a non-verbal sense of communicative expression to users. However, even after a decade of HypoSurface being built, it is disappointing to see that although a lot of architects have tried, there have been a very few or even no interactive installations which can compete with the impressive performance of this project. The MegaFon Pavilion of the Winter Olympics, held in Sochi, Russia, 2014, was designed based on the recently popular "selfie" idea and realized by using image processing technology and dedicated mechanisms to translate a 2D image into a 3D landscape like surface. Visitors could see their photographed faces on the wall 3-dimensionally. The sophisticated mechanism used behind this kinetic installation is not much different than the HypoSurface, which was developed a decade ago. The only major difference between the two is that instead of constructing the surface with triangulated panels, numerous color-changing LED light bulbs were used as the main expressive elements in this project. Although in this case too, the interactions between the façade and passerby reduce the architectural skin an information carrier, only possessing one directional communication, as compared to the HypoSurface's ability to influence people's behavior via a continual morphing space.

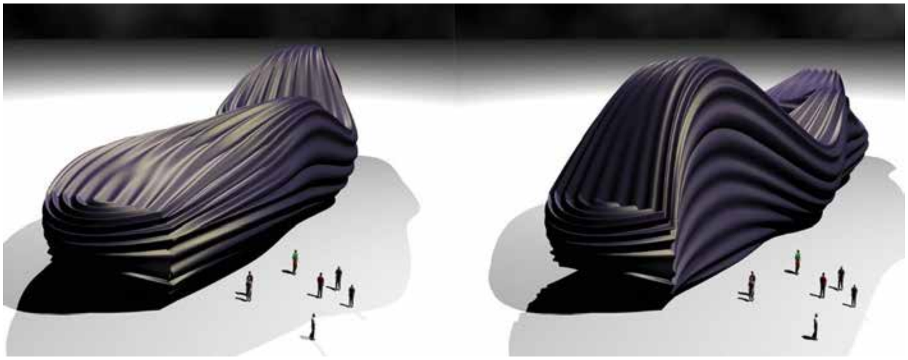

FIGURE 2.8 Transport, designed in 2000 by the ONL led by Kas Oosterhuis (source: http://www.onl.eu/?q=projects/trans-ports).

During the same time, Kas Oosterhuis, a visionary Dutch architect, had a different perspective regarding architectural skins, researched and realized through several challenging projects accomplished by his own architectural firm, ONL [Oosterhuis Lénárd], and the HyperBody Research Group, founded by him in 2000, at Delft University of Technology, the Netherlands. For Kas, an architectural skin is a continuous surface, as seamless as a human/any organisms' skin. An architectural skin contains, at least, double layers, the external skin and the internal skin, which can achieve a dynamically balanced homeostasis status corresponding to multiple forces working upon it from the inside out and from the outside inward, simultaneously. Therefore, an architectural skin should not merely be considered as a single external layer of a building, but a continuous surface to form a volumetric vectorial body which could simultaneously adapt accordingly to the forces both externally and internally, as a HyperBody (Oosterhuis, HyperBodies: Towards an E-motive Architecture, 2003). Like any living creature's physical body, it can sustain external forces from outside environments and maintain operations of internal organs/components and then make passive corresponding adjustments or even take unexpected actions. Under such a seamless surface logic, architectural components need to be looked at in a very different perspective. For instance, components such as windows and doors could be designed in the form of dynamic pores on the building skin. Kas' constantly morphing skin/spatial concept brought architectural thinking to another level wherein architecture transforms into a living creature with embedded sensing and actuating abilities and a will of its own. Oosterhuis has pushed this idea into practice through the design projects by his firm ONL and at times in co-operation with the HyperBody Research Group, TU Delft. Various projects such as the Transports (Figure 2.8), Emotive House, Muscle Reconfigured, and Interactive Wall projects illustrate such novelty. Oosterhuis's innovative ideas to treat or create architecture as an organic body shall be further discussed in Chapter 6.

§ 2.2 Materialization of Interactive Architecture

Current research experiments concerning interactive architecture can be categorized into two basic groups: Naturalized (material-related) and Motorized (mechanics-related). "Naturalized" studies look for deformation parameters of materials based on their physical characteristics (these materials are sometimes also called "smart materials"). "Motorized" studies attempt to achieve transformation through electronic devices based on mechanical principles. The ultimate goal for both types of studies is to provide practical assistance to enable kinetic and interactive architecture. This section illustrates the advantages and disadvantages of each category through multiple case studies.

One example of "**Naturalized**" studies is the experiment: ShapeShift, designed by the Materiability Research Network team led by Manuel Kretzer in the Swiss institute ETHZ CAAD, which, uses electro-active polymer(EAP) thin films which have the ability to physically bend as soon as they are induced by electric current. Through different combinations of components made out of these EAP units and an elaborate set of electricity controls, a large overall area of a morphing surface could be created. On one hand, the resultant spatial effects were quite strong and dramatic. But on the other hand, the EAP films were as thin as paper and could be easily ripped apart in case of large physical transformations either during the process of production or experimentation. Because of the nature of this material, it could barely be used for developing façade apertures or as interactive building skins. It was thus impossible to use the EAP material despite its great potential as regards physical morphing to conceive them as potential material systems for larger transformable architecture components or to bear any amount of weight[12].

Another example of a "**Naturalized**" experiment can be seen at the Centre Georges-Pompidou in France called: Hygroscope. The installation was developed at the ICD (Institute for Computational Design), Stuttgart University under the guidance of Achim Menges. In this case, the team studied how thin wood film bends according to humidity variations in a natural environment (Menges, A., Reichert, S., & Krieg O. D., 2014). Each unit of the hygroscope is composed of a hexagonal frame with 6 thin triangular wood films of the same size. These wooden films tend to open and close based on the humidity levels in the air, resulting in variable opening patterns. The hygroscope prototype was placed inside a glass box, whose humidity could be controlled to correspond with the humidity

12 Please refer to the website http://materiability.com/ for how EAP or other smart materials are made. Manuel has collected a lot of information regarding how to self-make deformable materials and the information is available on the website of his lab as an open source.

data in Paris. Dramatic and beautiful morphing effects could be observed instantly. Later, in 2013, the results of the hygroscope study were further improved and again designed to be implemented for the openings of the "Hygroskin Pavilion" (Figure 2.9) project. In this case, the same material is supposed to react with actual environmental humidity rather than being within a controlled setup such as the aforementioned glass box. Unfortunately, in this scenario, the same instant dynamic results could not be achieved in an outdoor setting with natural humidity fluctuations. Both experiments again operate at a skin level and thus lack the ability to be used as a transformable structural frame to eventually change the overall shape of the architecture.

FIGURE 2.9 The hygroscope in the Centre Georges-Pompidou designed by the ICD team led by Achim Menges (source: http://www.achimmenges.net/?p=5612).

Another "**Naturalized**" project example falling within the domain of programmable materials was developed at the MIT Media Lab led by Skylar Tibbits. They attempted to fabricate programmable materials using 3d printing technologies, consisting of material properties that are engineered to become multi-performative. This implied that 2d flat materials could be folded into pre-defined 3d forms by exerting simple external forces such as water pressure, swinging force, and slight thrust, in a relatively short time. This process was named as 4D-printing by Skylar. This implied that the initial product could be manufactured relatively cost-efficiently through 3D printing techniques, and because the pre-programed products are flat, they could be easily carried and cost-effectively transported to customers. Currently, the lab has already developed several material systems which operate on this idea, including carbon fiber, printed wood grain, custom textile composites, and rubbers/plastics. The next goal for them is to print composite materials and to further develop variable materials with better adaptability and variability without using any mechanical device as a support for adaptability applications in architectural and industrial design. They claim that they want to build true material robotics or robots without robots[13] (Figure 2.10, right). The experimentation with smart material fabrication and development is currently still in its initial stages.

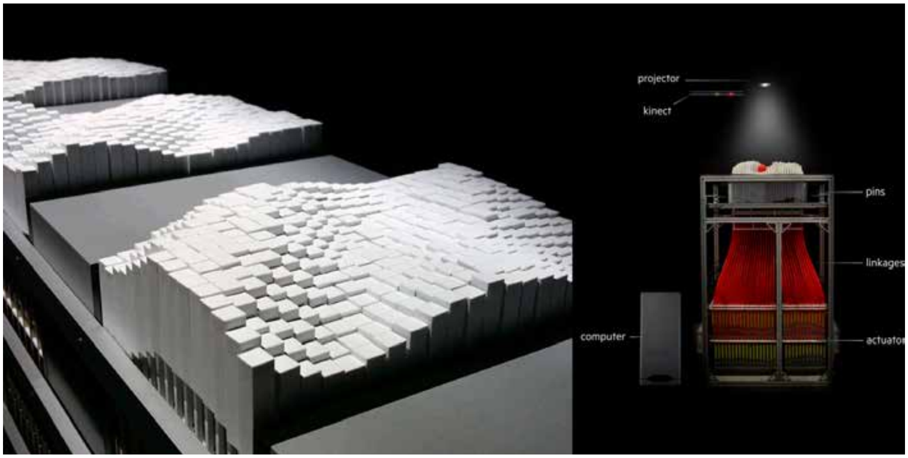

FIGURE 2.10 inFORM/TRANSFORM developed by the Tangible Media Group under the MIT Media Lab. The graph on the left shows the surface effect, and the one on the right shows the structure of the mechanical device (source: http://tangible.media.mit.edu/project/inform/).

As for "**Motorized**" experiments, one example can refer to the aforementioned project, HypoSurface by deCoi. A huge dynamic surface composed of numerous triangular metal panels morphing its overall shape by triggering the linear actuators behind, giving audiences immediate, direct and tangible impressions. Another example is the Kinetic Wall, which was exhibited at the La Biennale di Venezia 2014 designed by Barkow Leibinger. The basic mechanical make-up and motions are almost the same as HypoSurface. The only difference is that the triangular metal panels were replaced by elastic fabrics to make different expressions. This kind of a project normally delivers high intensity of interaction and significant performance to the audiences, yet at the same time, it relies on a lot more robust mechanism. Besides, the space for mechanical equipment is much larger than one can imagine. In other words, for example, almost nine-tenths of the overall space of the project is occupied by mechanical and electrical devices in order to actuate a thin layer of material which takes up hardly one tenth of the. This viewpoint is proven by the inFORM/TRANSFORM project developed by the

13 Please refer to http://www.selfassemblylab.net/index.php for Skylar Tibbits' research with the Self-Assembly Lab.

Tangible Media Group of the MIT Media Lab. inFORM/TRANSFORM is a pixelated transformable table-like platform composed of modular movable units of square masses. The upward and downward motion of the square masses can be controlled through hand gestures or based on an input digital graph to create three-dimensional spatiotemporal morphing effects in real time (Figure 2.10, left). Their current research direction is to implement the same design idea and mechanism to develop larger-scale and transformable furniture system fulfilling multiple functions in space. Yet, as one can observe from the mechanical structure below the installation, most space is taken by linear actuators and related devices below used for driving the motion of the square masses'[14] (Figure 2.10, right) The challenge ahead is thus how to create maximum physical impact in real time/space with the least possible actuating devices which will consume the minimum size. The same quest is prominent in the field of interactive architecture design, as regards finding ways to develop mechanical devices which are simple but efficient, solid but changeable and are able to consume lesser physical space.

To conclude in brief, as for "**Naturalized**" (material-related) experiments, we saw applications based on physical material properties, while simultaneously realizing that there are limitations to the nature of applications if we consider the relatively limited properties of such engineered materials. On the other hand, in the "**Motorized**" (mechanics-related) experiments, we witnessed tangible impacts of such projects on the users based on their physical transformation abilities, while becoming aware of the amount of space which needs to be reserved for mechanical equipment. The intention of pointing out the pros and cons from both "**Naturalized**" and "**Motorized**" research studies is not to oppose the outstanding contributions and achievements of these aforementioned experiments, but to question ourselves as interactive space researchers to look for a better materialization solution. Perhaps the idea of combining the application both from material properties and delicate mechanics can lead to the next leap for materialization of interactive Bio-architecture in larger scales.

14 Please refer to http://tangible.media.mit.edu/project/transform/ for the video regarding inFORM/TRANSFORM.

§ 2.3 Immediate Demands and Bodily Connection/ Communication of Interactive Bio-Architecture

FIGURE 2.11 TURNON designed by the AllesWirdGut team, an experimental work of a residence. The rotating wheel-shaped space can meet users' demands according to time (source: http://www.alleswirdgut.cc/en/project/trn-e/).

There can be no doubt that we are living in a vibrant and dynamic world. The 'you' at this moment and the 'you' in the previous one is completely different from both, the state of action and state of emotion perspectives. Especially in this age of information explosion, every single entity, object, substance, element, datum existing in the world can never hold still but changes constantly by adapting with the physical environment or information flow. Most of the time, data just simply pass through rapidly in front of you without being grabbed, used or even noticed. Why stubbornly persist in adhering to the old regulations and conservative design principles for architecture which remains stuck with static, non-responsive ways of interacting with the rapidly changing world around us? Why not think outside the box and design a new kind of architecture which can adapt to this dynamic world? With these questions, many architects have shifted their focus towards creating a real-time adaptive architectural body. However, for the general public, a space/place is nothing more than a container of activities or life, and they often ask why does space have to literally transform and adjust almost all the time to the environment? This question can be somehow metaphorically answered from the viewpoint of a natural biological/physical body. With the blood circulation inside a body, the cells can filter and exchange nutrition and energy through their membranes in order to achieve the optimal state of an individual's body. Imagine, if, in a similar fashion, an architectural body acts as a living entity and can adapt its constituting components to optimize sun shading and air flow rate in accordance with fluctuating environmental conditions in real-time, and avoids unnecessary energy consumption. However, this explanation is still a bit vague and a little distant and indirect for convincing people who lack knowledge pertaining to the architectural and biological domains.

To increase the substantive desire for the existence of interactive Bio-architecture, it should relate more to people's daily lives. In other words, if interactive architecture can be designed to somehow link with tasks of assisting us and improving our daily lives, it will strongly appeal to people's imagination and desires to invest in smart spaces. In 2000, the AllesWirdGut team designed "TURNON", an experimental project of a minimal residential space. All the functions required for a person's daily life were included in a compact wheel-shaped space. The space was manually rotated by the users to obtain the desired spatial usage (Figure 2.11). In 2012, Los Angeles-based architect, Greg Lynn, further developed this aforementioned wheel rotation idea to create the RV (Room Vehicle) House project by replacing the manual labor based control with an electronic driven mechanical system. The egg-form shape has been designed to have each part of the interior space used as a specific function all over the room. So, by automatically rotating itself by a motorized mechanism, the egg-shaped space based on pre-set timelines would perfectly meet users' demands precisely on time. However, this residential space seems to be a fantasy solution because it does require a relatively bigger area to install not just only for its irregular egg shape but also its motorized mechanism which is hosted underneath. In such a case, most people cannot afford such a large space for installation and also purchase a robust mechanism to rotate the space. This design can thus be seen as not an efficient and economical solution for people who live in an urban area where the price of the real estate is extremely high. Therefore, architects born and raised in a relatively high-density urban area seem to have a more realistic proposal for a highly economic design which is small in size but rich in function. Take Gary Chan, for example, a practicing architect from Hong Kong, which is a city well-known for its extremely high population and density. Gary designed transformable walls embedded with furniture which can be pulled out or reconfigured to achieve maximum space utilization under different requirements in a small apartment space. This kind of transformable furniture idea has been taken further and adopted by the MIT Media Lab to develop another interesting project, cityHome[15] (Figure 2.12), a digital interactive furniture/space which can be manipulated through free-hand gestures. The idea is similar to Gary's design to have transformable furniture. This way a user can have multiple functions such as a bedroom, a study, a living room, and a dining room available in a single footprint of space with intuitive control over the configurations through his/her own body gestures and movement. Briefly speaking, with this kind of transformable design, the spatial requirements for different functions becomes extremely compact and minimized, allowing young consumers living in high-density urban areas, to save money by not purchasing redundant space and to reduce their living load.

FIGURE 2.12 Image of the conceptual idea of cityHome by MIT Media Lab (source: http://cp.media.mit.edu/places-of-living-and-work/)

Recently, one can see a rise in people's desire to use gesture based non-verbal communication. This can be seen as a result of various technological developments in tracking technology, such as multi-touch touch screen and motion tracking cameras. With the launch of smartphones and tablets, people have already been trained and accustomed to attribute control to more intuitive gestures instead of a remote control, or a set of mouse and keyboard. 10 years ago, we wouldn't have believed that one of the most commonly performed gestures in our daily life would be sliding our finger

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

on a screen. Actually, years ago, lots of Hollywood sci-fi movies have imperceptibly influenced our imagination for such intuitive control and have pushed certain prevalent technological developments. For example, in "***Minority Report***", a sci-fi movie released in 2002, there is a scene with the main character, Tom Cruise, sophisticatedly moving his fingers controlling the transparent screen-like interface of a future computer is still very attractive and an inspiring moment to see it even 15 years later. Practically speaking, in order to reach the level of intuitive hand gesture based controls for spatial re-configuration, besides the immediate affect at an actuation/output end, analytical data systems to read/analyze environmental information or identify precise human body movements at the input end, are very crucial and challenging.

In 1964, Marshall McLuhan introduced the concept: "**medium (technology) is an extension of any human body**" in his masterpiece "***Understanding Media: The Extensions of Man***" (McLuhan, Understanding Media: The Extensions of Man, 1964). In the book, he defined the multiple meanings of 'medium' (technology) which covered a broad range; from the light bulb, text, typography, mobile vehicle, architecture, movie, a weapon to automation, basically indicating human inventions and technology. One of the most vital messages he delivers is that human inventions and technology can be considered as extensions of the body itself, or as an embodiment. For example, cars replace our feet for walking, arms/weapon replace our hands to attack, TVs replace our eyes to view, telephones replace our ears and mouth to communicate. Architecture is undoubtedly also one of the medium/body-extensions under his definition, and this architectural space seems to be more and more closely associated with our existing physical/human bodies, especially in the era of digital technology, and can be interpreted as a second skin of our physical bodies. Through current technology, such as the Internet connectivity and innovative electronic gadgets, interactive Bio-architecture seems to be able to fully embody and match this notion of body extension. Moreover, this realization could be a start to move away from the classic Modernist notion of "**a house is a machine for living**" towards incorporating organic ideas of real-time information processing associated with the human body. Imagine such an organic space, which humans can easily manipulate via intuitive hand gestures or body movement to suit their immediate requirements. Not only can redundant space be saved, but also customizing spatial re-configuration can be immediately met in such an interactive space. Besides architects, artists have fantasized regarding the concept of interaction. For instance, Keiichi Matsuda's computer simulation film titled "**HyperReality**" showed a future kitchen concept using augmented reality. Similar to the Google Glass idea, the film shows a device that can be worn by humans, to envision a kitchen as an information carrier showing real-time commercial advertisements of the all brands stored in it. Not only that, through the virtual interface of the glasses, users can simply manipulate all physical devices in this future kitchen by hand gestures, such as fine tuning the power of a microwave, or turn on and off the switch of the electric kettle[16]. "**Living Kitchen**", another animated simulation created by Michael Harboun, showed the emergence of a kitchen from a blank space composed of a smooth flat surface to a fully functional interactive kitchen by actuating the flat surface to convert it to a sink, tap, etc. All devices appear via gestural[17]. In addition to such imagined developments, in recent years, Google's research in technology has brought such a reality closer to the imagination. For instance, the Google ATAP (Advanced Technology and Projects) team is currently working on the "**Soli**" project to detect/capture the very delicate micro motion of hands such as twisting and clicking, etc., through the radio-frequency spectrum, which is a radar signal. A tuning knob, slider or button normally attached to a physical object, such as a watch, a radio, etc., can be replaced virtually by implementing such radar detecting technology without physically touching any controlling device[18]. With more and more research dedicated to the development of motion tracking and free-form gesture detecting technology, it is believed sooner or later that Interactive Bio-Architecture using body movement to control a space for a more convenient usage can surely become a reality. At that moment, space will not only be seen as an extension of the body but will literally become a second skin of the human body.

§ 2.4 Bio-Inspiration of Interactive Architecture

About 10 years ago, the first Arduino Micro-Controller chip was invented. Since then, architects and artists have been able to design and experiment with interactive prototypes on their own. The ease of learning programming language plus the simple circuit connections made it possible for architects to build physical interactive prototypes. Through Arduino, architects can now easily retrieve data received by any sensor worn by users or embedded within the environment, and then by applying conditional statements of scripting based on their design principles, this input data can be converted into output data in the form of an actuator's action. For example, a dynamic surface that can be opened and closed, a programmable lighting system that can be turned on and off rhythmically, a movable floor that can be lifted up and

16 Please refer to https://vimeo.com/8569187 for the video regarding hyperReality

17 Please refer to https://vimeo.com/16404038 for the video regarding Living Kitchen.

18 Please refer to https://atap.google.com/soli/ for the video regarding Project Soli.

down vertically as a tangible mockup rather than virtual simulation. Some architects even boldly attempted to create mechanized organisms through with these interactive tools. Minimaforms, a team led by the brothers Theodore & Stephen Spyropoulos, completed a project named Petting Zoo with Arduino, Microsoft Kinect camera, and a couple of servo motors. Several elephant trunk-like objects suspended from the ceiling could move up towards the visitors as if they were alive based on the tracking data of participants' approaching routes and velocities. These were accompanied with lighting effects of different colors, unconsciously pulling visitors and inducing within them the desire to interact via touching the life like trunks, or approaching them using diverse routes and speeds. In this space with plenty of life-like objects, visitors were no longer spectators watching a distant performance but rather became parts of the project within which they were engaged themselves. In such interactive spatial designs, success can often be measured via the degree of engagement that the users of such a space exhibit.

FIGURE 2.13 Strandbeest designed by Theo Jansen (source: http://roskofrenija.blogspot.nl/2012/10/theo-jansen-strandbeest-kineticke.html)

In the area of bio-inspired objects, Theo Jansen, a physicist from the Netherlands is considered as the modern Da Vinci. His Strandbeest (Sand Beast) project was a giant walking machine composed of plastic tubes which are common on construction sites to protect electricity cables. It is even more surprising considering that the Strandbeest, with its mighty size of 4 meters tall and 8 meters wide, could walk easily on the beach simply with the aid of wind force (Figure 2.13). Theo, at the age of 70, is still working on improving his Strandbeest to become smarter. He has designed successfully a non-electric inflating device to give the Strandbeest simple intelligence and a nervous system, in order to avoid it stepping into the sea which could damage it. Theo once made fun of his project by saying that with this new intelligence and nervous system embedded, even when he is gone, his beast can still stay alive and walk on the sand. Humans are always fascinated and attracted by these living mechanical objects. People have been trying to build robots which are like humans. With this kind of desire and advancement of technology, a world cohabited with humans and robots is just around the corner. This fact has made Steven Hawkins, Noam Chomsky, Steve Wozniak, Bill Gates, Elon Musk and hundreds of others, through an open letter[19] express their concern regarding the threats of AI (Artificial Intelligent) which can potentially be more dangerous than nuclear weapons to humans.

Besides bio-inspired projects, the Hylozoic Series installations by Philip Beesley are also very inspiring. Hundreds and thousands of acrylic tentacles were suspended from the ceiling creating an environment of an upside-down jungle (Figure 2.14). When visitors went under these devices, the interactive journey was initiated. These tentacles could be triggered to move and touch the visitors. Assisted by embedded sensors and control systems, the tentacles assumed their own will and were intent upon teasing visitors. The intelligence, in this case, is no longer referring to one-to-one responsive behavior but becomes a rather sophisticated operation, generated via specifically designed artificial intelligence algorithms. A centralized intelligent system with distributed intelligent controls is deployed. This enhances the visitors' curiosity as they are unable to figure out in a short time how this so-called living entity worked. Philip even added a metabolic system so that the Hylozoic Series could generate energy on its own without an external power supply. The visitors' experience in such a space was like being in a natural environment they had never been in before. They had to spend time experiencing it in order to get to know this dynamic environment. Philip's Hylozoic Series was not a bio-inspired project but was rather an attempt to create a living ecosystem (Beesley, 2013). What happened inside with the installation were not only interactions between objects and humans, but also internal interactions evoked among the tentacles as well. With this embedded intra-active system, the installation thus seems to have its own will and behavior to react pro-actively with the surroundings and visitors as a collective intelligent ecosystem. Based on Philip's project, the tendency of interactive architecture to shift from typical two-way responsive visible interactions to multi-dimensional intra-actions and relationships becomes apparent.

19 The full content of the open letter titled "Research Priorities for Robust and Beneficial Artificial Intelligence" can be found from the following link: http://futureoflife.org/ai-open-letter/#signatories

FIGURE 2.14 The Hylozoic Series designed by Philip Beesley, an organic space like nature (source: http://www.philipbeesleyarchitect.com/sculptures/1117_City_Gallery_Wellington/index.php).

§ 2.5 Organic Bodies for Interactive Architecture (from cell to Body)

Back to Kas Oosterhuis' idea of "Hyperbodies", which is a volumetric body composed of a continuous seamless skin surface. When forces are applied individually to the internal and the external layers, the body is driven to seek homeostasis or balance, and can thus morph. And how is this skin composed? The concept Kas introduced here is the "Swarm". Like a flock of birds flying in the sky, a school of fish swimming in the sea, a cluster of ants moving on the ground, or a group of bees looking for honey, every single entity has its own simple intelligence to communicate and exchange information. When they are clustering together, their collective intelligence helps them to make a decision pertaining to its immediate environment and produce a corresponding response/reaction accordingly. Therefore, the idea of creating a morphing intelligent skin/body is to form a composite body using basic intelligent single somatic cells. This is one of the crucial ideas this research deployed.

From a broader perspective on digital architecture nowadays, the definition of Organic Architecture seems to be limited to building organic forms. Through sophisticated 3D modeling software, easily accessible visual programming software (which has become more and more common nowadays), and infinite open source codes available online, building intricate organic shapes is no longer challenging. If we keep on addressing building organic shapes, we will lose opportunities to truly explore and discover new definitions closer to the true inner spirit of organic architecture. We indeed have some architects, who, try to build upon Biomimicry based research, via extracting certain traits from organisms in nature and translating them into procedures for operating human technology such as Robotic arms. However, digital form in the field of computer-aided design, digital fabrication and its association with structure, and Biomimicry from the perspective of function are all independently developed systems without comprehensive integration and thus are contrary to the holistic nature of growth in organisms. Hence, the authentic and original meaning of “being organic” is totally lost in the current Digital/Organic Architecture field. Take any organism for example: its form, structure, and functions should be designed and developed simultaneously instead of being three independent systems added to one another in a linear manner. Integrating (digital) form, (digital) manufacturing, and Biomimicry can help in achieving a form of interactive architecture, which is closer to the genuine idea of “being organic”. Janine Benyus, who coined the term “Biomimicry” (Benyus, 1997), once said in a speech that there are three phases of “**learning from nature**”. The first phase is to imitate natural forms; the second phase is to look into all-natural growth processes; the third phase is to deeply get involved into understanding natural ecosystems. After having mastered the art of producing organic looking form using complex 3d software, it’s time now to move to the next phase of learning about growth processes in nature. John Frazer, one of the pioneers of digital/computational architecture, has written an influential quote in his book “***An Evolutionary Architecture***” stating that **“...what we are evolving are the rules for generating the form, rather than the forms themselves**” (Frazer, 1995). His words strongly support the idea that digital architectural design should be developing logical design systems for generating forms instead of merely modeling/sculpting forms, which coincidentally aligns with the thought behind Janine Benyus’ second phase of learning about the process of growth in nature. Along with the aforementioned ideas, a new kind of digital organic architecture can thus be proposed: Imagine if architecture could grow like living organisms, having basic growth information at the embryonic stage, being influenced by the surrounding environment while growing, and going through all the sophisticated processes of cell differentiation, self-organization, and self-assembly, to eventually grow into a mature living architectural body. This mature architectural body which is able to communicate, adapt, and interact with the surrounding environment as a living organism will become a genuine organic Bio-architecture, a new kind of digital organic architecture (Figure 2.15).

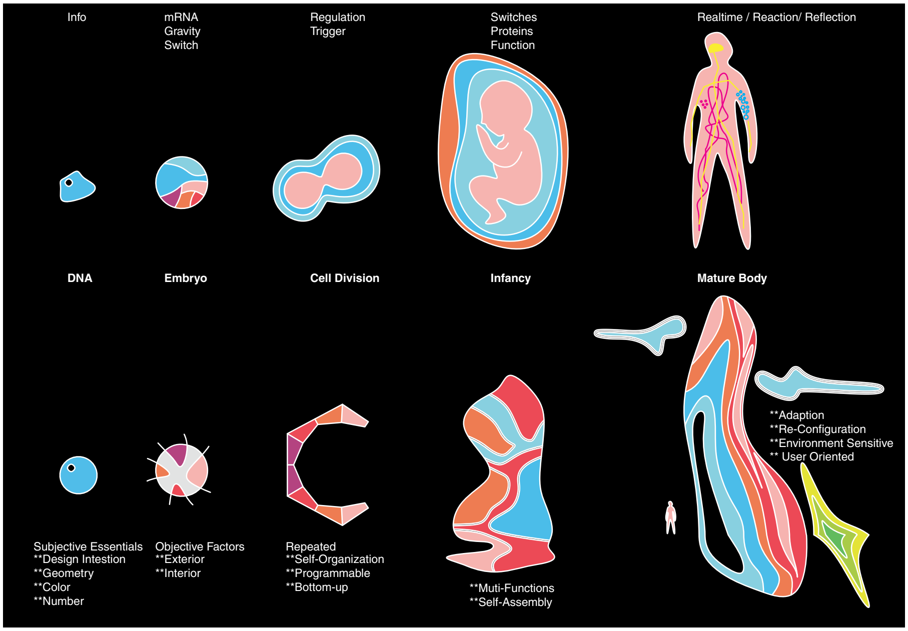

FIGURE 2.15 An illustration of how the growing process of organisms can be applied to architecture in the HyperCell research study.

According to this new-found design mindset, this HyperCell research attempts to offer a new methodology of building an architectural body composed of intelligent cell-like entities, which are based on several principles derived from biology (Biloria, Nimish & Chang, Jia-Rey, 2013), with a focus on Evolutionary Development Biology (Evo-Devo). One of the main notions extracted from Evo-Devo which can be potentially applied as a core idea in this research is to see how organisms develop and differentiate into a variety of animals although they come from similar embryos. With the current developments in biology, we already know that all living organisms share the same genetic toolkit. In other words, this is similar to the now popular idea of parametric design, as humans and all the other creatures have similar parameter sets to design/grow their organic bodies. They are different animals only because their gene sequencing and combinations (natural parameters) are different. This interesting process is worth being further discovered and translated into the parametric architectural design by learning from principles behind it in order to encourage digital architecture to step into the bio-inspired domain. Several interesting and useful logics that can be applied to architectural design systems can be extracted from the principles behind Evo-Devo, such as: the biological logic to create a complex body based on the repetition of simple, self-similar elements; the logic of distributed information communication pertaining to how cells are informed about their vital functions after cell differentiation through specific communication protocols; the switching (on/off)

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logic via which DNAs inform RNAs to produce protein to build different body parts, etc. (Carroll, 2005). In simple words, such a bottom-up understanding of the natural world can serve towards extracting a fundamental logic for a new organic architectural design process. Such a process would imply developing intelligent architectural cells at the smallest element level, to build an interactive architectural body which can stay alive to adapt and communicate with the environment

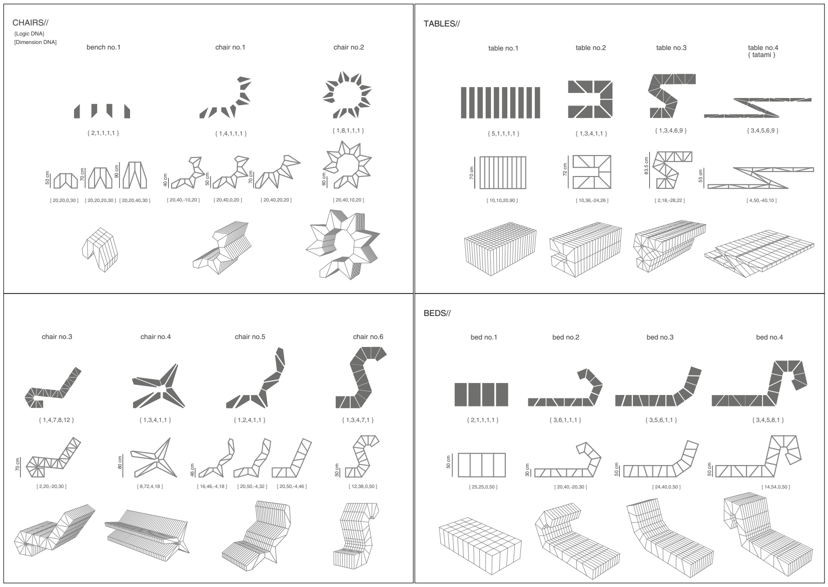

FIGURE 2.16 Possible variable furniture created by adjusting numbers and parameters like DNAs based on the transformation make-up of HyperCells.

In order to make this research more comprehensible and convincing, several design case studies have been developed to support it. Take the series of HyperCell furniture system design projects for instance: the basic geometric shape of a cell was a square in 2D and cubic shape in 3D. Although the lengths of the sides can extend or shorten, the changing degrees of the length is still constrained according to physical limitations, such as gravity and mechanical forces. Under these limitations, based on different arrangements and combinations with the adjustment of input parameter' values, the overall body can acquire complex forms even though it is composed of simple geometric shapes as basic elements. All input parameters of the basic geometric element (quadrangle in this case) can be changed in real-time to make transformation possible at any time in order to meet the users' requirements. In this project, instead of regular environmental factors such as lighting, wind flow, humidity, and temperature, etc., users gain paramount importance to trigger the transformation of the HyperCell furniture. A catalog of furniture designs which are possible via the aforementioned transformation logic was created to show a wide range of potential performance possibilities (Fig. 2). All adjustable parameters, in this case, can be considered as the DNA of the furniture. And based on different DNA information sets and the total number of HyperCell components, different types of furniture could be formed/ generated. In simple terms, you can imagine yourself going to a furniture wholesale store like IKEA to buy several HyperCell components and take them home. You can then follow the instruction to adjust the DNA by intuitive hand gestures to create a default table and a chair with them and when taking a break in the next hour you can simply and conveniently change the setting and transform the table and the chair into a deck chair[20] (Figure 2.16). Similar to the aforementioned example of cityHome, the users' demand for occupied space can thus be reduced to the minimum and the functional efficiency of a unit area can be optimized to the maximum extent. The difference is that the HyperCell furniture can be moved around instead of being fixed in a certain.

Another interesting aspect pertains to "**evolution**", which can be witnessed in nature. In the case of HyperCell furniture, the evolution is initiated by the users. When users become familiar with the operations and adjustments of the HyperCell DNA, they can modify these DNA parameters at will to create novel furniture pieces based on their needs. For example, a table can be combined with a chair to create new compound furniture. In the process of research development and design, certain dynamic simulation tools and Kinect cameras were also used to experiment with the possibilities of controlling the transformation of furniture by intuitive hand gestures or body movements so that the HyperCell furniture can be used more intuitively[21]. By designing the HyperCell furniture system, it was proven that this bio-inspired design

20 Please refer to the blog of P&A LAB (http://pandalabccc.blogspot.tw/search/label/HyperCell) for the research progress and the video regarding to "HyperCell" and the following papers of the authors for more detail 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?ecaade2012_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).

21 HyperCell interface is designed with the Microsoft Kinect cameras. So, the Mouse movements are replaced by free-hand gestures to adjust HyperCell parameters and change the shape of the HyperCell furniture here. To learn more about it, please refer to the video (http://pandalabccc.blogspot.tw/search/label/HyperCell)

method is feasible, and can be put into practice when all the digital architecture techniques (e.g., parametric design, digital simulation, digital fabrication, physical computing...etc.) are applied comprehensively. A more important question, however, is how to apply this logic to bigger architecture structures so that architectural bodies may be able to interact with the environment and communicate with users in a more intuitive way. Furthermore, it is also desired to increase the efficient usage of space and to achieve the goal of producing a genuinely organic architecture. (Please refer to Chapter 6 for more details about the development of the HyperCell design project).

§ 2.6 From Interactive to Intra-Active Architecture (from Inter-activeness to Intra-activeness)

Attaining responsive interaction in architecture is not the ultimate goal of this research. Instead, a multi-modal, multi-dimensional interaction between space and the human body, which challenges the physical and psychological perception of space becomes of vital value. The head of the HyperBody research group, Kas Oosterhuis, defined "**HyperBody**" more than 10 years ago[22], as a pro-active body with proactive actions before being driven, as if it has a will of its own. Adhering to this philosophy, the HyperBody constructed via this research using HyperCells can possess the collective intelligence to facilitate real-time information collation, producing informed action. Both, information from the outside obtained through sensors and internal communication between the swarm of HyperCells are key to give this HyperBody its own free will. Obviously, the primary goal of an architectural body is no longer limited to responding to the environment and users as usual. Users will interact with this "Space" through negotiations which can help with comprehension. If the Hylozoic Series projects by Philip wants to claim that "**space must return to nature**", then here the statement would be "**space is nature**". To achieve this goal, intra-activeness of space definitely needs to be created and constructed.

22 The original quote from the book, "HyperBodies: Towards an E-motive Architecture" by Kas Oosterhuis is: "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."

In summer, 2013, the researcher was invited to be involved in MetaBody[23], an EU culture research project. The team members included choreographers, digital media artists, sound artists, and music composers from 7 different European countries. The purpose of the project was to re-interpret bodies both of humans and space through the means of new media. The project considered how to empower architectural space in order to induce/evoke people to explore unknown/untapped potentials of their own body, as regards both, physiological and psychological aspects. The primary goal of the body of space here has no need to meet users' demands as typical architectural design thinking strives to do. Also, space is no longer seen as an extension of an individual body as McLuhan stated, but as an independent individual with its own emotions, actions, and behaviors like Kas Oosterhuis' HyperBody idea. Users would have to get along with the space by looking for possibilities to communicate with it through body movements instead of verbal language.

FIGURE 2.17 A space created by the interactive projection platform designed by the HyperBody Research Group (Jia-Rey Chang and Nimish Biloria) and Dieter Vandoren where visitors had to try to twist their body to complete different effective movements to interact with the swarm of units displayed by the beams.

In summer, 2014, the researcher with the supervisor, Nimish Biloria, cooperated with Dieter Vandoren, a Rotterdam-based multimedia artist to exhibit in the form of an experimental installation in the form of an immersive digital interactive space

23 To know more about MetaBody, please refer to the link: http://metabody.eu/ or http://www.hyperbody.nl/research/projects/metabody/.

called "**Ambiguous Topology**" (Chang, Jia-Rey, Biloria, Nimish, & Vandoren, Dieter, 2015) in Medialab-Prado, Madrid. The projection system platform developed by Dieter was different from the general approach of projecting images onto a 2D screen to represent/realize a 3D space. In the exhibition space, four projectors were set up at the four corners of the exhibition area. The geometry (points, lines, and planes) in the projection space was re-interpreted through the light beams in a specific manner. For example, a point in the space was precisely located at the intersection crossing of the beams from the four projectors. In Ambiguous Topology, we also built nearly 640 agents to construct the entire space based on the swarm logic. Seven different experiential scenes were displayed in chronological order so that visitors would feel like being in an immersive living space with projection inducing them to interact with the space using novel body movements (Figure 2.17). For example, in one of the scenes, the momentum of the agent/light beams was activated/disturbed when visitors touched them (projected light beams) by waving or pushing them. The colors of the agents/light beam also changed according to the velocity of the light beam. Aggressive colors, such as red and yellow indicated the high transmission value of locomotion compared to blue and green, which express relatively passive and stable light beam movement. When each agent has accumulated sufficient momentum by progressively storing the energy generated from the visitors' movements, the agents instead of acting in a responsive fashion, acquire a role wherein they are intimately attracted to a user's body. This implied, the agents/light beams to acquire aggressive colors (Red and Yellow) and to quite literally attach themselves to the visitors' limbs (attraction points), thus directly transforming their response. Visitors were not given any instructions about interaction scenarios before entering "**Ambiguous Topology**". Furthermore, the designers/programmers only set the rules/logic for each scene of the swarm's behavior as a set of gaming rules. So even the designers and programmers found it was impossible to predict the exact changes of the space and visitors' reactions to this dynamic and unpredictable space[24]. In other words, "**Ambiguous Topology**" became a space having its own life. Visitors in this installation had to use full body movement based non-verbal communication means to communicate with this dynamic space. This also opened up a new dimension for interacting with space for the disabled (Please refer to Chapter 6 for more details about the "Ambiguous Topology").

24 For more detail 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)

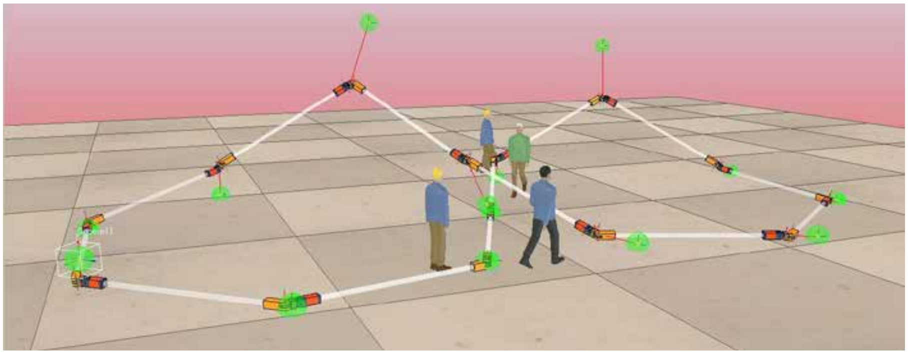

FIGURE 2.18 HyperLoop, a transformable pavilion space the HyperBody Research Group aims to implement, with all nodes being transformable and the sensors on the nodes being able to communicate for the purpose of spatial feedback. Please refer to the video: https://vimeo.com/117388146.

FIGURE 2.19 A scaled mechanical prototype model of HyperLoop.

The ultimate design goal of MetaBody was to deliver an intra-active transformable pavilion. The basic structure of the preliminary design was developed as a giant transformable mechanical frame structure in the form of an infinite loop (an 8 shape), called "**HyperLoop**" (Figure 2.18 and Figure 2.19). A motion tracking system would be implemented on each structural node to gather sensed data. The nodes with embedded microcontroller will have basic intelligence, like the agents of a swarm, communicating with each other through individual data transmission protocols under a certain network. And data will be fed back to the motorized joints on each node to activate physical transformations as the resultant process of collective intelligent swarm behavior. The idea of space with its own freedom akin to the HyperBody notion defined by Kas Oosterhuis can thus be eventually carried out. This behavioral structure with continuous data processing and actuating abilities is proposed to be covered with an interactive skin for more local interactions with users[25](Please refer to Chapter 6 for more details about the HyperLoop).

§ 2.7 Conclusion

Within this data driven context, we can conclude that architectural space can transcend the modernist definition of living machines and tend towards becoming a lively ecosystem with its own life and will, much like the natural world. This study boldly predicts that the innovative concept of organic body-like architecture comprised of intelligent components will soon be realized and will impact not only architectural design thinking but also the habits and imagination of people as regards the concept of space. The purpose of proposing the concept of a living space is not to suggest or predict that this is the only direction/solution for the future of architectural design, but to expand the young generation of architects' imagination regarding space. Similar to the avant-grade designs by Archigram, the research intends to free the mindset of young designers from the constrains of conventional/typical trends of architecture and broaden their horizons for creating new potentialities in architectural design. Furthermore, to improve architectural design, one must not constrain imagination to currently available technology. If those visionary ideas proposed by Archigram had all stuck to the technology of the 60s, their design concepts and projects wouldn't have influenced visionary architects in the generations which followed. Recently in the architecture design industry, digital architecture is becoming mainstream with its associated pros and cons. The advantage is that we gain more design efficiency by using computational tools, such as parametric modeling, and environmental analysis simulation, etc., than before. However, with the vigorous development of digital architecture, digital tools shouldn't be considered only as assistive, but should rather be used as generative tools to be used for exploring future possibilities.

25 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 the detailed description of the development process of HyperLoop and the related video.

Looking back at the context of Interactive Architecture's development, in the early days when Interactive Architecture was still in its embryonic stage of kinetic architecture, the main purpose was to achieve multiple spatial usage with manually movable elements, such as movable wall panels, or turning on/off of devices by using simple body gestures. More recently, with further technological development, the aim slowly shifted towards developing adaptiveness of façades in order to regulate environmental factors in an automated fashion through centralized data processing systems in an attempt to mimic how organisms react within nature. A visionary and ambitious goal for the future has been proposed in this research: to imagine a space having its own will and behavior akin to a living organism, needing constant negotiation and communication to explore and establish novel relationships between humans and space. With the advancement of technology, this notion of interactive architecture is getting closer to realization. If the principles of building organic architecture still adhere to mimicking organic designs, then the development of Organic Architecture will be at a standstill. In contrast, understanding Organic Architecture from an Interaction Design will imply re-considering our approach from mimicking to understanding the principles of morphological development and incorporate these in our design thinking. This way, we can approach the field of interactive architecture in a manner which corresponds much more closely with the definition of being Organic, thus marking the beginnings of a transition from interactive to intra-active architectural body to truly envision a new generation of Organic Bio-Inspired Architecture.

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