# 7 Conclusion and Future Recommendation

**"Simply stated, what we are evolving are the rules for generating form rather than the forms themselves. We are describing processes, not components; ours is the packet-of-seeds as opposed to the bag-of-bricks approach."**

*John Frazer*

## § 7.1 Conclusion

*Interactive Architecture should embody the features of "Information", "Improvisation", and "Integration" in order to generate sufficient "Intelligence" to embody the authentic kernel of "Organic Architecture".*

In the domain of Interactive Architecture, it is quite easy to become trapped in discussions predominantly focused on technical discourses. This is what can be observed in most of the published materials on Interactive Architecture available in the market today. These publications draw too much attentions in the manner of how to make technical systems, instead of focusing on why to make it. Partly, this may be because it is necessary to understand hands-on technical issues, however, there should certainly be more informative material to fertilize design thinking of Interactive Bio-Architecture. Some other publications in the same genre fall into a collection of on-going case studies in the domain of Interactive Architecture without properly arranging them into an organized systemic discourse. Unlike such publications, this research attempts to become a pioneering exploration attempting to address Interactive architecture as the convergence of three areas: **Computation**, **Embodiment**

(**Body**), and **Biology**. From the computational point of view, the research outlined the historic trajectory of computational applications in digital architecture design or CAAD (computer aided architectural design) and its evolution from data storage, rendering representation, towards sophisticated physical computing. From embodiment(body) perspective, a wide range of issues from diverse fields of metrology, philosophy, media studies, interactive art, VR and motion tracking technology have been elaborated upon in order to discover intimate relationships and connections between (cyber)space and (cyborgs)human. In the section of Biology, the discussion ranged from the so-called organic architecture design that remains at the stage of mimicking organic shapes, to extracting and translating the fundamental premises of morphogenesis from Evolutionary-Development Biology (Evo-Devo) in order to propose computationally assisted body-like interactive Bio-architectures. By leading the arguments slightly more towards the humanities, cultural, and social or even biological aspects, it aims to broaden the research scope of Interactive Bio-Architecture to reverse its stereotypical associations of being extremely technical and engineering oriented. This research thus concludes by providing critical emphasis on topics such as **Information**, **Improvisation**, **Integration**, and **Intelligence**, which are reflective of the fundamental essence of the inter-disciplinary research elaborated in each chapter of the thesis.

### § 7.1.1 Information

Data is omnipresent in our surroundings. It is not easily noticed in its raw form because it is translated via different means to produce various information and messages. Sunlight in the form of temperature is a form of information; blood pressure inside our body is another type of data; the text you put within the email is another one. It is only recently that through technological means, we can visualize data in multiple ways and thus a lot of emphases now is put into visual appearance of data via a plethora of interfaces. However, data has been interpreted and communicated since ancient times using different expressions. For instance, ancient paintings using animal blood or the engraved sketches drawn in the caves millennia ago are also a method of storing data. For that matter, all animals possess their own data storage in the form of their DNA. In nature, not only can the message received from the DNA define each individual animal body, it can also drive the evolutionary processes with respect to environmental information to make appropriate changes to organic shapes and related bio-functions in order to ensure survival and breeding.

Needless to say, may it be the computer or the body, they are both information processors which deal with data with their internal mechanisms. One of the crucial

features with data is that its nature is fluid. It is in constant flux and never ceases. It is either dynamically transforming internally or gradually moving externally which makes it always different than it was a moment ago. While dealing with such a dynamic entity, it is relatively unwise to build a cumbersome obstacle, which hosts only one instance of this dynamic data, which, unfortunately, is a typical way of conceiving a building right now. As Architects, we usually ignore such dynamic environmental data but rather tend to block them out by using the principles of "Utilitas, Firmitas, and Venustas" from the "De Architectura".

However, in today's information driven era, one should adopt a novel approach in architectural design wherein information flow is understood as vital in order to evolve performative solutions in the form of "Interactive Bio-Architectures". This is seen as a natural manner of dealing with a dynamic environment and that is also how the organic body (of an animal) operates. This is one of the key points emphasized constantly in this research. Computational technology is an accelerator, which assists us to build adaptable buildings. With the assistance of computation, a sensory space could eventually be achieved by implementing high-end precise technologies either in sensing or actuation in order to make the space adapt to the environment (in this research, the users' demands) akin to an organic body.

### § 7.1.2 Improvisation

Extending the idea of "**Space as Body**", the improvisations can be interpreted as an immediate reaction coming from both, the body and the space it inhabits. On one hand, a body manifests immediate external reflexes (external improvisation) in accordance with changing contextual circumstances. On the other hand, inside of any organic body, there is always a continuous flow of data in the form of metabolic activities, in order to keep the body functioning at an optimal level (internal improvisation). In other words, the body reacts not only to the external dynamic environmental conditions but also to internal metabolic changes. By replacing the term "body" with "space", every sentence mentioned above still holds true, if we follow the definition of Interactive Bio-Architecture proposed by this research. This implies a space acting as a body and should thus be real-time adaptive in nature towards its external environment as well as the towards the internal occupant demands. Since both of these aspects are essentially dynamic and unpredictable, thus, the term "improvisation", is apt for communicating the emergent adaptations which such a space shall embody. The improvisations here are interpreted as functional flexibility accompanied with appropriate comfort and convenient usage. As a vision, if a building

could adapt in order to optimally harvest sunlight and wind, as well as interact with its inhabitants it would immediately take appropriate actions to do so. This kind of real-time adaptive space, which can respond to user requirements is an inevitable tendency of Interactive Bio-Architecture. Borrowing its idea once again from Marshall McLuhan's body extension, an architectural space should be able to operate as an external organ to the human body, which can be manipulated freely using the users' body gestures.

"**Our architecture is a property of the process of organizing matter rather than a property of matter thus organized,**" (Frazer, 1995): This statement can also be interpreted as a property of space, who's body/matter is explicitly organized in real-time through a process, which is triggered by user's demands. In other words, space should be organized by matter in real-time and change its configuration to adapt to unpredictable events instead of acting upon pre-set functions. The road to achieve such intelligent behavior, as proposed via this research, involves componential interaction and collective decision making akin to the principles behind Swarm Behavior.

Following the HyperCell design thinking, using numerous intelligent mobile entities in the form of distributed furniture or building blocks, it is possible to achieve multiple assembly/deployment configurations in order to fulfill variable functional demands. For example, an explicit command of "Shelter" can be composed of various geometric forms within these re-configurable/transformable entities following the logic of Swarm Behavior. This, quality of HyperCells can have a fundamental benefit over typical pre-configured spatial automation systems: One can expect unpredictable outcomes of spatial formations satisfying the same functional criteria at different points in time. This quality is also intriguing to the user and is able to portray the essence behind the concept of improvisation without the space becoming sterile and predictable in the long run. From the perspective of a user's body, on the one hand, such improvisation of space provides for customized spatial usage, while on the other hand, it implies setting up of non-verbal communication between the human body and architectural space. Space thus literally becomes an extension of the body. "Improvisation", from a user's viewpoint, should thus free space from physical constraints of being static/non-responsive and in-turn empowers it with being both flexible and adaptable.

### § 7.1.3 Integration

Nature teaches us the importance of integration Although there are different organs and individual systems inside an organic body, they are all interrelated with each other as a holistic body. This notion of "integration" is pushed to the extreme if we study

the material properties which make up an organism. For instance, the stem of a plant, is multi-performative in essence due to its material make-up. The material system performs not only as a supportive structure, but it also performs efficiently to circulate water and nutrition from the roots to the leaves, at the same time, it can also generate sufficient energy from the chloroplast embedded in each of its componential cellular elements. Architecture, in order to embody such integration and multi-performative behavior, should embrace the direction of harnessing componential systems to build up an integrated, efficient and intelligent building. The emergent behavior observed in swarms can also be interpreted as a form of "Integration". A swarm of ant, a flock of bird, a school of fish...etc., generate a collective body using collective intelligence in order to act as a gigantic creature by means of following simple communication protocols embedded within each entity. This phenomenon of simple communication between the smallest entity/building block is what the research emphasizes as one of the key points when attempting to form complex objects such as buildings. This implies that every single decision as regards physical movement from any of the agents will have an influence on the other agents, which are a part of the object's ecology. This inter-activation, can also be traced in the philosophical thinking of Deleuze and Guattari's **Body Without Organs** (Deleuze, G., & Guattari, F., 2003) and Gottfried Leibniz's **Monadology** (Leibniz, Monadology, 1714).

As the research interprets it, "Integration" implies a combination or a connection between the virtual and the real world. The boundary between the real world and cyberspace has diminished with the invention of the Internet. Plus, the increasing creative exploration in the VR industry has now made it possible to merge multiple virtual universes together. As a space designer, it is thus immature to ignore current technological developments as well as social impacts along with it. The integration of virtual reality and cyberspace can potentially create a wide range of spatial diversity by either bringing the virtual into the physical world or by merging the physical environment with virtual reality. "Integration" in interactive architectural design should thus be a major criterion to be considered during the initial design thinking phase, the form generation phase, and during the development of integrated systems design.

### § 7.1.4 Intelligence = information + improvisation + integration

By merging the research of **Computation**, **Embodiment** (**Body** related issues), and **Biology**, and associated cultural and social implications, this research proposes a design framework for Interactive Bio-architecture by elaborating upon a series of

experimental design projects, which showcase the potential of this novel design thinking.

*Once the above features of "information", "improvisation", and "integration" are understood and implemented, the aspect of "intelligence" will naturally be collectively generated for the sake of the kernel of Interactive Bio-Architecture as Organic architecture.*

The research also tries to provide a different perspective on the embedded relation between Interactive Architecture and Organic Architecture. Interactive Architecture and Organic Architecture had been put into different genres for years, but by following this research's discourse, it becomes clear that they should ultimately reach a point of convergence to create a new kind of Organic Bio-Architecture. A parallel can be drawn between how natural organisms live and how Organic Bio-Architectures should perform: **Using their collective intelligence, they are able to actively interact (both externally and internally) with contextual data and are able to make immediate improvisations, in order to function as an integrated body/system.**

## § 7.2 Future Recommendation:

In this section, including some unfinished efforts, several thoughts of future developments following the principles and discourse of the thesis will be pointed out as recommendations under separate topics of **"Software", "Hardware",** and **"Design Thinking".**

### § 7.2.1 Software

Following and expanding on the bio-inspired ideas, this research translated essential rules from Evolutionary Developmental Biology (componential system, collective intelligence, and assembly system), to set up a set of design rules in the form of a framework instead of generating an ultimate design result. This is highly related to the ideas propagated by John Frazer's notion that "**...what we are evolving are the rules for generating form rather than the forms themselves. We are describing processes, not components; ours is the packet-of-seeds as opposed to the bag-of-bricks approach...**"

(Frazer, 1995). This kind of design thinking involves a **GAME** design strategy with customized rulesets. The HyperCell experiment, can be designed as a game for other designers or even its users, to develop and create their own customized furniture element as well as for developing an overall control system. In other words, with such rule-based interactive design thinking, it is possible to allow people to participate and customize design offerings. As Gordon Pask stated in his article, "***The Architectural Relevance of Cybernetics***" (Pask, 1969): "**...An immediate practical consequence of the evolutionary point of view is that architectural design should have rules for evolution built into them if their growth is to be healthy rather than cancerous. In other words, a responsible architect must be concerned with evolutionary properties...**" The idea of "**a rule-based design framework operates as a game**", thus allowing for certain degrees of design freedom (for adding, subtracting and modifying rules) for the designers' and the users' in order to satisfy their practical usage requirements. While Nicholas Negroponte developed his idea of "**Soft Architecture Machine**", he intended to involve the users to participate during the design process instead of having an intelligent computer playing the role of a designer to generate designs which might not match what the user exactly needs (Negroponte, 1975). With these settings, the game can be harnessed by any end-users regardless of whether they are experienced designers or have non-design oriented backgrounds. Nonetheless, there certainly should be a virtual visualization software to display the design outcome as a reference before proceeding to manufacture. The designer can play the role of a programmer to develop a game-like design software, or assume the part of an end user to create various results by utilizing this design software.

From a users' points of view, with the rapid development in VR technology, it would be even more impressive to envision not only rendered design results on monitor screens but allow one to, in real-time, manipulate space using VR and its immersive experience. This open-gaming idea applied to design provides flexibility to the users which in a sense becomes an evolutionary democratic process. Block'hood[71] is a game-base design tool developed by Jose Sanchez in which people can "play" the architectural design by adding cube-like spatial elements, such as private spaces, staircases, windmills...etc., to generate one's own unique design. It has been used in practical projects and planning phases in urban design projects as well. Similarly, HyperCells as a furniture system aims to become a real architectural building block. It would thus be ideal if a gaming-system in the form of an open platform for sharing different operational protocols driving various "HyperCell" installations globally is

71 Please check this website to learn more about the "Block'hood": http://www.plethora-project.com/blockhood/.

developed. This will give rise to a strong user community which can share creative rule sets for further enhancing the adaptability and customizability of the HyperCell.

### § 7.2.2 Hardware

The HyperCell furniture system has a great potential in terms of practical use. The research only managed to initiate a relatively rough design process and unfortunately did not yet have a chance to realize the HyperCell component physically. Theoretically, it is feasible to produce building components as HyperCells but it might have relatively high cost with all the required devices. It will thus be a prerequisite task to seek for proper coordinated peripherals and technologies not only in terms of embedded mechanisms but also with respect to material systems to be implemented in the future. Referring back to the discussion of merging the **Naturalized** and the **Motorized** applications in terms of material properties in interactive Bio-architecture, there should be practical possibilities to combine the mechanical and biological make-up together as a novel hybrid material for future development of HyperCell components, which is also an innovative but potential research field awaiting to be explored.

HyperCells intend to be initially designed as a furniture system in the research, but the end goal of the HyperCell is relatively ambitious: to be utilized as an interactive/transformable building block. In other words, the pragmatic usage of the HyperCell should not be limited by being functional for an interior space but should be operated outdoors as a real programmable architecture building block which is robust, structural, and space-defining. Within the idea of HyprCell as a real-time interactive building block, the pragmatic vision of the adaptive and pro-active environments will be the space for people to actually cluster, walk upon, and live in with, thus not merely limited to smaller-scale adaptive furniture to sit on or leans against. The Digital Pavilion in Seoul designed by Kas Oosterhuis(ONL) back in 2006[72], gives a perfect example of how the "living artificially intelligent space" comprised of programmable/interactive building blocks should be. By integrating the robotic system, ubiquitous computing, interaction and new media technology, it realized a living space with Voronoi cells as basic geometric/intelligent components to provide a pro-activeness, mixed-Virtual-Reality space people have never experienced. In this case, the Digital Pavilion accomplished 10 years ago has already set up an ideal model for HyperCell

72 Please check the website for more information and details about the Digital Pavilion, Seoul: http://www.hyper-body.nl/research/projects/digital-pavilion/

research to look up to. Moreover, if feasible, then this transformable building block could also be considered to have various mobility properties in order to cater to the "urban nomad" where the space would only be created by HyperCells once there is a requirement. Within this vision, the communication and control system would be heavily involved in the future development. In terms of organic body-like space, it is also crucial to think of wearable technology cooperating with the surrounding space to literally create an intimate relationship between the space and human to be integrated as a whole.

### § 7.2.3 Design Thinking

The goal of this research is to inculcate design thinking addressing interactive Bio-architecture as an organic body owing to its componential cellular makeup. The HyperCell component presented in this research is the first version of HyperCells. With its ambition to become an interactive building block, it is extremely important to develop more intelligent components following the direction of HyperCell. Such development will involve inter-disciplinary investigations by talented designers and experts to promote advanced development and realization. For instance, recently, Google exhibited the latest development of their ARA smartphone[73]. Unlike the usual smartphones, which come as a pre-configured package both in terms of their form and their electronics, the ARA phone provides flexibility to customize the phone by means of assembling the components which you need. This idea not only changes the way of making the product unique but also modifies the conventional manner of using this product as a smartphone. Such ideas, should not only become an inspiration but could also lead to real applications for spatial structuring in architectural design.

Such, user-oriented optimization ideas have been proposed through the research of the HyperCell in the form of a furniture system to customize your own space in time. To expand this idea to an even larger scale of architectural design, it is possible to develop multiple customized, replaceable, reconfigurable, and transformable building components not only different in shape, in material, but also in function. Marketing and business wise, there should be a platform akin to retail/on-line shops for selling these intelligent building blocks. These intelligent building components should be treated as hi-end technological products, such as smartphones and laptops, to be

73 Please check the webpage of "Google ARA" for more details: https://atap.google.com/ara/.

exhibited in specific stores where the designers or even users can purchase these intelligent building components developed by different brands of manufacturers. Envision a scenario where you can walk into a retail shop specifically selling such building components, and there are even multiple different demonstrations of the components for various purposes, or even a furniture setting composed of those components as a demonstrating living room section like how IKEA exhibits for designers or users to look around, experience, and purchase them. By simply filling in the product number and the brand of the components, they will be delivered by the supplier to your home the next day either for your own new design of a furniture piece or your on-going project for luxury housing. It is intriguing enough to expect this future scenario to emerge and evolve for smart living solutions.

While innovation is always easier said than done, to make this multi-functional building component idea a reality, there is a vast amount of research and prototyping, which is still needed. The HyperCell research envisions a potential to change the manner in which we conceive architectural and interior designs in order to promote smarter spatial environments which will result in a better quality of life.

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