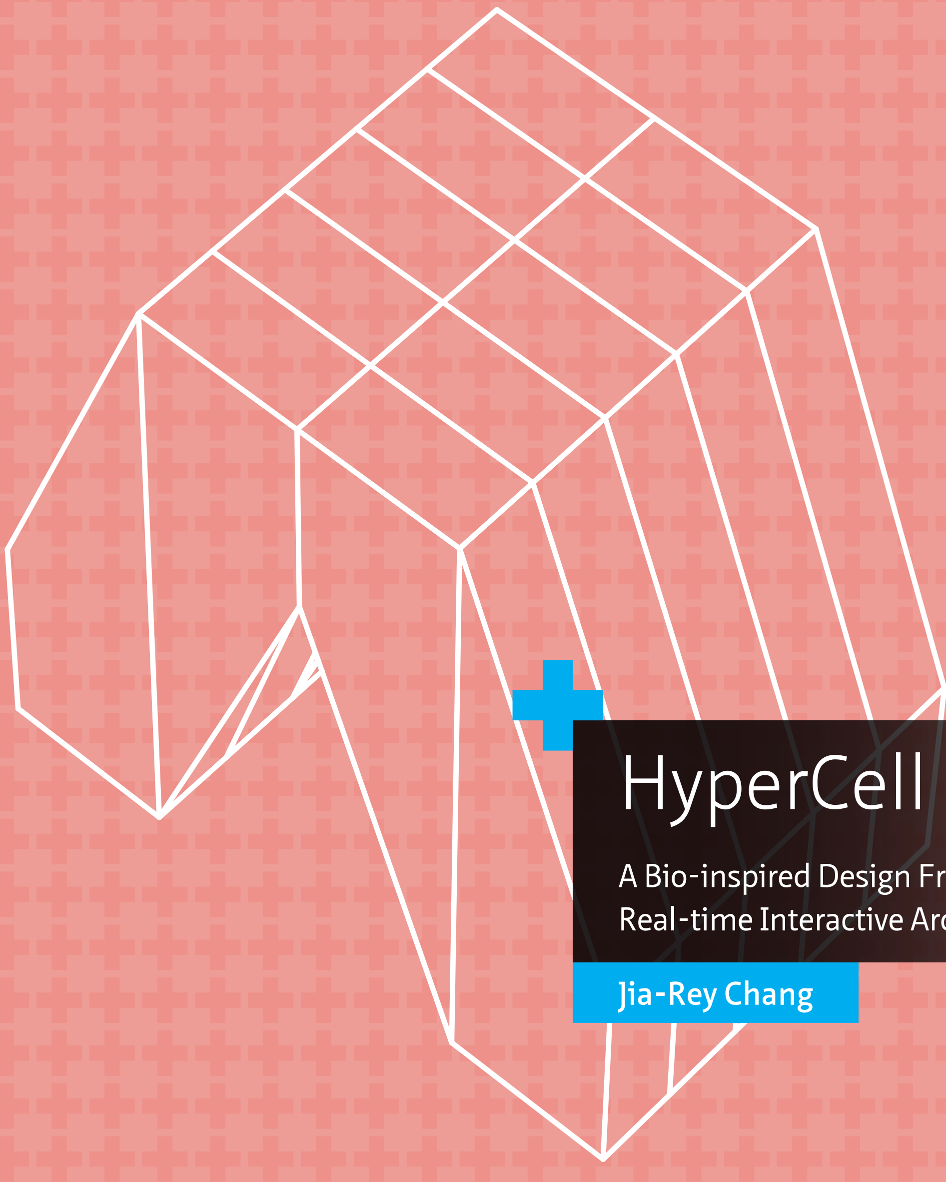
Architecture and the Built environment

#01
2018



HyperCell

A Bio-inspired Design Framework for Real-time Interactive Architectures

Jia-Rey Chang

HyperCell

A Bio-inspired Design Framework for Real-time Interactive Architectures

Jia-Rey Chang
Delft University of Technology, Faculty of Architecture and the Built Environment, Department of Architectural Engineering and Technology

Architecture and the Built environment

abe.tudelft.nl

Design: Sirene Ontwerpers, Rotterdam

ISBN 978-94-6366-004-4
ISSN 2212-3202

To my mother, Ling-Rong, my father, Jin-Fu, and my wife, Shu-Huang (Becky),
who cares, loves, and always be there for me.

TOC

Acknowledgements

It is a great honor to acknowledge my deepest thanks to my promoter, Prof. Kas Oosterhuis. Under his supervision, he gives me the visionary and the freedom to explore my experimental research in Interactive Architecture. I am also grateful to my co-promoter/daily supervisor, Dr. Nimish Biloria, who keeps constantly challenging my mindset with loads of critical inspirations/discussions to assist me in accomplishing my dissertation under his guidance.

Many thanks to all my HyperBody colleagues I've been working with, especially to Vera Laszlo, Marco Galli, Tian-tian, and Yu-Chou, for all the laughter, cares, and supports during my Ph.D. life (especially in the lunchtime). And thanks to the Ph.D. fellows, Achilleas Psyllidis and Sina Mostafavi, for sharing their critical thinking and knowledge. Many thanks to Dr. Paul Mass for keeping feeding me all kinds of up-to-date and useful knowledge via emails. A very special gratitude go out to all the students I've been tutored who help me gain immense and priceless educational experiences and allow me to learn/get inspired from their talents. I would also like to express my true appreciation to my mentor and friends in Taiwan, who continuously reach out to me just to be supportive and giving me warm concern, like Prof. Cheng-Chen Chen, Min-Chieh Chen, Mark Cheng, David Hsu…etc.

Words cannot express how grateful I am to my beloved and incredible parents, without their endless financial and mental supports, I will never manage to finish my Ph.D. degree. It is so thankful to have them as my parents with their tremendous love.

Last but not least, I would like to sincerely thank my lovely wife, Shu-Huang (Becky) Chiu, of always being my biggest fan and the strongest and most supportive backing, who gives me enormous courage, confidence, and inspirations to fearlessly move forward to the end of my Ph.D. journey.

Contents

List of Figures

Summary

"...The body says what words cannot..."

Martha Graham

This pioneering research focuses on Biomimetic Interactive Architecture using "**Computation**", "**Embodiment**", and "**Biology**" to generate an intimate embodied convergence to propose a novel rule-based design framework for creating organic architectures composed of swarm-based intelligent components. Furthermore, the research boldly claims that Interactive Architecture should emerge as the next truly Organic Architecture. As the world and society are dynamically changing, especially in this digital era, the research dares to challenge the Utilitas, Firmitas, and Venustas of the traditional architectural Weltanschauung, and rejects them by adopting the novel notion that architecture should be dynamic, fluid, and interactive. This project reflects a trajectory from the 1960's with the advent of the avant-garde architectural design group, Archigram, and its numerous intriguing and pioneering visionary projects. Archigram's non-standard, mobile, and interactive projects profoundly influenced a new generation of architects to explore the connection between technology and their architectural projects. This research continues this trend of exploring novel design thinking and the framework of Interactive Architecture by discovering the interrelationship amongst three major topics: "**Computation**", "**Embodiment**", and "**Biology**". The project aims to elucidate pioneering research combining these three topics in one discourse: "Bio-inspired digital architectural design". These three major topics will be introduced in this Summary.

"**Computation**", is any type of calculation that includes both arithmetical and non-arithmetical steps and follows a well-defined model understood and described as, for example, an algorithm[1]. But, in this research, refers to the use of data storage, parametric design application, and physical computing for developing informed

1 Please refer to the website: https://en.wikipedia.org/wiki/Computation for further understanding of "Computation."

architectural designs. "**Form**" has always been the most critical focus in architectural design, and this focus has also been a major driver behind the application computational design in Architecture. Nonetheless, this research will interpret the term "**Form**" in architecture as a continual "**information processor**" rather than the result of information processing. In other words, "**Form**" should not be perceived only as an expressive appearance based computational outcome but rather as a real-time process of information processing, akin to organic "**Formation**". Architecture embodying kinetic ability for adjusting or changing its shape with the ability to process the surroundings and feedback in accordance with its free will with an inherent interactive intelligent movement of a living body. Additionally, it is also crucial to address the question of whether computational technologies are being properly harnessed, if they are only used for form-generating purposes in architecture design, or should this be replaced with real-time information communication and control systems to produce interactive architectures, with embodied computation abilities?

"Embodiment" in the context of this research is embedded in Umberto Eco's vision on Semiotics, theories underlying media studies in Marshall McLuhan's "***Body Extension***" (McLuhan, 1964), the contemporary philosophical thought of "***Body Without Organs***" (Gilles Deleuze and Félix Guattari, 1983), the computational Logic of 'Swarm Behavior' and the philosophical notion of "***Monadology***" proposed by Gottfried Leibniz (Leibniz, 1714). Embodied computation and design are predominant today within the wearable computing and smart living domains, which combine Virtual and Real worlds. Technical progress and prowess in VR development also contribute to advancing 3D smart architectural design and display solutions. The proposed 'Organic body-like architectural spaces' emphasize upon the realization of a body-like interactive space. Developing Interactive Architecture will imply eliciting the collective intelligence prevalent in nature and the virtual world of Big Data. Interactive Architecture shall thus embody integrated Information exchange protocols and decision-making systems in order to possess organic body-like qualities.

"**Biology**", in this research explores biomimetic principles intended to create purpose-driven kinetic and organic architecture. This involves a detailed study/critique of organic architecture, generating organic shapes, performance optimization based digital fabrication techniques and kinetic systems. A holistic bio-inspired architecture embodies multiple performance criteria akin to natural systems, which integrate structural, infrastructure performances throughout the growth of an organic body. Such a natural morphogenesis process of architectural design explores what Janine

M. Benyus described as “***learning the natural process***”[2]. Profoundly influenced by the processes behind morphogenesis, the research further explores Evolutionary Development Biology (Evo-Devo) explaining how embryological regulation strongly affect the resulting formations. Evo-Devo in interactive architecture implies the development of architecture based on three fundamental principles: “***Simple to Complex***”, “***Geometric Information Distribution***”, and ***“On/Off Switch and Trigger***.”

The research seeks to create a relatively intelligent architectural body, and the tactile interactive spatial environment by applying the extracted knowledge from the study of the aforementioned principles of Evo-Devo in the following fashion:

A Extract a ***Self-Similar Componential System*** based approach from the “Simple to Complex” principle of Evo-Devo
B Extract the idea of “***Collective Intelligence***” from “Geometric information Distribution” principle of Evo-Devo
C Extract the principle of “***Assembly Regulation”*** from “On/Off switch and trigger” principle of Evo-Devo

The “HyperCell” research, through an elaborate investigation on the three aforementioned topics, develops a design framework for developing real-time adaptive spatial systems. HyperCell does this, by developing a system of transformable cubic elements which can self-organize, adapt and interact in real-time. These Hypercells shall comprise an organic space which can adjust itself in relation to our human bodies. The furniture system is literally reified and embodied to develop an intra-active space that proactively provokes human movement. The space thus acquires an emotive dimension and can become your pet, partner, or even friend, and might also involve multiple usabilities of the same space. The research and its progression were also had actively connected with a 5-year collaborative European Culture project: “MetaBody”.

The research thus involves exploration of Interactive Architecture from the following perspectives: architectural design, digital architectural history trajectory, computational technology, philosophical discourse related to the embodiment, media and digital culture, current VR and body-related technology, and Evolutionary Developmental Biology.

2 Janine Benyus, a biologist, who coined the term, “biomimicry”, has stated there are three different levels of learning from nature: one is to mimic the natural form of organisms; second is to study and apply the natural process of organisms; the last is to fuse into the eco-system of the nature. See: https://www.ted.com/talks/janine_benyus_biomimicry_in_action

“HyperCell” will encourage young architects to pursue interdisciplinary design initiatives via the fusion of computational design, embodiment, and biology for developing bio-inspired organic architectures.

References

Gilles Deleuze and Félix Guattari. (1983). *Anti-Oedipus.* Minneapolis: University of Minnesota Press .

Leibniz, G. W. (1714). *Monadology.* (J. Bennett, Trans.) Retrieved from http://www.earlymoderntexts.com/assets/pdfs/leibniz1714b.pdf

McLuhan, M. (1964). *Understanding Media: The Extensions of Man.* New York: McGraw-Hill.

Samenvatting

" ...The body says what words cannot..."

Martha Graham

Dit pionierende onderzoek is gericht op Biomimetische Interactieve Architectuur waarbij "**Computatie**", "**Belichaming**" en "**Biologie**" worden gebruikt om een intieme belichaamde toenadering te creëren voor het introduceren van een ontwerpkader dat is gebaseerd op nieuwe regels. Hiermee kunnen organische architecturen worden gecreëerd die bestaan uit zwermintelligentie-componenten. Verder beweert het onderzoek vastberaden dat Interactieve Architectuur de volgende daadwerkelijk Organische Architectuur dient te zijn. Terwijl de wereld en de maatschappij, zeker in deze digitale tijd, dynamisch veranderen, daagt het onderzoek de Utilitas, Firmitas en Venustas van de traditionele architecturale Weltanschauung uit, en verwerpt het deze door de nieuwe notie dat architectuur dynamisch, fluïde en interactief dient te zijn aan te nemen. Dit project reflecteert een traject van de jaren 60 met de komst van de architecturale avant-garde ontwerpgroep Archigram en de vele intrigerende en baanbrekende visionaire projecten. De uitzonderlijke, mobiele en interactieve projecten van Archigram hebben een nieuwe generatie architecten grondig aangespoord om de connectie tussen technologie en hun architecturale projecten te verkennen. Dit onderzoek bouwt voort op deze trend van de verkenning van de nieuwe ontwerpdenkwijze en het kader van Interactieve Architectuur door de onderlinge samenhang tussen drie belangrijke onderwerpen te onderzoeken: "**Computatie**", "**Belichaming**" en "**Biologie**". Het is het doel van het project om baanbrekend onderzoek te verhelderen door deze drie onderwerpen in één discours te behandelen: "Bio-geïnspireerd architecturaal ontwerp". Deze drie belangrijke onderwerpen worden in deze Samenvatting geïntroduceerd.

“**Computatie**” slaat op iedere berekening waarin zowel rekenkundige als niet-rekenkundige stappen worden genomen en volgt een goed gedefinieerd model dat bijvoorbeeld begrepen en beschreven kan zijn als een algoritme[3]. In dit onderzoek verwijst het naar het gebruik van dataopslag, parametrische ontwerptoepassingen en fysiek computerwerk voor het ontwikkelen van geïnformeerde architecturale ontwerpen. “**Vorm**” heeft altijd de meest kritieke focus gehad in het architecturale ontwerp en deze focus is ook een grote drijfveer geweest voor het toegepast computationeel ontwerp in Architectuur. Desalniettemin zal dit onderzoek de term “**Vorm**” in de architectuur interpreteren als een continue “**informatieverwerker**”, in plaats van als het resultaat van informatieverwerking. In andere woorden dient “**Vorm**” niet alleen als een uitdrukkelijk op verschijning gebaseerde rekenkundige uitkomst te worden gezien, maar meer als een real-time proces van informatieverwerking, verwant aan organische **“Formatie”**. Het betreft architectuur met kinetisch vermogen voor het aanpassen of veranderen van de vorm met de mogelijkheid om de omgeving en feedback te verwerken in overeenstemming met de vrije wil gecombineerd met een ingebouwde interactieve intelligente beweging van een levend lichaam. Daarnaast is het ook van cruciaal belang om de vraag te behandelen of computationele technologieën goed worden benut, of ze alleen worden gebruikt voor vorm-genererende doelen in het architecturaal ontwerp, of vervangen dienen te worden voor real-time informatie communicatie- en controlesystemen om interactieve architectuur te produceren met belichaamde berekeningsmogelijkheden.

“Belichaming” ligt in de context van dit onderzoek verankerd in Umberto Eco’s visie op Semiotiek, theorieën die ten grondslag liggen aan mediastudies in “***Body Extension***” (McLuhan, 1964) van Marshall McLuhan, de eigentijdse filosofische gedachte van “***Body Without Organs***” (Gilles Deleuze en Félix Guattary, 1983), de computationele logica van ‘Zwermgedrag’ en de filosofische notie van “***Monadologie***”, voorgesteld door Gottfried Leibniz (Leibniz, 1714). Belichaamde berekening en ontwerp overheersen tegenwoordig binnen de draagbare computationele en Smart-Living domeinen, welke Virtuele en Werkelijke werelden combineren. Technische vooruitgang en bekwaamheid in de VR-ontwikkeling dragen ook bij aan geavanceerd 3D smart-architecturaal ontwerp en display solutions. De voorgestelde ‘Organische lichaamsachtige architecturale ruimten’ benadrukken de realisatie van een lichaamsachtige interactieve ruimte. Interactieve Architectuur ontwikkelen omvat het opwekken van de collectieve intelligentie die voorkomt in de natuur en de virtuele wereld van Big Data. Interactieve Architectuur zal dus geïntegreerde Informatie-uitwisselingsprotocollen en keuzesystemen belichamen om zo organische lichaamsachtige kwaliteiten te bezitten.

3 Zie de website: https://en.wikipedia.org/wiki/Computation voor verder uitleg over “Computatie.”

TOC

“**Biologie**” verkent in dit onderzoek biomimetische principes bedoeld om doelgerichte kinetische en organische architectuur te creëren. Dit omvat een gedetailleerde studie/evaluatie van organische architectuur. Hierin worden organische vormen, op prestatie-optimalisatie gerichte digitale fabricatietechnieken en kinetische systemen gegenereerd. Holistische bio-geïnspireerde architectuur belichaamt meerdere prestatiecriteria verwant aan natuurlijke systemen, welke structurele infrastructuurprestaties in de groei van een organisch lichaam integreren. Zo'n natuurlijk morfogeneseproces van architecturaal ontwerp verkent wat Janine M Benyus omschreef als “***het natuurlijke proces leren***” [4]. Diepgaand beïnvloed door de processen achter morfogenese verkent het onderzoek de Evolutionaire Ontwikkelingsbiologie (Evo-Devo) verder, waarbij het uitlegt hoe embryologische regulatie de uiteindelijke formaties sterk beïnvloedt. Evo-Devo in interactieve architectuur impliceert de ontwikkeling van architectuur gebaseerd op drie fundamentele principes: “***Simpel tot Complex***”, “***Geometrische Informatie Verdeling***” en “***Aan/Uit Schakelaar en Trigger.***”

Het onderzoek wil een relatief intelligent architecturaal lichaam en een tactiele interactieve ruimtelijke omgeving creëren door de gewonnen kennis uit de studie op de bovengenoemde principes toe te passen op de volgende manier:

A Een benadering verkrijgen die is gebaseerd op een ***Zelfgelijkend Componentieel Systeem*** uit het “Simpel tot Complex” principe van Evo-Devo
B Het idee van “***Collectieve Intelligentie***” verkrijgen uit het “Geometrische informatiedistributie” principe van Evo-Devo
C Het principe van “***Montageregulatie***” verkrijgen uit het “Aan/Uit schakelaar en trigger” principe van Evo-Devo

Het “HyperCell” onderzoek ontwikkelt een ontwerpkader voor het ontwikkelen van real-time adaptieve ruimtelijke systemen door middel van een uitgebreid onderzoek naar de drie bovengenoemde onderwerpen. HyperCell doet dit door een systeem van transformeerbare kubische elementen te ontwikkelen die zichzelf kunnen organiseren, zich kunnen aanpassen en kunnen interacteren in real-time. Deze Hypercells zullen een organische ruimte omvatten die zich kan aanpassen aan onze menselijke lichamen. Het systeem is letterlijk geverifieerd en belichaamd om een intra-actieve ruimte te ontwikkelen die menselijke beweging proactief opwekt. Deze ruimte krijgt dus een emotionele dimensie en kan uw huisdier, partner, of zelfs vriend worden en

4 Janine Benyus, een biologe die de term “biomimicry” heeft bedacht, stelt dat er drie verschillende leerniveaus uit de natuur zijn: de eerste is het imiteren van de natuurlijke vorm van organismen; de tweede is het bestuderen en toepassen van het natuurlijke proces van organismen; de laatste is samensmelten met het ecosysteem van de natuur. Zie: https://www.ted.com/talks/janine_benyus_biomimicry_in_action

dezelfde ruimte kan zelfs op meerdere manieren worden gebruikt. Het onderzoek en de voortgang ervan zijn ook actief verbonden aan een 5-jarig collaboratief Europees Cultuurproject: "MetaBody".

Het onderzoek omvat dus de verkenning van Interactieve Architectuur vanuit de volgende perspectieven: architecturaal ontwerp, digitaal architecturaal historisch traject, computatie-technologie, filosofisch discours gerelateerd aan belichaming, media en digitale cultuur, huidige VR en lichaam-gerelateerde technologie en Evolutionaire Ontwikkelingsbiologie. "HyperCell" zal jonge architecten aanmoedigen om interdisciplinaire ontwerpinitiatieven via de fusie van berekeningsontwerpen, belichaming en biologie voor het ontwikkelen van bio-geïnspireerde organische architecturen na te streven.

Referenties

Gilles Deleuze and Félix Guattari. (1983). *Anti-Oedipus.* Minneapolis: University of Minnesota Press .

Leibniz, G. W. (1714). *Monadology.* (J. Bennett, Trans.) Retrieved from http://www.earlymoderntexts.com/assets/pdfs/leibniz1714b.pdf

McLuhan, M. (1964). *Understanding Media: The Extensions of Man.* New York: McGraw-Hill.

1 Introduction

"Like medicine, it (architectures) must move from the curative to the preventive."

Cedric Price

§ 1.0 Structural Introduction

This research examines three fundamental topics: Computation, Embodiment, and Biology to develop a design framework for developing Organic, Interactive Architectures. The design framework is termed "HyperCell", which involves, developing real-time interactive designs leading to novel organic architectural proposals. Furthermore, such a biotic space advances the next level of artistic and philosophical discourse via broadening the range of innovative interactive architectural design thinking. The ultimate goal of the research is to evoke and enrich more innovative interactive architectural design to take place in the near future.

§ 1.1 Background and Problem Statement

Digital, Organic, and Interactive Architecture.

The semantic and semiotic sense of "**Digital**", "**Organic**", and "**Interactive**" architecture is explored. "**Digital**" refers to designs using digital design and fabrication technologies including parametric design, generative computation, digital form finding etc. "**Organic Architecture**", apart from the original definition coined by Frank Lloyd Wright, now incorporates overtly complex appearances of architectural space produced using contemporary computational techniques. "**Interactive Architecture**", is usually perceived as a building covered with either a delicate mechanical façade which adapts to its surrounding environment or a media skin in the form of an information vehicle.

Digital Architecture is undoubtedly associated with "**Computation**". By perceiving the evolutionary process of CAAD (Computer Aided Architecture Design), it is quite impressive to note how architecture took advantage of computational technologies in various aspects: from data storage, spatial modeling, rendering based representation, and animation, to the current design trends of parametric design and digital fabrication. Computation is omnipresent in contemporary architectural design practice from the initial conceptual design phase to the end production process. Nevertheless, computer usage is largely dedicated to redraw and store technical drawings. This makes one wonder whether computational technology has been properly implemented in current architecture design. Is it possible to shift the mind-set of designers from developing "**Computer Aided Architecture Designs**" to a mindset promoting "**Computation embedded within Architecture**"? This will imply empowering the entire space with computational intelligence, thus allowing it to interact not only with the surrounding environment but also with the users inside the space and with the building components formulating the architecture itself. As a second evolution in this change of mindset, is it possible to create a biological cell-like intelligent architectural building block with embedded computation, which can sense, react, communicate, and even interact, in order to compose a holistic intelligent architectural body?

The same issue applies to **Organic Architecture**, especially in today's context, when young architects are mostly fascinated with computational assistance for Form Generation. As mentioned before, **Organic Architecture** at present is mostly a term used for describing formal architectural qualities akin to organic curvilinear shapes by taking advantage of computational techniques of parametric and algorithmic design. Multiple algorithms for generating such so-called organic shapes are freely available and easily assessable to young architects to apply to their architectural designs. Unfortunately, this approach of focusing on mimicking organic shapes without understanding their biological significance seems to be an inevitable wave rapidly spreading out in today's digital architectural context. Computational technology is thus disembodied and reduced to a mere generative tool for churning out strange organic shapes, while it could be deployed to embody an intelligent environment. The other critical issue is that even when such forms of architecture are ingenuously generated by the application of complex algorithms, almost all of such so-called **Organic Architectures** end up with a static optimized character which is totally contrary to how the organic world factually operates: in a dynamic fashion. Every living/organic entity is constantly changing/evolving (at variable scales: atomic, cellular) whether rapidly or gradually at its own pace and is naturally condition to follow the flux of the environment within which it is embedded. This primary quality of the organic world should be echoed in any architectural, entity which claims to be **Organic**. This implies not crystallizing architecture into static expressions of flowy forms, but rather the embodying the ability to process contextual information flow like a natural organic body.

Apart from developing such organic-appearance-oriented design, some architects have dedicated themselves to seriously investigating bio-inspired principles in their architectural designs via material studies, understanding structural/energy flow logics or via advanced bio-digital fabrication (e.g., Neri Oxman in Arts and Sciences at the MIT Media Lab, and Achim Menges of Institute for Computational Design at the University of Stuttgart). However, still, a crucial character in nature, which is constantly forgotten, is "**Integration**". Nature is mostly multi-performative, unlike artificial mono-performative architectural systems. In nature, to build up organic bodies, the material is applied as supporting structures as well as the transporting paths for water and nutrition through a self-assembly approach. It thus integrates multiple functions for enhancing efficiency and intelligence of the organic body. This is why the organic body is so mysterious, admirable and worth studying and learning from. But to be aware of this is not the ultimate goal of the research. Rather, creating a novel living, constantly data processing architectural species, embedded in the principles of natural morphogenesis, as a refined interactive architecture becomes the ultimate goal of the research.

Examining the current development of Interactive Architecture, it becomes apparent that most projects remain at the level of façade design adapting to the external environment instead of having tangible impacts on the users inside the space (e.g., Arab World Institute in Paris designed by Jean Nouvel, and Al Bahr Towers in Abu Dhabi designed by Aedas). The research suggests a change in this prevailing scenario and provides a direction involving real-time user-space interactions from a user-centric perspective. In this case, both the human body and the architectural space become crucial communication mediums. **The ultimate goal of the research is thus to create buildings as embodied organic bodies which can interact with the external environment, the users inside as well as amongst their constituting building components.** When it comes to the discussion of The Architectural "**Body**", it certainly implies the embedding of computational technologies concerning real-time sensing, actuation, communication & control protocols. To achieve true "**Integration**", one must strive to achieve synergy between **Digital/Computational Architecture**, **Organic Architecture**, and **Interactive Architecture**. The questions of how to conceive and design such an integrated, intelligent, and interactive architecture shall be answered in the explorative journey of this research which will cover the domains of **Computation, Embodiment, and Biology (Organic).**

TOC

§ 1.2 Research Questions

The main research question addressed in this research involves issues pertaining to a synergistic combination of the three major domains of: "**Computation**", "**Embodiment**", and "**Biology**". Several sub-questions subsequently emerge from this main research question and these are elaborated in accordance to these individual associated domains:

Is it possible to develop a rule-based design framework for creating interactive architecture for the generation of novel authentic organic architecture which aptly utilizes computation capabilities to generate an intelligent, body-like, and tactile interactive environment following the principles of morphogenesis derived from natural organisms?

In order to answer this main question, several related sub-questions are explicitly outlined:

Computation (Chapter 3):

How have computational technologies and their applications in architectural design evolved?

It is crucial to have an overall picture of the evolution of computational technologies and their application in architectural design to predict future trends and propose novel directions to ensure the apt usage of computational technologies. Computation techniques have been harnessed in architecture in various capacities, ranging from data storage, renderings as representation purposes, 3-dimensional modeling, to develop parametric models with relational logics etc. to name a few. But most of the time these technologies are used for form-generation purposes, which limits its potential applications in architectural design. The research would like to propose a novel approach for utilizing computational technologies for developing embedded intelligence within architectural components (smart building blocks) which populate a built form. Communication protocols between such components to enable collective intelligence based decision making can thus become a vital feature of such architectural bodies in a bottom up fashion.

With the assistance of computational techniques, what will be the new role/definition of "FORM" in the context of this research?

Computers essentially were meant to be invented as calculating machines dealing with numbers and data sets. After the emergence of computation as a plausible assistant to architects, it became possible to sculpt various non-standard forms could be by using 3D modeling software. In this context, "**Form**" has been treated as a generative outcome of a computation process in the form of an architectural object with a certain expressive appearance. However, this research proposes to interpret "**Form**" in a different manner, as an information processor in accordance with the preferable computational methodologies the designers choose. Along with the evolution of the computational technology and their implementation in architecture design, this research also defines Form as a ***Form Sculptor, Form Generator***, ***Form Animator***, and ***Form Interactor*** in accordance with the means with which the designer generates and defines their architectural **Forms**. Ultimately, it intentionally implies that the development of computational technology in architectural design should shift more towards providing for Interactivity in Architectural Form via dynamic engagement with the natural and artificial environment.

Embodiment (Chapter 4):

What is the connection between architectural space and embodiment from a theoretical or conceptual point of view?

Expanding upon Marshall McLuhan's "***Body Extension***" notion (McLuhan, Understanding Media: The Extensions of Man, 1964), Architecture or rather the built environment can be seen as a second skin of the human body especially in today's hyper-connected era. By connecting one's body to the internet through various gadgets, for example, by using a mouse and keyboard in the early years and VR helmet and Google Glasses in today's times, technology gives people a chance to de-construct their body and re-assemble it as an AVATAR throughout the Internet in a parallel digital universe. The manner in which each digital embodiment (IP address) attaches itself to the network of internet/cyberspace, can be equated with individual beings as machines with embedded desires adhering to the smooth surface of a "Disembodied ***Body Without Organs***". This idea of individual entities relates to the notion of "***Monadology***"[5] proposed by Gottfried Leibniz (Leibniz, 1714).

5 The Monadology is one of Gottfried Leibniz's best-known works representing his later philosophy by sketching in some 90 paragraphs a metaphysics of simple substances, or monads. As far as Leibniz allows just one type of element in the building of the universe, and this unique element has been 'given the general name monad or entelechy' and described as 'a simple substance' (the text was cited from: https://en.wikipedia.org/wiki/Monadology#Text).

A sophisticated network constructed by the Monad can be equated with a complex system composed of small intelligent entities in a system. In other words, either a single cell of a body, a bird in a swarm, a tiny dust particle in the air, or a planet in the universe, all follow certain dynamic principles to maintain their interrelationships and thus maintain the homeostasis of the overall network. From this perspective, both notions of understating "architecture as a body" or "the body as architecture", implies space being a refined object composed of multitudes of intelligent entities. This research also considers this notion as an inspiration to generate the proposed organic body-like architecture.

Is now the time to take both Reality and Virtual Reality into account while conceiving spatial/architecture designs?

It is no longer considered a magical moment if a person is omnipresent in different spaces at the same time using the Internet. Once you are "on-line", you can be present in any virtual environment playing the role of as many different characters as you like in the so called "parallel digital universe". The Internet or Cyberspace has become common in people's daily lives for several decades now. Nonetheless, Virtual Reality, although a part of Cyberspace, now refers more to an immersive and relatively tangible experience by utilizing wearable technology. In other words, Virtual Reality is not completely a different concept than Cyberspace, but with Internet connectivity, the being virtually omnipresent idea, can now be achieved in a relatively more tactile and sensory environment with feelings enhanced with the use of wearable gadgets. Within the Internet environment in a conventional on-line game, you might see yourself as an AVATAR inside the world through the interface of the "**SCREEN**" in front of you, but with electronic gadgets like Google glasses, you are able to envision the whole surroundings as a simulated environment through another interface of the "**LENSES**" which makes you feel more authentically engulfed inside this Virtual Reality environment. This relates to Marcos Novak's idea that "the Cyberspace itself is architecture, but it also contains architecture". Regardless of whether physical space contains Cyberspace or the other way around, it has become "an architecture nested within architecture" (Novak, 1991). It is now considered inadequate to ignore the true sense that people gain from the world of Virtual Reality and to claim that Virtual Reality is totally fake. It is now the time to confront the integration of Virtual and Real to seek an equal/dynamic balance between the two since both conditions occupy almost the same time and space in people's lives.

How to materialized an organic body-like space as an interactive architecture?

"How to materialize" a body-like interactive architecture has always been a difficult issue for both interactive and "organic body-like" architectures. But this is one of the main challenges this research would like to explore. A common analog for comparing technological devices to an organic body is to envision the body being composed of sensor and actuator parts and the brain being the seat of computation, which acts as a commander/orchestrator. By observing the current development of body parts in interactive architecture, which mainly comprises of actuating systems, one can delineate the features in two different categories, "**Naturalized**" and "**Motorized**". The "**Naturalized**" features refer to actuation utilized by the natural material properties to achieve kinetic movement; the "**Motorized**" functions indicate those requiring electricity to perform relatively strong and powerful kinetic mechanical actuations. The "**Naturalized**" systems tend to be more sensitive and energy efficient but such engineered materials are normally structurally weaker to support architectural scale built work and thus tend to be deployed as non-structural building skins; the "**Motorized**" ones are sufficient enough for holding the bigger construction and but suffer from disadvantages of being relatively less sustainable as regards energy consumption and take up larger proportions of space for performing their tasks. Therefore, the research questions if it would be favorable to develop a Hybrid condition wherein the advantages of each system can be considered for developing Interactive Architecture. As for the notion of the brain operating as the centralized commander to control the sensing and actuations of a body, it is quintessential to state that the natural brain works in the manner of a highly distributed system. The main components of the intelligence of the brain that makes you think, sense, and react are the brain cells or so-called the neurons. They are constructed nearby and form the cerebrum for the reason to get the extreme protection of the skull by nature but it doesn't make the cerebrum a centralized controlling machine because of their close location. In fact, they are assigned to different specific tasks through networking communications and to eventually have the ultimate emerging decision which makes it actually akin to a more de-centralized system in terms of its operational logic[6]. For the proposed embedded intelligence based organic space, the computation would thus acquire a distributed systemic quality as regards its control systems, akin to a swarm of agents. This property will also insure the performance of the entire system to be intact even while any one of the constituting entities of this space is out of operation.

6 Please refer to the website for further understanding of brain and neuron: https://en.wikipedia.org/wiki/Neuron

Biology (Chapter 5):

What are the current developments in Biomimetic design developments in the context of "Organic" or "Bio-inspired" architectures?

Investigations into the current Biomimetic design developments of "Organic" or "Bio-inspired" architectures, lead to their categorization into "**Morphological**", "**Material**", and "**Behavioral**". As for the "**Morphological**", various digital approaches of either using 3D modeling software to create the organic-looking shapes or applying generic algorithms from "Chaos Theory" for organic form-finding is covered in this chapter. The "**Materials**" part under the tag of organic and bio-inspired designs focus on material properties, which include the development of smart materials, transplanting bio-organs into physical architecture or utilizing biomimetics in conjunction with advanced digital fabrication techniques. In the section of "**Behavioral**" aspects, swarm logic is applied as a generic form-finding solution to crystallize real spatial objects. The section also elaborates upon some experimental architectural projects, which translate swarm simulation based outputs into advanced applications such as generating intelligent building blocks as basic elements composing the entire architectural body. A wide range of studies and research have been covered in this section to give a clear picture of what is the current status quo of "**Organic**" and "**Bio-Inspired**" **Architecture** as a Biomimetic or Bio-ARCH resource.

What novel application of natural/biological systems based knowledge can be applied within architectural design instead of merely focusing on the prevalent form based mimicry approach?

Janine Benyus, a biologist who coined the term "Biomimicry" once stated in a public TED talk[7] that there are three levels of learning from nature. The first one is to learn from the appearance/form of natural organisms; the second is to learn the processes of natural growth and evolution; and the last is not only to learn from nature but to actually integrate with natural eco-systems. After spending years into mimicking animal organic forms with the help of digital sculpting or algorithm generation, it can be sufficiently claimed that much progress has been achieved in mimicking such outward appearance. A shift to the next level of learning from nature: understanding "Process" is thus our challenge now. John Frazer in his influential publication, "***An Evolutionary Architecture***" (Frazer, 1995), simply but explicitly stated: ***"what we are***

7 Please find the link of the Janine Benyus' TED lecture here: https://www.ted.com/talks/janine_benyus_bio-mimicry_in_action

evolving are the rules for generating forms, rather than the forms themselves". Keeping in line with Frazer's proposition, to understand processes of growth, evolution, and development in nature it is thus deemed essential to conceive a rule-based design framework as a new way of architectural design thinking of Organic Architecture. We should thus look fundamentally into the principles of morphogenesis to understand how natural organisms end up having differentiations even though they share the same gene toolkits as an essence of the proposed organic architectural design framework. The research hence makes serious investigations into Evolutionary Development Biology (Evo-Devo) which offers an interesting insight into evolutionary principles. Intriguingly, the research is able to extract three fundamental principles from Evo-Devo intended to be translated and applied systematically to the proposed organic body like architecture: "**Simple to Complex**", "**Geometric Information distribution**", and "**On/Off Switch and Trigger**".

§ 1.3 Research Objective

The research apart from addressing the main and sub-questions mentioned above points towards future directions for Interactive Architecture (as active organic Bio-architecture) and strongly provokes researchers and architects to dedicate themselves to this realm.

By extracting the three biological morphogenesis principles of "Simple to Complex", "Geometric Information Distribution", and "On/Off Switch and Trigger", and translating them into three design rules of "Componential System", "Collective Intelligence", and "Assembly Regulation", the primary objective of the research is the following: To develop a rule-based design framework for interactive Bio-architecture, which can interact and improvise its performance in response to its context in real-time. This will encompass active reconfiguration of space in accordance with user demands akin to a living organism.

Extending the discussion of the research questions, the study sets up a rule-based design framework by translating the three crucial morphogenesis principles from Evo-Devo (Carroll, 2005) into design rules for Interactive Bio-Architecture. The "**Simple to Complex**" idea was translated to deploy the notion of a modularity idea in the form of a "**Componential System**". This relates to the fact that complex shapes within the animal kingdom are composed out of the repetition of simple, self-similar modules. Following this componential idea, the "**Geometric Information Distribution**" principle was abstracted as a rule set fostering "**Collective Intelligence**". This relates to the context of cellular development and the manner in which a distributed information system regulates the morphological evolution of successive cells in order to create diverse organs. A collective intelligence protocol which aids in the real-time growth and evolution of building components from a morphological and behavioral perspective is thus set up. The "**On/Off Switch and Trigger**" principle, which regulates the process of morphogenesis in living organisms, is utilized as a strategy for conceiving protocols for the development of an informed architecture comprising of numerous smart autonomous entities: "**Assembly Regulation"**. These principles are exemplified upon in greater detail in the first half of Chapter 6. The research is thus primarily concerned with the intricacies of processing, generating, transforming, and communicating principles rather than having an outwardly focus on the generation of organic form.

Organic + Embodiment + Bio-Architecture = Componential System + Collective Intelligence + Assembly Regulation

Apart from the aforementioned bio-inspired rule based principles, what is the practical end goal/output that this biomimetic Interactive Bio-Architecture can provide? This design framework is essentially aiming to produce a user-centric reconfigurable space, which responds to the users' varying ergonomic and activity patterns through a 24 hrs. cycle. Unlike former developments in Interactive Architecture that mostly focused on environmental response, which gave the users inside the space a relatively indirect influence, this research concentrates on the user-centered design to deal with the real-time responsive space, which will have a strong and direct impact on the people occupying it. It is the core idea of this study to use a minimum footprint of space to fulfill the maximum activity based spatial requirements of the users, thus encouraging a sustainable space usage strategy. By creating such a user-centric reconfigurable space, it not only ensures that the users can experience optimal spatial usage but could also lower the price of real estate for residential space, thus providing a new perspective to solving critical problems of urban.

Sub-Objective:

Considering that architecture can have its own intelligence and own behavior implies establishing new relationships between it and human bodies. This hypothesis already marks a reversal of conventional design thinking in conceiving architecture while challenging our perception of architectural space.

Taking inspiration from Marcos Novak's Liquid Architecture (Novak, 1991) and Kas Oosterhuis' HyperBodies (Oosterhuis, HyperBodies: Towards an E-motive Architecture, 2003), this research would like to address the future of cognitive architecture with embodied intelligence how it could forge a new relationship between its own

TOC

living creature-like attributes and its human occupants. Such spatial evolution can certainly become a probable future scenario considering the fast pace of technological development coupled with advanced research in the domain of Smart Living solutions using Artificial Intelligence and Machine Learning. It would thus not be surprising to witness a time in the near future when space embodies its own intelligence.

§ 1.4 Research Methodology and Proof of Concept

To achieve the research objective, a wide range of inter-disciplinary studies were conducted. These included explorations within the domains of architecture, contemporary technological innovations, interactive art, media culture and social contents, associated with the topics of interaction, computation, and biology. This wide body of knowledge apart from operating as literature review helps in providing abundant resources for subsequent research for the younger generation of architects who wish to dedicate themselves in investigating the domains of interactive, computational, and or bio-inspired design in architecture. By extracting, organizing, translating, and mastering the above knowledge, a comprehensive design framework: "**HyperCell**" is derived for developing organic body-like architectures.

Subsequently, experimental design projects based on the "**HyperCell**" design framework were conducted as proof of concept. These, are divided into two major parts, the "**User-For**" and the "**User-Less**". The first series of the experimental design projects, "**User-For**", was aimed at conceiving a user-oriented re-configurable space idea in the form of a furniture system, termed as "**HyperCell**". Hypercell builds upon the concept of a transformable building component similar to the traditional Asian tangram concept. A series of "**HyperCell**" furniture applications are illustrated in this part of the study. "**User-Less**" is the second part of the experimental design projects addressing the topic of a non-utilitarian with a central hypothesis, which considers space akin to a living creature with embedded intelligence and behavior which challenges the human body towards adopting novel movement and instigates a shift in perception. Two major projects under "User-Less" were conceived and executed; "**Ambiguous Topology**", which leans towards an immersive new-media driven spatial experience and the "**HyperLoop",** a scaled prototype of an interactive pavilion design. Both projects were a part of "**Metabody**", a European Culture Project which, focused on the inter-disciplinary development of an Intra-active architectural space (Elaborated upon in Chapter 6).

Two kinds of experiments, one engulfing a real-time utilitarian response and the other covering a self-evolving behavioral interaction are conducted as proof of concepts of the research objective. These experiments (HyperCell[8], Ambiguous Topology[9], HyperCell Pavilion) are elaborated upon extensively in Chapter 6.

§ 1.5 Research Outline

The research is structured explicitly, providing each chapter within its own particular focus. After an overview of the trajectory of the project, which extends into Chapter 2, the three major topics of "**Computation**", "**Embodiment**", and "**Biology**" are sequentially elaborated separately, yet in an intimate interconnected fashion through Chapters 3-5. In conclusion, a design framework for Interactive Architecture for developing novel Organic Architecture is proposed in Chapter 6. An application of this Design Framework via the projects HyperCell furniture system, Ambiguous Topology and the Prototype of HyperLoop Pavilion serves as proof of concepts in Chapter 6. Chapter 7. The research subsequently points towards several ideas and directions for future research development not only as a reference to other researchers interested in this interdisciplinary exploration but also as a reminder towards the vital contributions made by this research to the three intriguing topics.

Chapter 2-

Chapter 2 elaborates upon the contributions of the avant-garde architecture group, "Archigram", from the 60's and challenges the long-term fundamental attributes associated with architecture; Utilitas, Firmitas, and Venustas. An alternative focus on developing dynamic, fluid, and interactive attributes of Architecture, which focus on today's transient societal, the environment, and user based issues. Post this, an introduction to the evolution of Interactive Architecture mainly focusing on shifting

8 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.

9 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.

the emphasis of Interactive Architecture as associated with environmental conditions as a façade/skin system to a more user-oriented usage is presented. Moreover, the research categorizes the current Interactive Architecture developments in accordance with their actuating system; "Naturalized" and "Motorized" in order to assess the pros and cons of both. Apart from the designer's viewpoint concerning spatial usage, the practical utilization of space from the users' point of view is also elaborated upon via case studies and design projects. A series of developments within the domain of bio-inspired design were included in this Chapter. A connection to the latest research developments in Evolutionary Development Biology is thus put into context for illustrating the potential usage of this organic body like architecture. Also, a series of design projects; HyperCell Furniture relating to the HyperCell design framework is elaborated upon sequentially. Chapter 2 concludes with the design projects, "Ambiguous Topology" and "HyperLoop", outlining the next level of artistic discussions on cognitive architecture with its own intelligence and behavior as a proactive space and how to set up a new relationship with this kind of living creature like space.

Chapter 3-

Chapter 3 exhibits the evolution of computational applications in Architecture. The chapter categorizes the different approaches of harnessing computational technologies by designers as "**Form Sculptor**", "**Form Generator**", "**Form Animator**", and "**Form Interactor**". "**Form Sculptor**" indicates the category wherein architects use 3D modeling software as a tool for form modeling in a top-down aesthetics driven decision-making capacity; The "**Form Generator**" category refers to the usage of computational technology deploying generative algorithms to assist architects within the form-finding process (current prevalence of parametric or algorithmic design); The "**Form Animator**" category refers to computational experiments which tend to identify how organic bodies were formed and how they evolve while they are within specific environmental conditions to generate their resulting forms, while "**Form Interactor**" refers to a category wherein computational applications are used for dynamic interaction with the surroundings to evoke an active, cognitive approach. The Form Interactor category is what the direction which the research exploits further.

Chapter 4-

Chapter 4 emphasizes on the topic of "**Embodiment**" with a deep focus on the concept of "**Body Extension**" as suggested by Marshall McLuhan (McLuhan, Understanding Media: The Extensions of Man, 1964), "**Body Without Organs**" from Gilles Deleuze and Félix Guattari (Deleuze, G., & Guattari, F., 2003). "**Body Extension**" and its philosophical linkage to a virtual space, as well as the "**Body Without Organ's**" and its philosophical linkage with the world composed of Monads as proposed by Gottfried Leibniz's Monadology (Leibniz, Monadology, 1714), refer to the same principle of a network-like structure with the smallest entities constituting the surface possessing exerting highly synergistic, fullerene-like influential forces on each other. Apart from the theoretical discussion on the body relating to reified, embodied and wearable technology, the focus subsequently shifts to the discussion between Virtual and Real and the current developments of Hi-Technology gadgets such as Virtual Reality and Augmented Reality devices. Speaking about Cyberspace and Virtual Reality, these can be seen as evincing the first intentions of generating Interactive Architecture through software and games like SIM City. After years of developments in the physical computing world, with devices such as Arduino, artists and architects now have the opportunity to bring the virtual kinetic/interactive idea into the real world. Since then, rapidly increasing numbers of interactive spatial installations/architectural designs relating to physical computing were created. These have been categorized in this Chapter in two major divisions of "**Naturalized**" utilizing natural material properties, and those that are "**Motorized**" relying heavily on electronically driven mechanical systems. A novel thinking driven by the idea of collective intelligence involving the merger of **Naturalized** and **Motorized** systems into an efficient hybrid system for conceiving interactive architecture might become the next step for a technological breakthrough.

Chapter 5-

Chapter 5 elaborates upon the topic of biology or bio-inspired/Biomimetic design. Numerous current developments are featured under three major divisions in this Chapter: "**Morphological**", "**Material**", and "**Behavioral**". The "**Morphological**" aspect looks into the relationship between organic form and artificial architectural forms comprising methods of 3d modeling and generative algorithms in the form-finding process. The "**Material**" category involves explorations involving the usage of bio-materials (for instance transplanting natural flesh as architectural components), and the biomimicry approach including materialization aspects involving digital fabrication techniques and contemporary scientific principles from physics or chemistry. The "**Behavioral**" factor is akin to the logic of swarm behavior wherein every building block becomes an intelligent entity constituting the whole architectural body. Instead of researching optimization based solution for generating a static form, the research involves evolving real-time adaptive kinetic architectural bodies that can respond to different conditions through dynamic optimization. Unlike the most common approach of mimicking organic form, this research paid attention to the principles of morphogenesis, specifically Evolutionary Development Biology (Carroll, 2005). The research explicitly involves extracting growth and adaptation rules from such studies and applying it to Interactive Architectural design. Three biological morphogenesis principles of "Simple to Complex", "Geometric Information Distribution", and "On/Off Switch and Trigger", are translated into three design rules of "Componential System", "Collective Intelligence", and "Assembly Regulation". These are explicitly identified upon in this Chapter and elaborated upon in Chapter 6.

Chapter 6-

Chapter 6 is a summary of the aforementioned domains of **Computation**, **Embodiment**, and **Biology**, and merging the findings via principles derived from Evo-Devo to develop a design framework, "HyperCell", for developing Interactive Architecture as an authentic form of Organic Bio-Architecture. The rules comprising this design system: "**Simple to Complex**", "**Geometric Information Distribution**", and "**On/Off Switch and Trigger**" are all transformed and applied towards developing "**Componential System**", "**Collective Intelligence**" and "**Assembly Regulation**" logics. To prove that the architecture design can follow this design framework to create novel and useful usage of space, a series of **HyperCell** experiments were conducted in the form of experimental design projects elaborating upon the potential flexibility and efficiency of this real-time adaptive furniture system. Extending the discussion of creating an organic body-like interactive architectural space to a techno-artistic level of making a cognitive, smart space having its own intelligence and behaviors, the research involved further developing an immersive interaction based project: "**Ambiguous Topology**", and a scaled prototype of an interactive pavilion, "**HyperLoop**". These projects further open up a novel direction of design development challenging the norm where architecture relates to solid, concrete and static built form.

Chapter 7-

In Chapter 7, the research categorizes the entire narrative into three vital features: "**information**", "**improvisation**", and "**integration**", and concludes with the idea of "**intelligence**" as a merger of these features. Future recommendations are proposed in the form of **Software**, **Hardware**, and **Design Thinking methods**. In conclusion, while addressing **Software**, the research proposes a game-like structure in the form of a design tool embodying the proposed rule-based design framework which can even combine VR and motion tracking technology. It is the vision of the author to realize the **HyperCell** furniture component as physical **Hardware** extension of the research, go beyond developing such components for interior purposes but develop them as real physical building blocks constituting architecture. Intelligence driven Self-assembly could become an active feature whereby both construction and disassembly of the space is automated. In this case, a hybrid material merging the advantages of naturalized and motorized systems would naturally be needed to work in synergy. Concerning **Design Thinking Methods**, the HyperCell design framework is used to inspire people to further the componential idea based proposed bio-inspired architecture development. It is not necessary to follow the exact principles provided in this research, but it is crucial to stimulate this kind of interdisciplinary and robust design thinking in architectural design. The research ultimately envisions a near future comprising various spatial and product based options customized to user choices akin to the "**HyperCell**" based outputs proposed in this research.

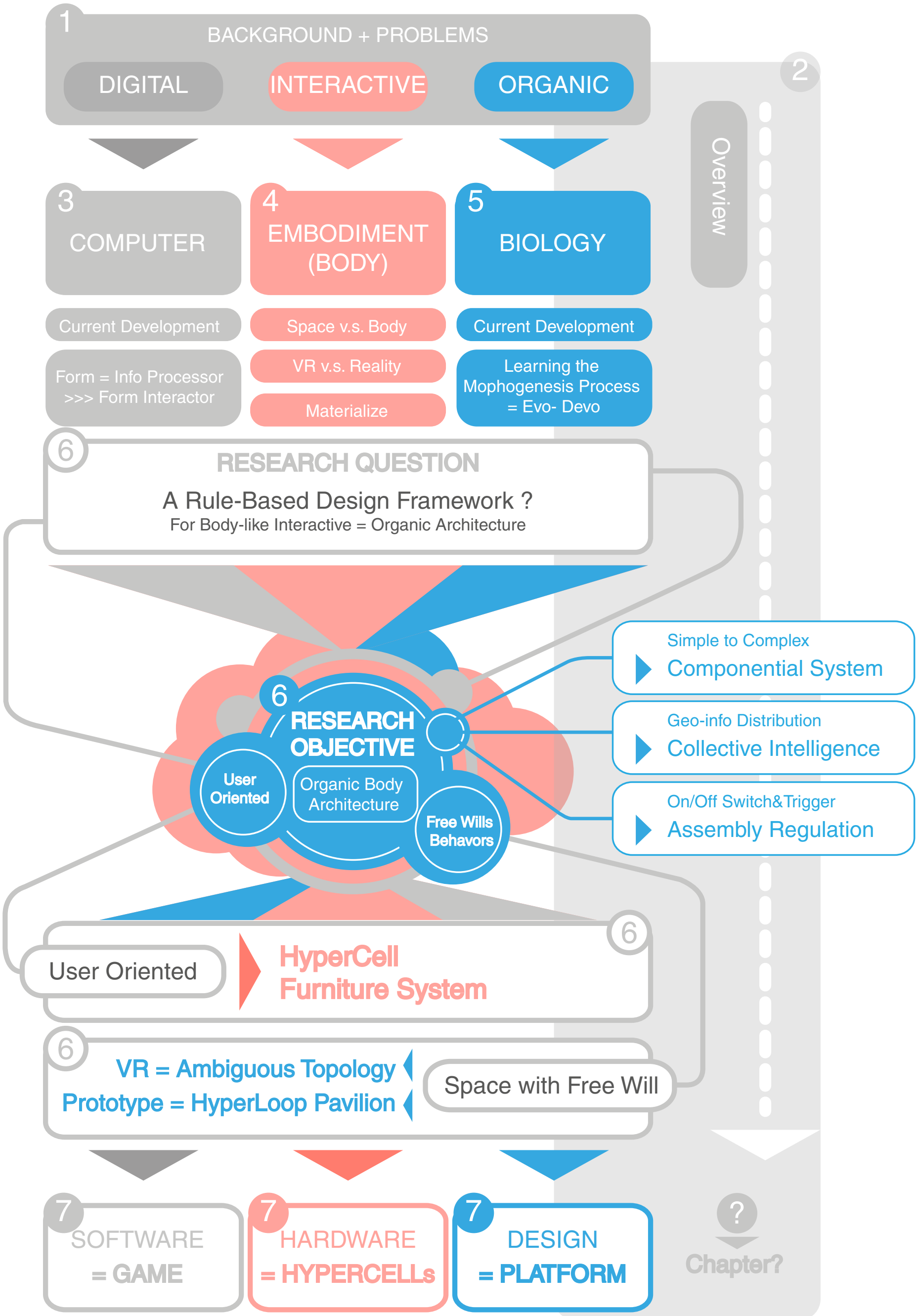


FIGURE 1.1 Overview of the Research Framework Map.

References

Carroll, S. B. (2005). *Endless Forms Most Beautiful: the New Science of Evo Devo*. New York: W. W. Norton & Company, Inc.

Deleuze, G., & Guattari, F. (2003). *Anti-Oedipus: Capitalism and schizophrenia*. London: Continuum.

Frazer, J. (1995). A Natural Model for Architecture/ The Nature of the Evolutionary Mode. In J. Frazer, *An Evolutionary Architecture*. London: Architectural Association.

Leibniz, G. W. (1714). *Monadology*. (J. Bennett, Trans.) Retrieved from http://www.earlymoderntexts.com/assets/pdfs/leibniz1714b.pdf

McLuhan, M. (1964). *Understanding Media: The Extensions of Man*. New York: McGraw-Hill.

Novak, M. (1991). Liquid Architectures in Cyberspace. In M. Benedikt, *Cyberspace: First Step* (pp. 225-255). Cambridge: The MIT Press.

Oosterhuis, K. (2003). *HyperBodies: Towards an E-motive Architecture*. Basel: Birkhäuser.

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.

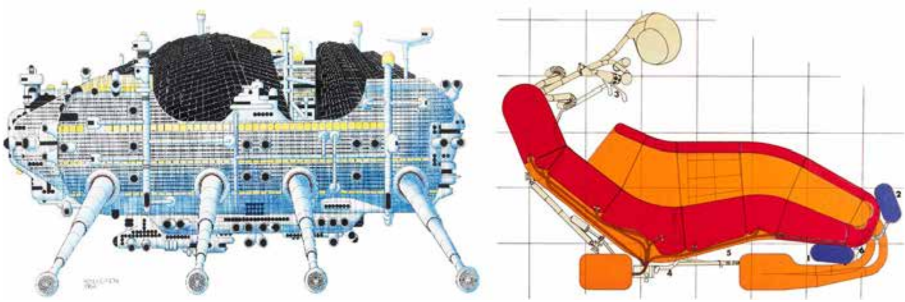


FIGURE 2.2 Left: Walking City (1964) (source: https://www.archdaily.com/tag/archigram) and right: Cushicle (1966) (source: http://archigram.westminster.ac.uk/project.php?id=92).

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.

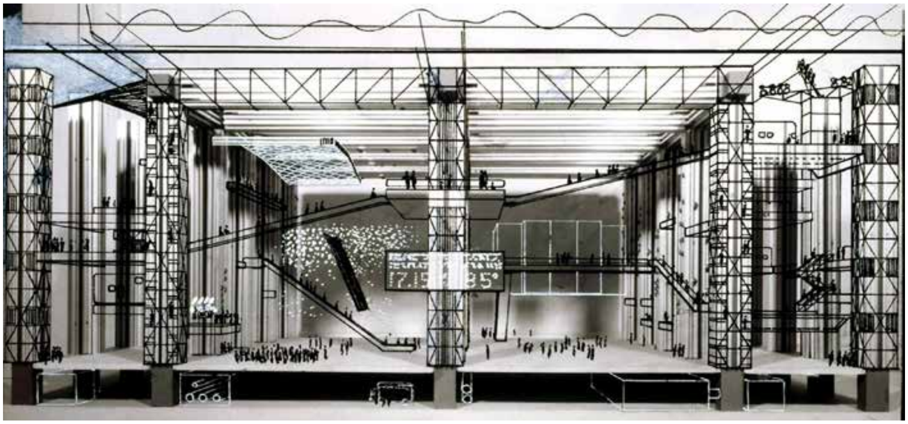


FIGURE 2.3 The perspective drawing of Fun Palace (1966), proposed by Cedric Price in 1961 (source: http://www.cca.qc.ca/en/collection/283-cedric-price-fun-palace).

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

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).

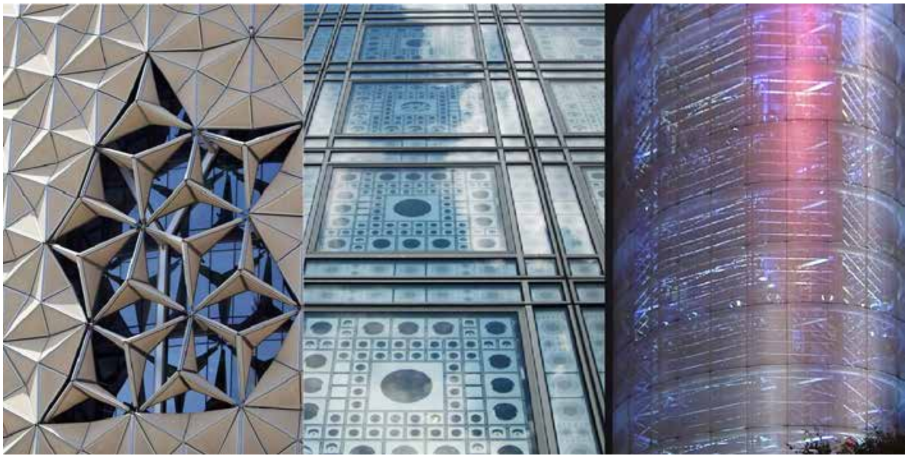


FIGURE 2.6 From left to right: Al Bahr Towers in Abu Dhabi by AEDAS (source: http://www.thenational.ae/business/property/in-pictures-international-property-awards-success-for-uae-developments), Arab World Institute in Paris by Jean Nouvel (source: http://www.archdata.org/buildings/12/arab-world-institute),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

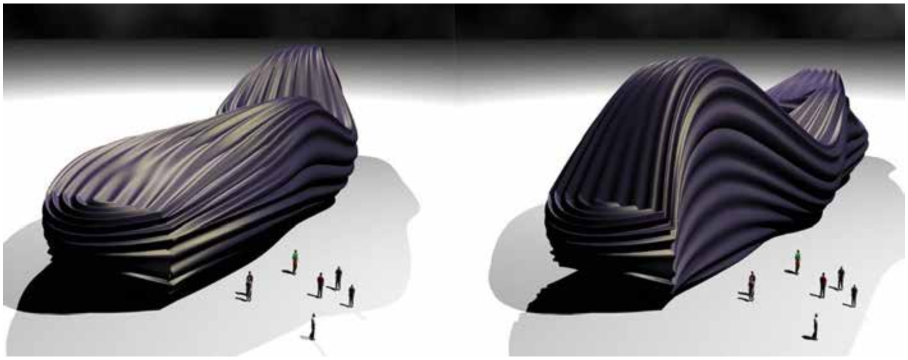


FIGURE 2.8 Transport, designed in 2000 by the ONL led by Kas Oosterhuis (source: http://www.onl.eu/?q=projects/trans-ports).

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.

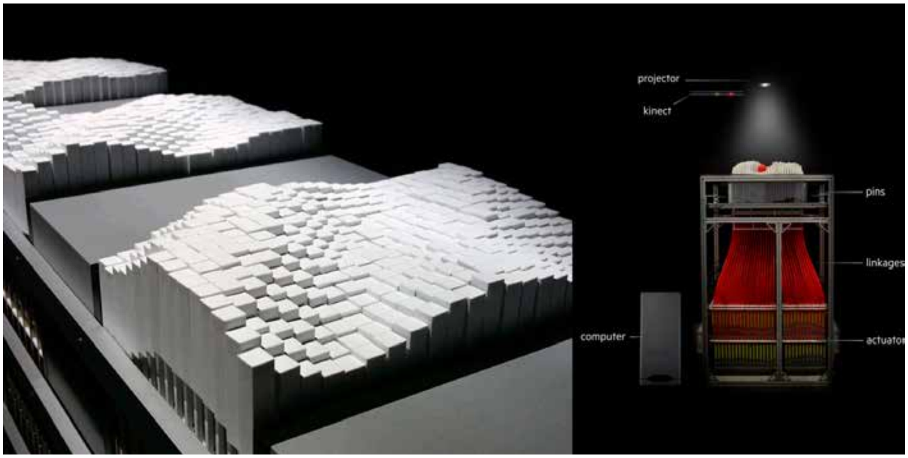


FIGURE 2.10 inFORM/TRANSFORM developed by the Tangible Media Group under the MIT Media Lab. The graph on the left shows the surface effect, and the one on the right shows the structure of the mechanical device (source: http://tangible.media.mit.edu/project/inform/).

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

TOC

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).

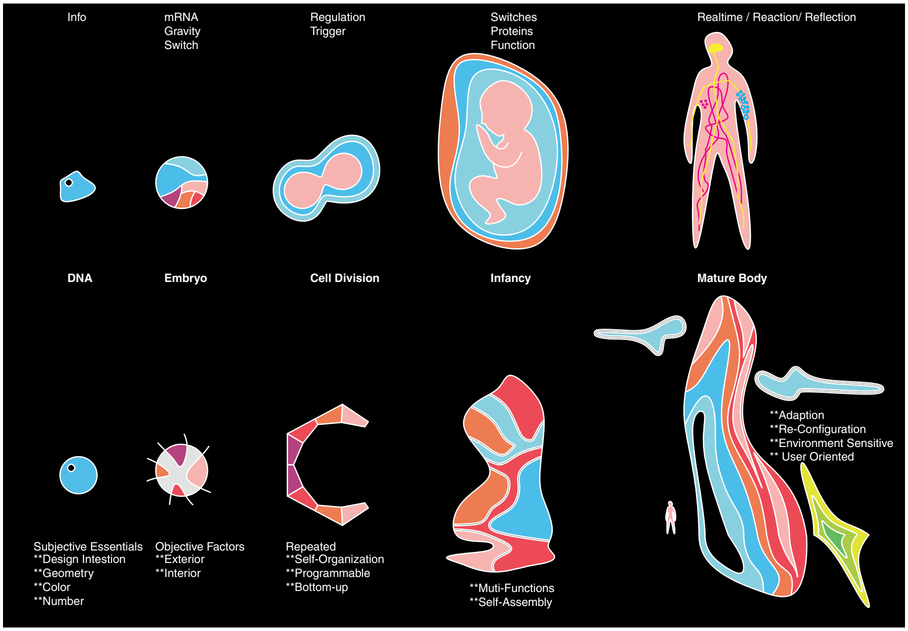


FIGURE 2.15 An illustration of how the growing process of organisms can be applied to architecture in the HyperCell research study.

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) 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

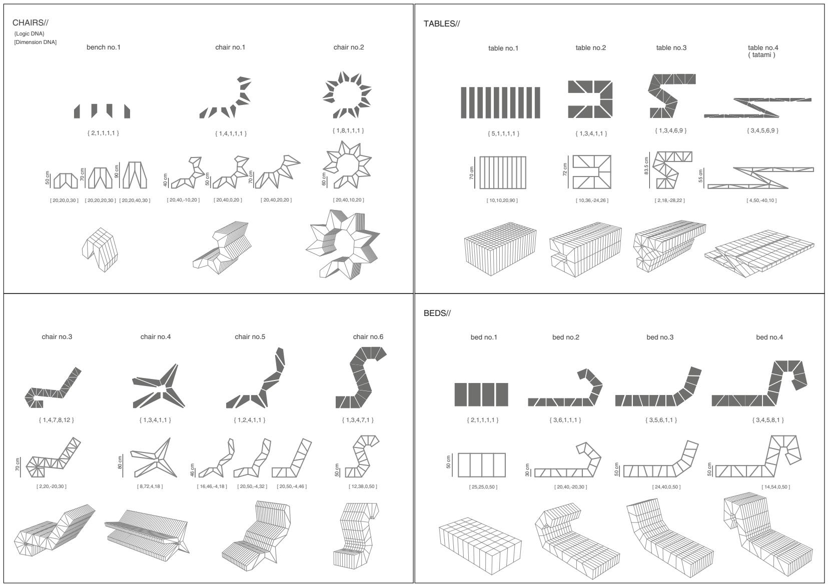


FIGURE 2.16 Possible variable furniture created by adjusting numbers and parameters like DNAs based on the transformation make-up of HyperCells.

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,

TOC

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."

TOC

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)

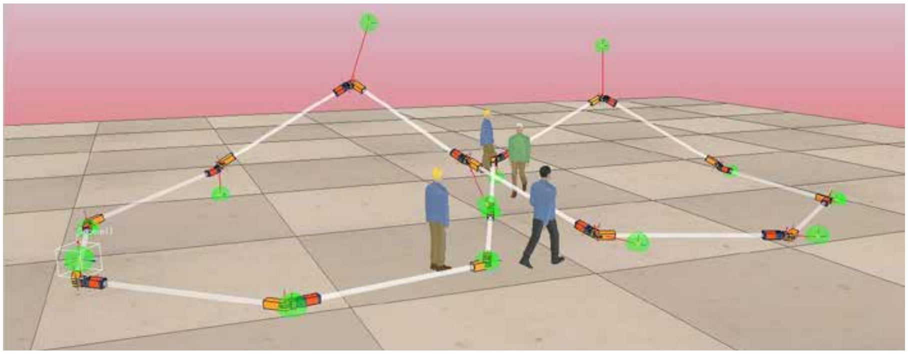


FIGURE 2.18 HyperLoop, a transformable pavilion space the HyperBody Research Group aims to implement, with all nodes being transformable and the sensors on the nodes being able to communicate for the purpose of spatial feedback. Please refer to the video: https://vimeo.com/117388146.

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.

References

Beesley, P. (2013). Architecture in Formation: On the Nature of Information in Digital Architecture. In P. Lorenzo-Eiroa, & A. Sprecher (Eds.), *Architecture in Formation: On the Nature of Information in Digital Architecture* (pp. 268-275). New York: Routledge.

Benyus, J. M. (1997). *Biomimicry: Innovation Inspired by Nature.* New York: HarperCollins Publishers Inc.

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.

Carroll, S. B. (2005). *Endless Forms Most Beautiful: the New Science of Evo Devo*. New York: W. W. Norton & Company, Inc.

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.

Crompton, D., & Archigram (Group). (2012). *A Guide to Archigram 1961 - 74.* New York: Princeton Architectural Press.

Deluze, G., & Guattari, F. (2004). *A thousand plateaus: Capitalism and schizophrenia.* London: Continuum.

Frazer, J. (1995). A Natural Model for Architecture/ The Nature of the Evolutionary Mode. In J. Frazer, *An Evolutionary Architecture*. London: Architectural Association.

Imperiale, A. (2000). *New Flatness: Surface Tension in Digital Architecture.* Basel: Birkhäuser .

McLuhan, M. (1964). *Understanding Media: The Extensions of Man.* New York: McGraw-Hill.

Menges, A., Reichert, S., & Krieg O. D. (2014). Meteorosensitive Architecture. In K. M., & L. Hovestadt (Eds.), *ALIVE: Advancements in Adaptive Architecture* (pp. 39-42). Basel: Birkhäuser.

Oosterhuis, K. (2003). *HyperBodies: Towards an E-motive Architecture*. Basel: Birkhäuser.
Palumbo, L. M. (2000). *New Wombs: Electronic Bodies and Architectural Disorders*. Basel: Birkhäuser.
van Schalk, M., & Macel, O. (Eds.). (2005). *Exit Utopia: Architectural Provocations, 1956-76*. London: Prestel Publishing.

3 Information Processor - Digital Form with Computational Means

"Give me a gun and I will make all buildings move."

Bruno Latour, Albena Yaneva

§ 3.0 Introduction

How computational technology start to take place and gradually become being heavily involved/implemented in the design process of architectural design.

In the architecture domain, not only the proportion of the assistance from computational techniques has been increasing exponentially, but also, the role they play has been gradually shifting from a supporting one to a generative one. No longer limited to being a complex mathematics calculator, computers, have become a ubiquitous necessity in our daily life and even influence the way we live. This, is especially true for the young generation who were born in this digital world, mainly referred to as the "Generation Z"[26]. Business Insider, a fast-growing business media website, mentioned that "Gen Z-ers are digitally over-connected. They multitask across at least five screens daily and spend 41% of their time outside of school with computers or mobile devices, compared to 22% 10 years ago, according to the

26 Generation Z are the cohort of people born after the Millennials. The generation is generally defined with birth years ranging from the late 1990s through the 2010s or from the early 2000s to around 2025. Please see the details through: https://en.wikipedia.org/wiki/Generation_Z

Sparks & Honey report[27]." When Alan Turing first invented the room-sized "Turing Machine" to decipher Nazi codes, he couldn't have expected that this giant machine could one day be put into one's pocket and efficiently compute a million times more data. As compared to the era of tools, such as paper and pen, the computer, in today's context has been heavily utilized and relied upon as a powerful instrument. This change is remarkable, considering the relatively short period of time, especially after 1981 when the first IBM personal computer was released (Mitchell, 1990). Architecture Design cannot be excluded from this inevitable technological tendency. Even the most conservative architecture firms are now required to deliver digital technical drawings to communicate amongst designers, clients, and construction firms in the present scenario. Incorporating computer technology in today's context also provides young designers the opportunity to experiment with creating relatively complex geometry based architectural space. But before applying this powerful technology in architectural design, the crucial knowledge behind it that architects had to understand and realize was the manner and procedure of "Processing of Information". Without information, the computer would be just lying on one's desk as a useless cube, like a vehicle without a driver, or a body without a soul. The shifting roles of computer technology in architectural design are obviously defined by the manner of how designers interpret, digest and operate/process the streams of information flow.

However, dealing with information is not new to architectural design, which already thrived on multi-stakeholder based information exchange long before computers arrived. In order to preserve the measurements underlying his design ideas, Brunelleschi, as an architect in the early Renaissance, investigated means of making projective geometric drawings in order to capture 3-Dimensional information, which subsequently led to the development of parametric perspective space for the first time (Lorenzo-Eiroa, Form:In:Form on the relationship between Digital Signifiers and Formal Autonomy, 2013). During the 14th and 15th century, Girard Desargues developed the concept of "the point at infinity" to create an alternative way of constructing Euclidean geometry in perspective drawings by using vanishing points as references (Lorenzo-Eiroa, Form:In:Form on the relationship between Digital Signifiers and Formal Autonomy, 2013). Not to mention the great influential invention of the Cartesian coordinate system by René Descartes, who, set up the fundamental principles of spatial collaboration both in 2D and 3D graphics. Implausible, in the early 15th century, when paper began to replace parchment as a drawing medium, Italian architects had well understood the concept of graphic projection as communication document shared amongst people dedicated to the

27 Please see the full report and statistics through the website referred: http://www.businessinsider.com/generation-z-spending-habits-2014-6?IR=T

construction process (Weisberg, 2008). The communication documents here refer to the so-called technical/engineering drawings as a medium where the projects are represented in a proper scale, with precise measurements and understandable geometric visualization. To use these technical/engineering drawings not only in terms of translating, preserving, creating but also communicating information of their spatial ideas, architects have shown remarkable abilities to confront information communication as a necessity in the design process, and also reveal the intensive and intimate relationships between information and form since the Renaissance. In other words, architectural design can be seen as an on-going process coupled with streams of information in order to seek/generate a relatively rational form as a specific resulting outcome (with/without computational techniques).

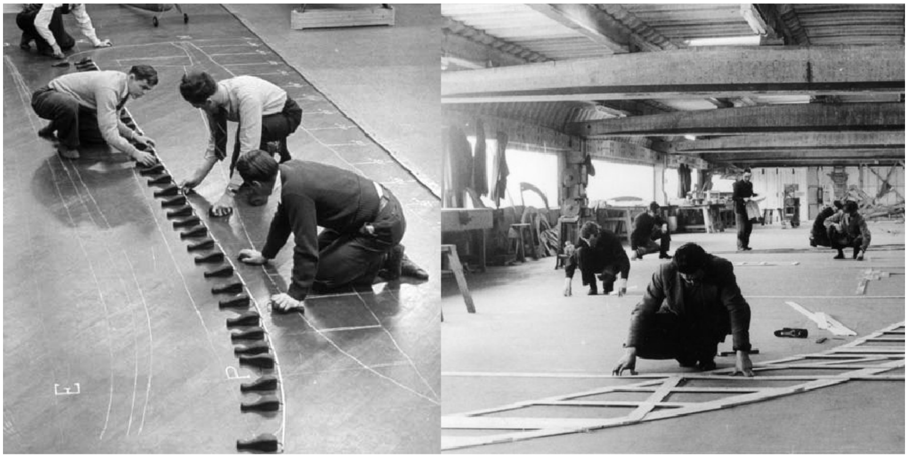


FIGURE 3.1 Left: Course in Airplane Lofting, Burgard High School, Buffalo, NY, USA, January I, 1941. Right: Picture of People working on Airplain Lofting(source: http://cornelljournalofarchitecture.cornell.edu/read.html?id=74, https://i.pinimg.com/736x/0e/79/bb/0e79bbaa467027c649fd7452afb0cfe3.jpg).

With the original intention of "Technical/Engineering Drawings", designers (not only architects) basically created two fundamental methods of dealing with information pragmatically for a long time: 1. To store precise references for fabrication and construction. 2. To present design ideas to the clients with understandable visualization as a communicating medium. But the increasing intricacy of the design, the precise demands for measurements, and the amount of requirements for the reproduction of construction drawings made it extremely difficult to manually illustrate hard copies with hand drawing by traditional tools such as pen, paper, and ruler. Take aeronautical drawings for example, it is even more challenging, because of the demands to produce accurate drawings at 1:1 scale for large components of an aircraft, where it is impossible to convert smaller drawings into the templates needed for production (Weisberg, 2008)(Figure 3.1). This is the moment when computers started to become important and be considered as a new medium/tool to assist and accelerate both the design and production processes. It was also this time when the terminology of "CAD"(Computer Aided Design) was first introduced to the world. Although the main goals of CAD techniques back then still remained embedded in storing and presenting designs, computational techniques have increasingly changed their role by providing multiple ways of generating, analyzing and visualizing data. This in-turn has resulted in developing informed complex geometry based design solution sets as novel spatial outcomes.

The Form is interplaying amongst itself as an information emergence by executing particular approaches for conveying information.

"**Design is the computation of shape information that is needed to guide fabrication or construction of an artefact**" is an apt definition for the early stage of Computer Aided Design by William Mitchell (Mitchell, 1990). However, in this case, information is mainly considered as shape/geometry related data, extracted from a pre-conceived form to assist in any production process after the design decisions have been mostly completed. However, since years of developments and evolutions of the computer technology utilized in architectural design, computers are not treated merely as drawing machines to generate documents for construction work, or modeling machines to create fascinating rendering graphics to present and convince clients. The computation technology has successfully adapted/shifted itself to become an "information processor" rather than a pure "information duplicator". In the publication of "***Algorithm Form***" (Terzidis, 2006), Kostas Terzids made an explicit distinction about "**Computerization"** and **"Computation**". "**The dominant mode of utilizing computers in architecture today is that of computerization; entities or processes that are already conceptualized in the designer's mind are entered, manipulated or stored in a computer system. In contrast, computation or computing, as a computer-based design tool, is generally limited. The problem with this situation is that designers do not take advantage of the computational power of the computer**". This concise quote not only reveals existing problems of architects being predominantly occupied with computerization, yet, it also indicates a clear turning point of feeding and extracting information to and from computers in a different but also efficient way.

"**Form**" has always been a complicated and debated topic as regards the role it plays in architectural design no matter what kind of dogma is followed. Here, it's crucial to state that this research emphasizes that form should be perceived as having an intimate relationship with relevant contextual data in a dynamic fashion, and the approaches involved in processing this data into form-finding information.

The key concept delivered here is: "**The form can be informed by contextual information as a continual process".** The following sections will open up discussions focusing on different strategies for associating form and information with different computational methodologies in architectural design (computation) far beyond the conventional computational approaches which served towards storing and presenting (computerization) form. These methodologies have been categorized as: **Form Sculptor, Form Generator, Form Animator, and Form interactor.**

§ 3.1 FORM SCULPTOR

= utilizing 3D software intuitively as an exploration tool for design purposes/intentions.

Form Sculptor is defined as a method wherein existing 3D software is used to explore design ideas in architecture. It doesn't sound like an innovative idea at all, but in fact, this methodology has been only executed since just over a decade. Sketchpad[28](Figure 3.2), developed by Ivan Sutherland using the TX-2 computer in Lincoln Laboratory in 1959, which was around 20 years before IBM released the first personal computer was one of the first pioneering CAD systems (Weisberg, 2008). Ivan's original idea about Sketchpad operating in the design process was clearly written in his Ph.D. dissertation: "**Construction of a drawing with Sketchpad is itself a model of the design process**" (Sutherland, 1963). However, major developments of implementing computer graphic systems in architectural design went in a contrary direction inclined towards becoming a convincing visualized representation of the designers' ultimate vision of the project. This conservative way of using computer graphic systems as a virtual template/canvas or material to draw or model the final design project is obviously considered as a "computerization" process. Certainly, there is no design intention involved in the words and notions of making a "digital drawing" or "digital model", which is in a sense the common and typical misleading idea of the terminology of "Digital Architecture" and "CAAD Process" prevalent amongst the general public. Architects who engage with reproducing and storing tasks for the purpose of re-presenting their designs virtually with digital tools should thus not be considered as members of the "Digital Architecture" realm. **Form Sculptor** does not refer to such kind of computerized architecture.

---

28 Please check the videos for more information about Sketchpad: https://www.youtube.com/watch?v=USy-oT_Ha_bA and https://www.youtube.com/watch?v=BKM3CmRqK2o.

Manifesting curvilinear geometries has always been seen as a difficult geometric task within digital software and fabrication sectors for the architectural community. This issue, however, has been successfully addressed within the automobile, aircraft and naval shipbuilding industry with "Computer Numerical Controlled" (CNC) machines for fabrication purposes. But long before the computer was invented, analog crafting methods of building curvilinear structures have been developed with relatively conventional tools and devices. For instance, lofting is one of the crucial techniques of constructing a boat frame through several sectional profiles, and sweeping is another approach by carving out clay or sand as a doubly curved surface from the other directions perpendicular to the lofting axis. Both of these are fundamental functions in surface modeling software (Young, 2012). It took a few years for computer scientists to translate most of these crafting techniques into a computer algorithm to build up a curvilinear line with compatible computational processing power so that it appeared on screen in real-time. For instance, albeit it's still being in a wireframe geometric system, Pierre Bezier, in 1972, while working with Renault managed to mathematically define a digital automobile surface and generate data corresponding to it in order to drive a milling machine for production. This is when he created and implemented the well-known techniques behind the Bezier curves and surfaces. A year later, at the "PROLAMAT" conference, Ian Braid from Cambridge's CAD Center, presented BUILD using B-Rep(Boundary Representation) technology for 3D modeling in 1973. At the same conference, Professor N. Okino from Hokkaido University has developed a CSG-based solid modeling which could operate boolean combination with primitive shapes. B-Spline(Basic Spline), originally represented as a long strip of wood or metal to mark out the curves created by the lofting profiles while building a boat, was also described as a new digital approach by Rich Risenfeld, a Ph.D. graduate of Syracuse University in the same year. Two more Ph.D.'s from Syracuse University, Ken Versprille and Lewis Knapp, are credited by many people as being the developers and key figures behind the evolution of NURBS (Non-Uniform Rational B-Spline) around 1975 to 1979 (Weisberg, 2008). All the aforementioned researchers contributed to making a huge leap not only in the realm of CAD but also CG (computer graphics), but it was still somehow a bit difficult for architectural designers to execute directly such computer programs even during the year 1986 when AutoCAD initiated its launch of the first PC version software and took over the design software market. After years of evolution of UI (user interface) of modeling software, architects can now freely manipulate and improvise 3D modeling functions to create complex shapes. With this freedom of shape making, computers are now involved in the design process itself, rather than being used as a representational machine duplicating the designers' ultimate ideas. This conclusion coincidentally matches to what Mario Carpo stated in his article, an introduction of "***Twenty Years of Digital Design***" (Carpo, 2012), "**In fact, in the first instance, a meaningful building of the digital age is not just any building that was designed and built using digital tools: it is one that could not have been either designed or built without them**".

Thus, **Form Sculptor** should be seen as an approach where computational power becomes a necessity for discovering not only the form but also the spatial quality of architecture.

FIGURE 3.2 Introducing and Demoing the Sketchpad to the general public on a TV program. (source: https://www.youtube.com/watch?v=USyoT_Ha_bA).

Under this definition, architects who have been metaphorically deemed to be **Form Sculptors,** try to explore the diversity of forms to a certain extent by utilizing the capability of the 3D software. Forms should be seen as a "formation" process rather than a static and solid result. Unlike the real sculptors, who execute crafting techniques, like carving, shaping, modeling and fashioning according to chosen materials in the real physical world, the **Form Sculptor** deploys essential transformation functions within the selected 3D software, such as scaling, shifting, twisting, tapering, etc. in general digital modeling, and lofting, sweeping, patching, fairing, etc. in surface modeling work with principles of B-Spline, B-Rep, NURBS or even topological (blob) calculation to determine the shapes of the objects in a virtual reality space. However, a crucial aspect has to be repeatedly emphasized here: ideally, **Form Sculpting,** as a computational approach, should go beyond utilizing computer technology to produce pre-determined form. On the contrary, such free form manipulation with user-friendly interfaces in current 3D modeling software undoubtedly enhance design creativity and tend to further architectural development to challenge the conventional and conservative definition of space and functions (Carpo, 2012). In the stage of the **Form Sculptor**, the required information for the design tasks can be searched, filtered and digested during the operations of the modeling process with the powerful 3D software, and simultaneously collaborating with the designer's mind. Architects gain complex form modeling based advantages from powerful 3D modeling software, while the disadvantages/missed opportunities are revealed from the way these are utilized. Since the **Form Sculptor** relies too heavily on existing generic modeling functions, to a certain extent it constrains the creativity within the box of "default modeling functions". Besides, the operation of form modeling remains a relatively linear procedure which also further limits the potentials of computational processes which could utilize modeling processes from a distributed perspective, akin to a swarm. In other words, modeling each and every step of the formation process in linear detail is a misuse of the powerful computational technology in design. The other crucial critique of **Form Sculptor** is that the design output depends too much on an architect's personal intuitive sensibility for aesthetics, albeit this also is a central issue in most other design methods wherein subjectivity determining computational processes remains difficult to prevent. In order to search for solutions to such challenges, some architects decided to look for an answer by shifting from the "**Form Sculptor**" to the "**Form Generator** " methodology as a potential escape.

§ 3.2 FORM GENERATOR

= development of algorithms with multiple parametric inputs to generate performative forms associated with the appropriate usage of computational power in architectural design.

The "algorithm" as an information processor, obviously becomes the crucial element within the form generating process. But before rapidly jumping into the world of algorithms, it's crucial to acknowledge the time when complex geometries were being visualized without the assistance of computers but via mechanical tools. This will help in establishing hidden connections leading to today's algorithmic and coding driven innovations. So to begin with a different starting point, instead of relating directly to mathematical formulas, algorithms can in a sense be realized as physical instruments to illustrate simple to complex geometric principles via mechanical tools since yesteryears. Parametric thinking resembles the logic behind mechanical equipment, which has been used for decades as tools to record crucial physical notation (such as a drafting compass). For instance, Albrecht Dürer, who demonstrated curvilinear-line tracing during the time of German Renaissance (Cache, 2012). The illustrating instruments Albrecht Dürer invented to a certain extent have already embedded the relevant algorithms defined according to the combination of a mechanisms' movements and the equipment's dimensions in a parametric relationship. More importantly, these logics underlie ways in which computers can realize similar graphical effects via algorithms on screen in real time. Most of these drafting tools can be seen as a physical realization of the algorithms/formulas. Take the simple drafting compass as a common example, with its dimensions, it can concisely define the central point with the needle in one leg and open up a certain distance as a radius with the other leg attached to a pen. Then once the needle is fixed on the paper, the movement of spinning the head of the compass to make traces of the pen can be interpreted as a methodology to draw a perfect circle. This fundamental setting can be easily translated and applied to the computer as an algorithmic code to exhibit another perfect circle digitally on screen. Here, it is crucial to point out that without numerous explorations with such inventions of illustrating tools, computer graphics as a base of digital design would have been relatively difficult to realize through scripting alone.

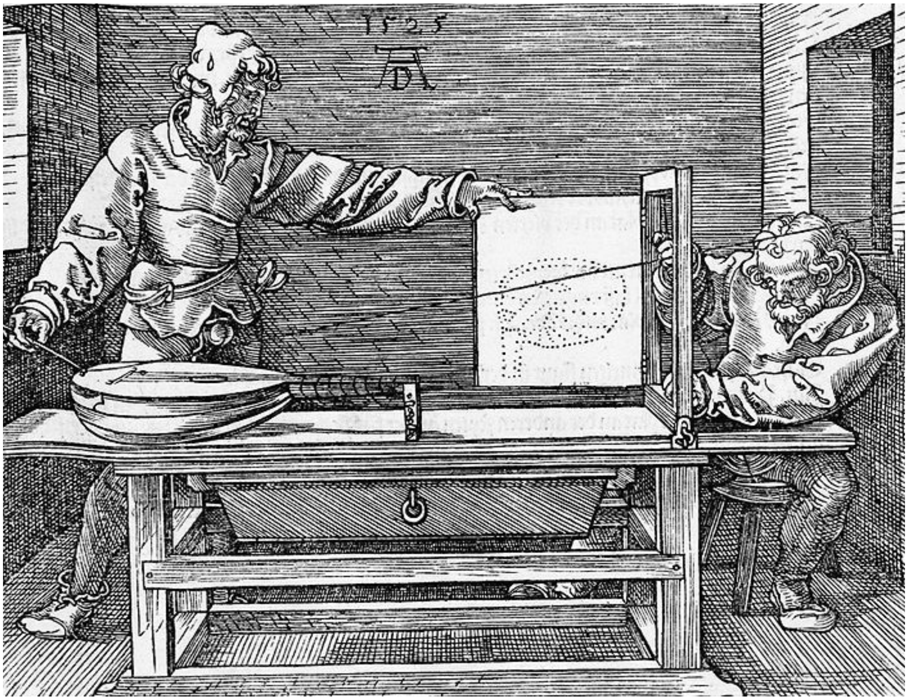


FIGURE 3.3 A drawing showing the usage of the perspective drawing instrument invented by Albrecht Dürer in the 15th century (source: https://commons.wikimedia.org/wiki/File:Duerer_Underweysung_der_Messung_fig_001_page_181.jpg)

In "***Underweysung der Messung (Instrument in Measurement)***" (Dürer, Albrecht & Formschneider, H. Andreas (Nürnberg), 1525) several curvilinear geometries are seen as the ancestors of B-Spline and NURBS used in current CAD software, such as snail curve, spiral curve, epicyclic circle, serpentine curve (even in 3D). These were demonstrated by Albrecht Dürer's incredible mechanical drafting instruments. Amongst one of the first theoreticians of perspective, he even invented the first mechanical imaging device requiring no human eyes as references to visualize 3D space on a 2D planar surface (Figure 3.3). If Dürer's instruments can be interpreted as a graphics generating tool, so do algorithms in computers which can be seen as parametric visualization machines. The algorithms and parametric principles executed by the **Form Generator** are akin to Albrecht Dürer's physical instruments, attempting to discover more complex spatial formations with the assistance of computing power. This kind of parametric design thinking had been ignored for years until the invention of computers showed their potential in architectural design for generating relatively complex shapes under the demands initiated from the Deconstruction movement (Deconstructivism) (Carpo, 2012). Who would have imagined that this form-finding process with parametric algorithms would become mainstream today through the possibilities offered by coding techniques?

So far in this section of the **Form Generator**, algorithms were interpreted to play the roles of form finding/generating processes/tools operating on the input of a geno-type, which results in the production of pheno-type, without offering insight into the generative process (Akin to a blackbox). This sentiment is echoed in Malcolm McCullough's article "***20 Years of Scripted Space***" (McCullough, 2006): "**First you set up some rules for generating forms, then you simulate them to see what kind of a design world they create and then you go back and tweak the rules**". Especially after user-friendly visual programming languages were introduced to architectural design within parametric modeling software suits such as Grasshopper in Rhino, Dynamo in Revit, young architects were all fascinated to see what parametric computational technology can offer and were tempted to use these for the sake of generating more complex design. Instead of manipulating the virtual model with the default modeling functions of the 3D software step by step, architects can now generate thousands of iterations of emergent outcomes with different sets of input variables fed into the same algorithm within a short period of time. This ability to discover novel emergent forms by harnessing computational power can be seen as a push in the right direction if compared to acts of modeling a pre-determined form. Influenced by scientific discoveries, such as system theory, complex science and genetic engineering, and the improvement of personal computational processing power, some architects began to execute well-known algorithms, such as L-System, Fractals, Subdivisions, Genetic Algorithms, Game of Life, etc., to generate complex geometric shapes related to their design concepts. However, in less than five years of development, a plethora of misuse of algorithms only for the sake of making complex desired forms to satisfy the personal desire of architects has become unprecedented. Such a trend of processing computational algorithms in architectural design fails to empower architecture in the digital age.

For digital architecture to be seen as a continuation of Deconstruction, computation should have a chance to challenge the stereotypical definition of architecture followed for thousands of years, not only in terms of "the appearance of form" but also its fundamental essence, which remains somehow missing in this category. The "**Form Generator**"/algorithms applied here should be capable of filtering excessive data into useful information to produce meaningful results not to be judged by aesthetic intuitive evaluation. Creating an algorithm should be seen as an inclusive part of the design in the process of the **Form Generator**. No matter how simple or complicated the algorithm is, the utilization of the algorithm should be embedded within contextual data to aid in the informed generation of form rather than being used as a tool for purely aesthetics driven Form Generation. John Frazer's quote in his work, "***An Evolutionary Architecture***", "**What we are evolving are the rules for generating forms, rather than the forms themselves**" (Frazer, 1995), adequately portrays the ideal definition of the **Form Generator**.

§ 3.3 FORM ANIMATOR

= A process wherein surrounding/contextual forces become instrumental in actuating the evolution of form to ultimately reach a dynamic equilibrium in real time.

Information undoubtedly involves a dynamic flow of data, so should **Form,** if interpreted as a representation of this information. Therefore, the **Form Animator** must have the ability to deal with the dynamic flow of information in real time. The **Form Animator** portrayed as a **real-time** adaptive information processor can drive its represented form as an actively morphing object following the rules of dynamic equilibrium. If this is still too abstract to understand, try to imagine a free-falling raindrop from the sky. it continuously morphs its form each and every minute based on its interaction with the surrounding forces and the principles of dynamic equilibrium, until it lands. The name of the **Form Animator** is derived from the well-known article "***Animate Form***" by Greg Lynn (Lynn, 1999), but the essence of the **Form Animator** is mostly pointing against what Greg Lynn states. Greg Lynn tried to make a distinction between "motion" implying movement and action, and "animation" implying the evolution of a form and its shaping force. But under the definition of **Form Animator,** in this research, these two categories of Motion and Animation involves different time-scales: a relatively slow morphological progress of growth or an immediate reaction via fast movement. In other words, a form, if seen as a mathematical representation, should consider relevant forces/parameters as dynamic variables to alter the resulting shape through time. This, coincidentally, matches the central idea described in "***On Growth and Form***" by D'Arcy Thompson (Thompson, 1992)(Figure 3.4) long before Greg Lynn's "***Animate form***". As a digital pioneer, Greg Lynn, in "***Animate Form***", attempts to break the dominant cultural expectations from architecture, which implied Architecture to be static and permanent. This is achieved by utilizing computational topological modeling tools, such as B-Spline, B-Rep and Blob techniques with continuous mathematical relationships to search for an optimized/universal geometric solution: a continuous unibody dealing with all the potential vector forces around it. Although simulation engines work in advanced forms in contemporary CAD software, such as MAYA, it still seems inefficient to manually drag control points of a relevant B-Rep body to model an optimized form and to examine it back and forth using evaluation tools. The **Form Generator**, with the assistance of computational technology, can generate optimized solutions, given a set of parametric inputs and fitness criteria. But if we accept that "information is dynamic", to a certain extent, the input parameters for generating form could also acquire a dynamic nature. This is what the **Form Animator** takes into consideration and should be thus seen as dealing with dynamic parametric inputs, which are able to produce multiple optimized sets of results.

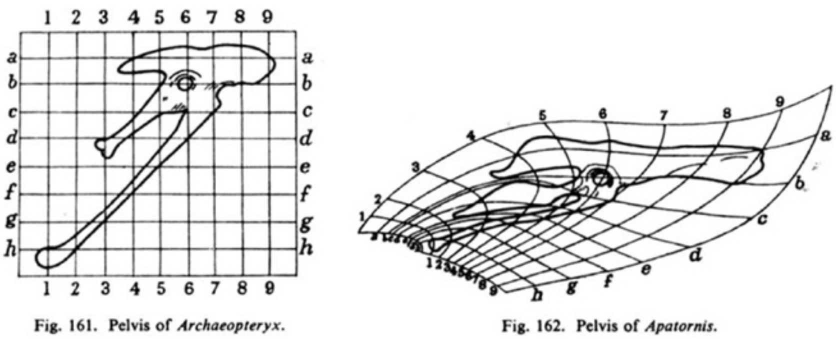


FIGURE 3.4 Analyzing the various morphology of animals using deformable grids by D'arcy Thompson (source: On Growth and Form, The Complete Revised Edition, New York: Dover Publications, Inc., 1992).

"**The problem with buildings is that they look desperately static,**" says Bruno Latour, who also further indicates that this is connected with the fundamental communicating medium, which architects use, namely, "**the drawings**" which are fixed to a particular perspective view illustrated in Euclidean space (Latour, B., & Yaneva, A., 2008). He further states that "**Euclidean space is a rather subjective, human-centered or, at**

TOC

least, knowledge centered way of grasping entities, which does no justice to the ways humans and things get by in the world". However, since architects work in Euclidean space, it becomes intuitive to ignore the fact that time and matter are actually married to space in a real living embodiment and not as static illustrations in the form of drawings. Even with current technologies to simulate render and animate, most building projects use them to merely portray lifestyle pertaining to how people adjust themselves to "happily" live inside the designed building, rather than using this data to take active action to influence spatial adaptation in a dynamic manner. The other issue Latour points towards is that since buildings have so many performative demands and considerations, that there is utterly no possibility to consider buildings as static artefacts which ultimately need to responsively transform with respect to internal and external forces they experience from the users and the environments they are embedded in real-time. He thus comes to the conclusion that **"...we should finally be able to picture a building as a moving modulator regulating different intensities of engagement, redirecting users' attention, mixing and putting people together, concentrating flows of actors and distributing them so as to compose a productive force in time-space**". This statement and its intent further points towards the essence of the next category, the "**Form Interactor**", which not only considers architecture as a one to one responsive system but also engulfs it within the domain of a collective intelligence based interactive system.

"**It is a liquidizing of everything that has traditionally been crystalline and solid in architecture.**" (Novak, 1991) Unlike Greg Lynn in Animate Form who realized static, yet complex architecture with existing topological modeling software, Marcus Novak proposed another vision of "**Liquid Architecture**" to liberate rigid architecture from the physical environment into Cyberspace (Novak, 1991). He argued that it is possible to envision architecture nested within architecture (Cyberspace), which basically proposed a co-existing environment where physical and virtual worlds bundle together. Within a virtual environment, architecture design can in a sense neglect the realistic physical constraints, such as gravity, but still, have the capability to deliver sensory perception via VR (Virtual Reality). Cyberspace is a virtual reality construct which smoothly liquidizes the hard boundary of physical space. To liquidize entities which have been crystalized in architecture is just the first phase of Marcus Novak's "**Liquid Architecture**", the ultimate goal is to adapt to real-time information flow and respond interactively to changing contextual data as an active living organism. Although this mode of conceiving architecture still involves an extensive amount of time to confront and resolve technical issues too, it still has the potential to ultimately change the dominant stereotypes of what architects could be doing. In contrast, it is quite disappointing, yet common, that most architects working in the digital realm do admit that working with dynamic information flow though does work at a theoretical and simulation level, but ultimately, they abandon this path to freeze the projects in a static manner. Under the technical limitations of the 3D software back then, Greg Lynn stood up to the challenge to alter the fundamental essence of architecture from a computational perspective. His concept of "**Animate Form**", considering todays context of real-time information management, can now be re-interpreted and re-appropriated as "Animate Form (**Form Animator**)."

In a new interview: Pablo Lorenzo and Aaron Sprecher with Greg Lynn, documented in the publication "***Architecture in Formation: On the Nature of Information in Digital Architecture*** (Lorenzo-Eiroa & Lynn, Interview and projects by Greg Lynn FORM, 2013)", Lynn states: "**I had thought it was too simplistic and literal to reduce animation media to the role of designing moving projectiles and transforming objects. But, now I have to admit that a sensibility in culture is willing these moving environments into being. People expect their cities and buildings to literally move for a variety of reasons**", which to a certain extent is a modification of his former definition of "**Animate Form**." Based on Greg Lynn's re-interpreted notion of "**Animate Form**", Bruno Latour's, theories on liberation of building, and Marcus Novak's "**Liquid Architecture**", the **Form Animator** tends to inevitably operate more likely as a **Form Transformer.** This implies operating akin to a delicate mechanism constantly responding to input forces and actuating a relevant dynamic form. Moreover, the **Form Animator** can radically acquire the scope of a **Form Interactor,** which, not only passively react to direct environmental inputs, but can also pro-actively alter human and spatial behavior. Following this tendency, Latour's daring assertion of "**making all buildings move**" might actually come true.

§ 3.4 FORM INTERACTOR

= An emergent organic body composed of numerous singular intelligent entities possessing dynamic interaction. This dynamic interaction via internal/external information exchange can be seen during the process of growth and in the pro-active immediate behavior, which the body possesses.

Embedded in this immersive digital world surrounded by dynamic information flows, architecture has no excuse to keep with its static or essentially passive response state. It must be transformed into a living-creature-like entity which can react instantaneously and possess free will. It seems to be an inevitable trend that architects are yearning for making buildings as living organisms after adequate exploration of the **Form Animator**. Unlike the **Form Animator** principles, which are used for projects which acquire algorithmically driven passive formal variations, the **Form Interactor** has an advanced proactive system akin to an artificial intelligence to make informed and immediate decisions compatible with dynamic data. The title of "**Form Interactor"** might at first seem misleading with the initial impression of merely focusing on the creation of an expressive phenotype, however, the "**Interaction**", is equally crucial for the creation of an implicit genotype, in an emergent fashion. In **Form Interactor**, the issue of interaction is different ways: "**Internal Interaction**", which, takes inspiration from biological growth processes, and "**External Interaction**", which mainly deals with immediate behavioral reaction, and both of these can be associated with the notion of "**Emergence**".

§ 3.4.1 Internal Interaction

Genetic Algorithms should not be seen as a process for optimizing form finding functions only: "Form Generator", but rather as an environmentally sensitive interactive process involving dynamic information flows: "Form Interactor".

The body, as a living entity, can be interpreted as a confluence of several complex systems interacting with each other akin to the multitude of systems which operate simultaneously to create architecture. During the growing process of an organism, there is, **Internal Interaction**, information embedded in genes as a basic instruction interacting with external factors from the environment to proportionally produce organic materials. This self-organizing process interested numerous pioneering architects to experiment with Genetic Algorithms, for form-finding purposes. These, however, turn out to be misleading examples, considering that the processes of real-time "Interaction" within natural growth processes tend to be completely missing during the computational processes of such algorithms. Michael Weinstock, in "***Morphogenesis and the Mathematics of Emergence***" (Weistock, 2004) clearly illustrated the generic computational approach of exploiting Genetic Algorithms in architectural design and other research fields, "**Genetic Algorithms initiate and maintain a population of computational individuals, each of which has a genotype and a phenotype. Sexual reproduction is simulated by random selection of two individuals to provide 'parents' from which 'offspring' are produced. By using crossover (random allocation of genes from the parents' genotype) and mutation, varied offspring are generated until they fill the population. All parents are discarded, and the process is iterated for as many generations as are required to produce a population that has amongst it a range of suitable individuals to satisfy the 'fitness criteria'**". Genetic algorithms undoubtedly enhance powerful computational applications supporting the process of morphogenesis in architectural design. However, in most cases, Genetic Algorithms in architectural designs, based on defined fitness criteria are used for obtaining "Optimized", often static, outcomes for digital fabrication purposes. This, is contrary to the essential notion of "**growth**", which, is a real-time adaptive material producing "**process**". According to Micahel Weinstock (Weistock, 2004), "**Strategies for design are not truly evolutionary unless they include iterations of physical (phenotypic) modeling, incorporating the self-organizing material effects of form finding and the industrial logic of production available in CNC and laser-cutting modelling machines". This** illustrates the exact misuse of implementing Genetic Algorithms. However, still, a majority of architectural designers still use Genetic Algorithms specifically for producing aesthetically pleasing form without considering material performance and production logics. Genetic Algorithms directly implemented in architecture in this sense, act no more than an **algorithmic machine** akin to the role of the **Form Generator**, generating an optimized solution, opposed to John Frazer's idea to take natural science as a source of inspiration rather than explanation (Frazer, 1995).

John Frazer's idea of taking Genetic Algorithm as an **inspiration** implied not to directly execute these algorithms extracted from nature, but further, translate them into a design methodology for creating the instructions of the morphogenic formation in architectural design. **"...DNA does not describe the process of building the phenotype but constitutes instructions that describe the process of building the phenotype, including instructions for making all the materials, then processing and assembling them...These are all responsive to the environment as it proceeds...**". (Frazer, 1995). John Frazer emphasized in his significant article"***An Evolutionary Architecture***" that "**... what we are evolving are the rules for generating form rather than the form themselves. We are describing processes, not components**" (Frazer, 1995). This suggests that architects should design specific Genomes considering the context within which the design has to be embedded, rather than merely apply existing algorithms as a form-finding tool. Under the premise of John Frazer's rule-generating idea, the **Internal Interactions** of a living creature/building can be designed/interpreted as several internal information processing systems embedded in **Genomes** interacting with each other as well as external environmental inputs, forming a constant emergent mechanism for the overall growth "**process"**. The formation of the **Genome** is an on-going process with the inherited relationship of each cell that cannot be simplified as a one to one input-output mathematical formula neglecting the crucial fourth dimension, time, which is equal to the role of **Internal Interaction** implemented in the "**Form Interactor**". Common sense would state that "living" should be considered as an activity/state involving a continuous process involving constant data exchange between the body and its natural context, and thus can never be interpreted as an ultimate frozen state in time. If the **Form Interactor was** seen as a metaphor of a building, then it should also "live" in the existing environment rather than being

TOC

"located" or "crystalized" on site. "**Bones, for instance, which are full of living cells, can heal and adapt to their environment. In particular, the cells will rebuild the structure to adapt to the load it carries; a bone can change its physical shape after a fracture that heals out of position so that the load is adequately supported**" (Fox, Michael, & Kemp, Miles, 2009), the **Internal Interaction** within the example here reveals the vital ideas of real-time calculation, immediate adaptation and material interaction by distributed information systems amongst cells, to carry out the healing task, an which can be seen as an emergent behavior. Extending this healing function is associated back with the issue of "growth" and "fabrication", it is not that the **Internal Interaction** fights against the idea of fabrication, but the **post-optimised production** method is what the **Internal Interaction** refuses to accept in the section of the "**Form Interactor**". The ideal fabrication process within the concept of **Internal Interaction** should be akin to how an organism builds up its body based on the "Genome instructions" and "environmental influences" in real time. Each single moment is unique and with the summation of all internal and external forces emerging, the organism grows that particular body part based on each single task assigned to the living cells which cannot be repeated. This is exactly the emergent performance principles to be traced in **External Interaction**. (More Genetic Algorithm and Evolution Process will be discussed in the chapter of Bio-Inspired Architecture).

§ 3.4.2 External Interaction

External Interaction, following Swarm Behaviors-like principles, a dynamic equilibrium, should have capabilities to confront immediate circumstances locally to take action by individuals but interrelated componential intelligence agents and emerge from bottom-up as a global behavior to embody as a volatile actor.

To understand the issue of **External Interaction** in the **Form Interactor**, the notions of Emergence and **Swarm** Behaviour have to be introduced. "**...Emergence is applied to the properties of a system that cannot be reduced from its components. Properties 'emerge' that are more than the sum of the parts**", "***The Architecture of Emergence: The Evolution of Form in Nature and Civilisation***" (Weinstock, 2010), which simply and clearly explained the notion of **Emergence**. Michael, further quotes Aristotle's words to support this explanation, "**that 'whole' has distinctive properties that emerge through the processes of successive interaction between different levels of organization and integration**". It can thus be said that **Emergence** can be considered as a process of formation through interaction between different individuals systems/entities, and the overall property of emergence cannot be observed by studying each distinctive individual. Based on this definition, the **Internal Interaction** can definitely be seen as an Emergent Behavior, which merges several interactive interacting systems together to gradually develop the process of growth as a whole. In the case of **External Interaction**, the focus is the individual entity comprising the overall whole and the networked relationships between them. This idea of a larger property described by smaller componential entities can be traced back to the philosophical definition of a "Monad" in Gottfried Leibniz's Monadology back in 1714 (Leibniz, Monadology, 1714). The "Monad" here stands abstractly for the simplest substance which cannot be split apart and considered as a basic element comprising a composite object. As a result, in this respect, Leibniz made his point that "**In a plenum [= word that is full], any movement must have an effect on distant bodies, the greater the distance the smaller the effect…As a result, each body feels the effects of everything that happens in the universe, so that he who sees everything could read off from each body what is happening everywhere**". Therefore, every object, person, and every single matter existing in the world are all intimately interconnected to each other in this rapidly dynamic and hyperlinked Internet age. One can also connect, Emergent Behaviour to principles of Monadology, wherein every single monad, as a bird in a flock, has an influential interactive relationship with each other to emerge as a whole plenum(overall performative body) in a bottom up fashion. From the historical trajectory of these philosophic aspects, Leibniz's Monadology had great influence on Deleuze's thought process behind the "**Folding**" and "**Body Without Organs**" concepts, which profoundly impacted further philosophical inspiration in contemporary architectural design.

In Nature, **Emergence**, can be traced in the principles underlying **Swarm** behavior. **Swarm Behavior** principles embody numerous animal species, which tend to move collectively, for example, a flock of birds, a school of fish and a group of bees (Figure 3.5). Without any leader's top-down command, each individual forming in such groups of living entities make bottom-up decisions, resulting in bigger collective behavior. Each entity is equal, in stature, to each other and thus any of singular entity's movement/decision, profoundly impacts the overall performance of the whole. This characteristic fits perfectly with the science of **Emergence** as well as Leibniz's **Monadology** philosophy. After observing flocks of flying birds, Craig Reynolds, as a computer scientist started to develop swarm behavior simulation back in 1987 (Reynolds, Flocks, herds and schools: A distributed behavioral model, 1987). Three major principles of "**Separation**", "**Cohesion**", and "**Alignment**[29] underlying the steering

29 Separation implies avoiding crowding next to each other; Alignment implies steering towards the average direction of the neighboring flocks; Cohesion implies driving the agents' movement towards the average position of the local agents. More information can be found referring to Craig Reynold's website illustrating the flocking behavior: http://www.red3d.com/cwr/boids/

behavior behind a digital flock of birds was thus successfully realized in a virtual environment with intuitive and smooth movement. Since then, this Swarm behavior algorithm has been broadly applied to different paradigms of research including game design, swarm robotics, distribution and communication systems...etc., and certainly in architectural design applications as well. John Holland, another pioneer working on **Emergence** and genetic algorithms, pinpointed three major principles required to set up a basic Emergence system: **element**, **rules**, and **interactions** (Holland, 1998). If we follow John Holland's proposal, the three major principles of **Swarm behavior** simulation developed by Craig Reynold can be accordingly modified by further enhancing the fundamental principles in relation to implementation/task based deploy ability. Computationally speaking, one can modify the basic principles/rule sets of agent interaction, in order to develop customized "**basic intelligence**" within the algorithm associated with smarm simulations. Recently, architects have taken advantage of growing computational power for developing **Swarm based design systems**, as novel approaches in architectural design.

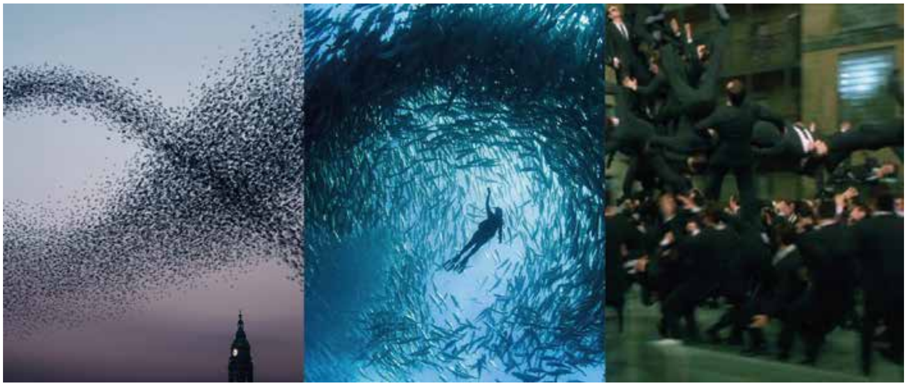


FIGURE 3.5 Images exhibiting the swarm idea either in nature or in the film. A swarm is a group of animals that aggregate and travel in the same direction(https://en.wikipedia.org/wiki/Swarm_(disambiguation)). From left to right: a swarm of insects, a school of fish, a group of agent Smiths in the Matrix (source from left to right: http://www.ayni.institute/swarm, http://www.dailymail.co.uk/news/article-2834570/Divers-caught-middle-huge-school-fish-snap-selfies-them.html, and http://movies.stackexchange.com/questions/27942/is-there-a-trope-for-a-pile-on-fight).

Roland Snooks, one of the leading characters in this new domain, also one of the directors of **Kokkugia** has for years conducted experiments using **Swarm** algorithms for promoting self-organization principles in architectural design, under the title "**Behavioral Formation**," which is also the title of his Ph.D. dissertation in RMIT, Melbourne. Some of the experimental designs were developed together with his design partner, Robert Stuart-Smith in practice, and some with his master students

TOC

both at the AA, London, UK and RMIT, Australia as design research experiments. Roland Snooks' idea of a self-organized body within **Swarm behavior** principles is explicitly illustrated as follows, "**These methodologies operate by encoding simple, local architectural decision within a distributed system of autonomous computational agents. It is the interaction of these local decisions that self-organizes design intention, giving rise to a form of collective intelligence and emergent behavior at the global scale. Such behavioral formation represents a shift from 'form being imposed upon matter', to form emerging from the interaction of localized entities within a complex system**" (Snooks, 2013). In other words, the behavioural formation can be interpreted as a self-organizing system constituting agents of a swarm, which produce unique/local material properties due to underlying collective decision-making principles set forth by the designer. Akin to the aforementioned concept of **Internal Interaction** constituting the process of growth or similar to the process of self-healing of living bone cells. However, even volatile topology has been heavily addressed in Roland Snook's concept with Swarm logics, as all his computational generative formation processes are frozen in a particular moment, which, is fundamentally against his original idea of "**volatility**". Various young digital savvy architects are extremely fascinated by this emergent behavior and its capability and have started following this trend of executing swarm algorithms in architectural design again as a form/pattern finding process. Roland Snooks' approach of utilizing swarm algorithms is still, in general, in a relatively initial stage. Although he advanced the development of algorithms for making local collective decisions to materialize creative projects, he somehow overlooked the inherent character of swarms, which, points towards a **continual dynamic process**, which cannot be crystallized at any moment in time. For instance, in nature, simply taking groups of ants for example, they can form an emergent holistic body such as a bridge, helping each other to cross a pond of water or gap between leaves. However, once the temporary goal is reached, they will re- distribute themselves going back to doing their own tasks and form new configurations according to the new tasks they need to accomplish in time.

To a certain extent, we can still interpret this as another much-advanced version of the **Form Generator/Animator** due to the fact that it remains frozen in its ultimate state, which, makes his projects less commensurate to the terminology of "Swarm Architecture". Swarm Architecture, in its true sense, should possess the substantial potential to deal with immediate interactions similar to how living entities adapt to dynamic contextual demands. "Swarm Architecture" based research should thus be highly advanced in order to produce intelligent buildings with capabilities of real-time adaptation and interaction. This is the ideal goal for what **External Interactions** should embody in a "**Form Interactor**".

"**Space is a computation**." Kas Oosterhuis made this bold and strong assertion in the very beginning of his article "***Swarm Architecture II***" (Oosterhuis, Swarm Architecture II, 2006), which was proposed years before Roland Snooks presented his Behavioral formation idea. According to Kas Oosterhuis "**space computes information**". This links perfectly with the key concept of this chapter: to consider **form(space) as an information processor**. Following Kas Oosterhuis' steps, an architecture can also be seen as a networking instrument communicating actively with the users of the space in real-time via various inter-connected actuated building components, "**The actuators are being orchestrated like the birds in a swarm**", Kas concluded. Kas Oosterhuis thus proposed the idea to bring computational technology for practical usage by embedding it into building components for active internal communication and external adaptation instead of utilizing the computing power merely as a form generating tool. This mode of thinking perfectly embodies the authentic intent of the "**Form Interactor**." This intent can further lead to the production of buildings, which, in essence, become alive and thus a species in their own right. This is further reinforced by, John Frazer's statement:"**We never try to copy the superficial appearance of a biological species. Rather we try to invent new species which by its complexity and due to their complex behavior may eventually familiarize with living objects as we already know**" (Frazer, 1995). It is time to shift towards utilizing computational power to develop practical operational spatial solutions rather than for creating front-end form generating machines. In other words, it is time to utilize the principles of "**Swarm behavior**" as the fundamental basis behind "**Form Interactor**" to develop a novel approach for integrating computational technologies within building component for developing a networked distributed system for realizing an architectural body which can adapt to its immediate context.

§ 3.5 Conclusion

In this chapter, "**Form**" has been interpreted as an information processor inspired by Kas Oosterhuis' "**Space is a computation**" approach. Actually, in every scale, all existing objects are to a certain extent related to information which can be translated and represented in diverse forms. Simply take a small device like a pen, for example, it has information embedded associated to its dimension, color of ink, and material it is made of. Furthermore, with its essence of being a pen, it has a given function of making traces. This kind of "Object-Oriented" concept is mainly utilized in computer science to illustrate a category, constituting certain characteristics, where you can generate objects from its essence, but vice versa it can logically categorize any existing object with a similar principle. In the introduction section of this chapter, it is clearly emphasized that people have dealt with spatial information long before the computer had been invented, the only crucial difference is that the computational technology accelerated the processing of data. In the digital architecture domain, the means and degrees of utilizing computational technology have been categorized into different sections in this chapter, namely: **Form Sculptor**, **Form Generator**, **Form Animator** and **Form Interactor**. Not only the manner but also the philosophy and the logic of a computational application in architectural design behind them have been reviewed in this Chapter in order to trace the advantages and disadvantages within each category. There are definitely "pros and cons" but no "rights or wrongs" of these formative approaches from the design perspective, it is only a question of the methodologies and strategies the designer prefers. The **Form Sculptor** tends to favor a more intuitive approach compared to the **Form Generator** relying on rational algorithms as a form-finding method. The **Form Animator** starts to be aware of the influential impact from dynamic information flows, while the **Form Interactor** takes the dynamic information into account as either the slow morphing process, in the case of growth or immediate morphing process, in the case of an immediate reaction. **Form thus has** an intimate relationship between the architectural design process and contextual information.

Based on what Stephen Wolfram has stated in "***Towards a New Kind of Science***", **"... nature[the Universe] as we know it is a pure form of computation**" (Wolfram, 2002), it is extremely rational to claim that "**Space is a computation**" as proposed by Kas Oosterhuis in 2011. The other crucial factor of "**dynamic equilibrium**", indicates the need to be constantly changing/evolving with information flow, and that this will drive architectural design to acquire the dimensions of a living organic body. "**Liquid Architecture is an architecture that breathes, pulses, leaps as one form and lands as another...It is an architecture that opens hallways, where the next room is always where I need it to be and what I need it to be**" (Novak, 1991) noted Marcus Novak who proposed a volatile architecture operating as a living creature almost 15 years ago. During the same period of time, Kas Oosterhuis has even put this living architecture idea to the next level with an architecture that actually has its own will by proposing the **HyperBody** concept, "**True hyperbodies are pro-active bodies...actively propose actions. They act before they are triggered to do so. HyperBodies display something like a will of their own. They sense, they actuate, but essentially not as a response to a single request**" (Oosterhuis, HyperBodies: Towards an E-motive Architecture, 2003). In Kas Oosterhuis' mind, the way of constructing this intelligent architectural body with free will is not by complicated AI(Artificial Intelligence) system, but instead, by using Swarm logic as a system which thrives on collective intelligence. "**Think of a type of architecture where all building elements are intelligent agents flocking the herd, (re) configuring themselves in real time**" (Oosterhuis, HyperBodies: Towards an E-motive Architecture, 2003), this (re)configurable body can achieve real-time interaction with relatively smaller entities with simple intelligence. In this case, computation is no longer seen as a form-finding machine which generates a nearly optimized, fixed architecture, but is embedded in building components which can communicate through protocols and to a certain extent actuate/react akin to living cells in an organic body.

References

Cache, B. (2012). Instruments of Thought: Another Classical Tradition. In C. O'Donnell (Ed.), *The Cornell Journal of Architecture 9: Mathematics* (pp. 17-26). New York: College of Architecture, Art, and Planning, Cornell University.

Carpo, M. (2012). Twenty Years of Digital Design. In M. Carpo (Ed.), *The Digital Turn in Architecture 1992 - 2012* (pp. 8-14). New York: Wiley.

Dürer, Albrecht & Formschneider, H. Andreas (Nürnberg). (1525). *Underweysung der Messung* . German: Nürnberg.

Fox, Michael, & Kemp, Miles. (2009). *Interactive Architecture*. New York: Princeton Architectural Press.

Frazer, J. (1995). A Natural Model for Architecture/ The Nature of the Evolutionary Mode. In J. Frazer, *An Evolutionary Architecture*. London: Architectural Association.

Holland, J. H. (1998). *Emergence: From Chaos to Order*. Oxford: Oxford University Press.

Latour, B., & Yaneva, A. (2008). Give Me a Gun and I Will Make All the Buildings Move: An Ant's View of Architecture. In R. Geister (Ed.), *Explorations in Architecture: Teaching, Design, Research* (pp. 80-89). Basel: Birkhäuser.

Leibniz, G. W. (1714). *Monadology*. (J. Bennett, Trans.) Continuum. Retrieved from http://www.earlymoderntexts.com/assets/pdfs/leibniz1714b.pdf

Lorenzo-Eiroa, P. (2013). Form:In:Form on the relationship between Digital Signifiers and Formal Autonomy. In P. Lorenzo-Eiroa, & A. Sprecher (Eds.), *Architecture in Formation: On the Nature of Information in Digital Architecture* (pp. 11-22). New York: Routledge.

Lorenzo-Eiroa, P., & Lynn, G. (2013). Interview and projects by Greg Lynn FORM. In P. Lorenzo-Eiroa , & A. Sprecher (Eds.), *Architecture in Formation: On the Nature of Information in Digital Architecture* (pp. 286-295). New York: Routledge.

Lynn, G. (1999). *Animate Form*. New York: Princeton Architectural Press.

McCullough, M. (2006). 20 years of scripted space. (M. Silver, Ed.) *Architectural Design Special Issue: Programming Cultures, 76*(4), 12-15.

Mitchell, W. J. (1990). A New Agenda for Computer-Aided Design. In M. McCullough, W. J. Mitchell, & P. Purcell (Eds.), *The Electronic Design Studio: Architectural Education in the Computer Era* (pp. 1-16). Cambridge: The MIT Press.

Novak, M. (1991). Liquid Architectures in Cyberspace. In M. Benedikt, *Cyberspace: First Step* (pp. 225-255). Cambridge: The MIT Press.

Oosterhuis, K. (2003). *HyperBodies: Towards an E-motive Architecture*. Basel: Birkhäuser.

Oosterhuis, K. (2006). Swarm Architecture II. In K. OOsterhuis, & L. Feireiss (Eds.), *The Architecture Co-Laboratory: Game Set and Match II, on Computer Games, Advanced Geometries, and Digital Technologies* (pp. 14-28). Rotterdam: episode publisher.

Reynolds, C. W. (1987). Flocks, herds and schools: A distributed behavioral model. *Compute Graphics, 21*(4), 25-34.

Snooks, R. (2013). Self-Organised Bodies. In Lorenzo-Eiroa P., & A. Sprecher (Eds.), *Architecture in Formation: On the Nature of Information in Digital Architecture* (pp. 264-267). New York: Routledge.

Sutherland, I. E. (1963). *Sketchpad: A Man-machine Graphical Communication System*. Cambridge: University of Cambridge.

Terzidis, K. (2006). *Algorithmic Form*. Oxford: Routledge.

Thompson, D. (1992). *On Growth of Form*. London: Cambridge University Press.

Weinstock, M. (2010). *The Architecture of Emergence: The Evolution of Form in Nature and Cilvilisation*. New York: Wiley.
Weisberg, D. E. (2008). *The Engineering Design Revolution: The People, Companies and Computer Systems That Changed Forever the Practice of Engineering*. Retrieved from www.cadhistory.net
Weistock, M. (2004). Morphogenesis and Mathematics of Emergence. In M. Hensel, A. Menges, & M. Weinstock (Eds.), *Architectural Design, Emergence: Morphogenetic Design Strategies, Volume 74, Issue 3* (Vol. 74, pp. 10-17). New York: Wiley.
Wolfram, S. (2002). *A New Kind of Science*. Champaign: Wolfram Media. Retrieved from http://www.wolfram-science.com/nksonline/toc.html
Young, M. (2012). Digital Remediation. (C. O'Donnell, Ed.) *The Cornell Journal of Architecture 9: Mathematics*, 119-134.

4 Body Conjunction = Wavering Between Actual and Virtual Spaces

"You take the blue pill, the story ends. You wake up in your bed and believe whatever you want to believe. You take the red pill, you stay in Wonderland, and I show you how deep the rabbit-hole goes."

Morpheus, to Neo (the Matrix, 1999)

§ 4.1 From Body Measurement to Body Extension to Body without Organ

In the present digital age, the body tends to extend beyond it being flesh, it can be extended, it is a body without organs, and it might belong to more than your own-self.

The "Body" as a living entity with its embedded sensory system, not only embodies who we are but also lets us understand and explore the sensitive, unpredictable but fascinating world. The body is an information receiver as well as information reactor. Through years of medical experiments and research on the body, medical devices and instruments are able to allow us to look into the deepest and the most mysterious spots in the human body. For instance, if seen through an HD monitor, while being probed by an endoscope, the body appears as an immersive and infinite landscape. By observing the smoothness and the folds of the surfaces encountered within the body, it is quite simple to project your individual self into this body-scape for a while to imagine and experience this immersive organic space. Various potential ideas of designing a body-like space have become the subject of design fantasies of a number of architects.

The "Vitruvian Man", which, Vitruvius described in the third book of De Architectura, and was later interpreted and illustrated by Leonardo DaVinci, has served as the human figure/body representation to be used as a measuring unit rather than being considered as a sensitive object. Unsurprisingly, it was a relatively long journey for architects to abandon this dogma. After the industrial revolution (during the modernist era), the concrete evidence of considering body proportions as potential measurements could still be seen in the projects of Le Corbusier, which accompanied his famous school of thought: "**A house is a machine for living**". He developed the "**Modular**" in a mathematical proportion of space based on figures and intended to replace the old Vitruvian man with it as a new generation's typical model. However, with the rapid development of electronic technology, the trend of realizing sensory environments akin to living bodies has no longer remained a thought but can be seen as an initial action to refuse to see the human body merely as a measuring unit. The turning point came about the time while the medium of news media, television, and social media became relatively mature, and thus started making people conduct critical reflections. Marshall McLuhan, a well-known pioneering media theorist, stated in his well-known publication, "***Understanding Media: The Extension of Man***" (McLuhan, Understanding Media: The Extensions of Man, 1964). **This explicit shot made the researcher foresee the potential and intimate relationships between the body, technology, and space, and somehow have a rational explanation to extend the physical body to endless space, which is crucial in this chapter.**

"**Today, after more than a century of advancements in electronics, we have extended our central nervous system itself in a global embrace, abolishing both space and time as far as our planet is concerned**" (McLuhan, Understanding Media: The Extensions of Man, 1964), Marshall McLuhan who invented the terminology of the "Global Village", thus opens up a ceaseless discussion around his discussions around " **media being the extension of man**", and by doing so, he profoundly influenced the general perspective/reflection of technology and helped in reshaping a new relationship between body and technology. "***All media are extensions of some human faculty—psychic or physical***" (McLuhan, M., Fiore, Q., & Agel, J, 1967). The "Media" here is no longer the synonym of the press or mass media but rather indicates human technology. For example, "... **the wheel (media) is the extension of the foot**"; **"...the book is the extension of the eye**"; "**...clothing, an extension of the skin**"; "**...electric circuitry, an extension of the central nervous system**". It's not that the Internet or electronic technology which initiated the extensions of the body. According to Marshall McLuhan, Body extensions have been developed for thousands of years, much earlier than the Internet and electronics. Although his conceptual idea about "**Hot & Cold Media**" is controversial due to the reason that the distinction is based on a relative standard rather than an absolute definition, he still explicitly argues that the medium/technology requires a critical degree of audience participation. Interactive environments align with this line of thought since they serve as a medium of expression and involve real-time engagement of participants for seeking critical reflection. ("Hot media are, therefore, low in participation, and cool media are high in participation or completion by the audience." (McLuhan, Understanding Media: The Extensions of Man, 1964).

Eliminating the traditional notion of the medium as the vehicle carrying messages, Marshall McLuhan argued via his revolutionary idea that "**Medium is the Message**". The medium itself has embodied meaning even without embedding any content. For instance, an automated machine, in itself is a medium/technology, it has thoroughly altered the relationship of man-machine in human society, and it thus carries its own meaning. Marshall McLuhan gave a precise and understandable example as follows, "**The railway did not introduce movement or transportation or wheel or road into human society, but it accelerated and enlarged the scale of previous human functions, creating totally new kinds of cities and new kinds of work and leisure**" (McLuhan, M., Fiore, Q., & Agel, J, 1967). Another example can be listed here, like human communication methods from the handwritten letter, the telegraph, the telephone, and today's smartphones and email technology, are all seen as the medium only changing the scale and speed of communication. With the rapid development of technologies, such as the Internet and computational processing power, the physical body is further extended into virtual space while interweaving and interacting with all the other involved technologies. Within this technologically rich context, despite of being empowered by this medium, the incremental loads and tasks experienced by the body have to be scaled up to a comparable level. Besides, based on Marshall McLuhan's idea, this kind of imbalanced condition and way of diminishing the natural role of the senses was initiated long ago while the phonetic alphabet was invented. "**... in the tribal world, the senses of touch, taste, hearing, and smell were developed, for very practical reasons, to a much higher level than the strictly visual. Into this world, the phonetic alphabet fell like a bombshell, installing sight at the head of the hierarchy of senses. Literacy propelled man from the tribe, gave him an eye for an ear and replaced his integral in-depth communal interplay with visual linear values and fragmented consciousness**" (Playboy Interview: Marshall McLuhan, 1969). Since then, the holistic idea of man became **fragmented** with ubiquitous professional body extensions catering to specific missions. This phenomenon gradually leads to a tendency of pushing the body to the extreme by means of assisting and enhancing various bodily senses via suitable technological mediums, akin to continuously pressing and pushing, the body like a massage. This is where the medium appears to become the "**massage**" rather than the "**message**."

In the chapter of "**The Gadget Lover: Narcissus as Narcosis**" in "***Understanding Medi***a" (McLuhan, The Gadget Lover: Narcissus as Narcosis, 1964), Marshall McLuhan uses an ancient Greek story to bring out the issue of "**Numbness**". This young Narcissus was so fascinated by his extension: the reflection in the water (although he didn't know it was his own reflection), that he transformed himself and his extension into a completely closed system, or in other words became "**Numb**". Simply saying, the stimulation of his extension was so powerful that he refused to accept other contextual information and became operating as a closed loop. From the physiological point of view, Marshall McLuhan found support from two medical researchers, Hans Selye and Adolph Jonas, when he stated: "**all extensions of ourselves, in sickness or in health, are attempts to maintain equilibrium. Any extension of ourselves they regard as "autoamputation," and they find that the autoamputative power or strategy is resorted to by the body when the perceptual power cannot locate or avoid the cause of irritation** (McLuhan, The Gadget Lover: Narcissus as Narcosis, 1964). This is the reason why people tend to play sports in order to combat the irritations and stresses of real life. Furthermore, **"...In the physical stress of superstimulation of various kinds, the central nervous system acts to protect itself by a strategy of amputation or isolation of the offending organ, sense, or function**" (McLuhan, The Gadget Lover: Narcissus as Narcosis, 1964), in addition to this, "**...Shock induces a generalized numbness or an increased threshold to all types of perception"** (McLuhan, The Gadget Lover: Narcissus as Narcosis, 1964), it is explicitly clear that the autoamputation, as numbness are ways to protect selves from sudden superstimulation. To make it easier to understand, take the news reports for example. Through the broadcasting of the news, people might get shocked and have moral anxieties of seeing these skinny children suffering from the specific problem of famine in Africa. But after every 10 minutes of constant information bombarding with the repeated images (**massage**), people become completely numb (**autoamputation**). In accordance with Marshall McLuhan's explanation, the "**autoamputation/numbness**" has to happen as a protection mechanism to prevent people from feeling self-condemned from a moral perspective and for survival. Nonetheless, reconnecting back to the title of the reference in this section, the term of "**the Gadget Lovers**" nowadays, can metaphorically and intuitively indicate for those who love to explore/hack with these small electronic devices with specific applications. Under this particular context, the gadget lovers, with their main bodies, attempt to utilize all the hi-end technological gadgets to extend their body parts infinitely in time and space. They almost unconsciously seek temporary immortality in virtual space via the medium of the Internet. There is no way to distinguish each explicit body part in the virtual world such that the individual thought might not belong to one's conscious self. The body extension is thus autoamputated and distributed ubiquitously even after losing major control by the main body. On the other hand, metaphorically speaking, getting continuous electronic accumulating shocks by the message, the body will no longer treat it as stimulation, but rather turn it into the feeling of "numbness". Instead of peremptorily embracing the temptation of the new technologies, Marshall McLuhan actually would like us to reflect on the relationship between the technologies and the human bodily senses, and to keep to the qualities of each individual's authentic self, especially in this boundless world composed of the web of the Internet where one can get lost and easily deconstruct with alienation.

Here, Marshall McLuhan's "**Body Extension**" seems to imply a linkage to the notion of "**Body Without Organs**" proposed by Gilles Deleuze and Felix Guattari (Deleuze, G., & Guattari, F., 2003). Before finding the linkage between "**Body Extension**" and "**Body Without Organs**", it is crucial to have a brief and generic understanding of the notion proposed by Gilles Deleuze and Felix Guattari. "**Body Without Organs**" shouldn't be literally interpreted as an organic body. In fact, it represents a concept which has no hierarchy, is not organized, and has no rigorous system similar to schizophrenia and tries to break the existing and ingrained mortal dogmas. While talking about "**Body Without Organs**", it is undoubtedly necessary to mention the concept of "**machine**" or so called "**desiring machines**" at the same time. Gilles Deleuze and Felix Guattari claimed that **everything is a machine** and some of them can produce a certain kind of **flow**, such as milk, thought, and energy. If accepting the idea of everything is a machine as a premise, then basically, they claimed that there should not be any distinctions between nature and industry, and man and nature. Because it's all about the concept of "**produce and products**". For example, a cow produces milk, as well as a meat-machine, produces sausages. According to the notion of **machines** from Gilles Deleuze and Felix Guattari, there must be another linkage machine connecting to the flow-producing machines to interrupt or draw off part of this flow. (For example, the breast is the flow-producing machine, the milk is the flow, and the mouth of the baby is the connecting machine which absorbs the milk and converts the milk into another form). Within the capabilities of connection, these machines are able to link themselves to the body without organs. In fact, the body has to connect with a certain desiring machine to keep it alive. This is beautifully illustrated by the painting: "**Body with Machine**" drawn by Richard Lindner, as an example taken by Gilles Deleuze and Felix Guattari in their article. Until now, it seems that there are various possibilities of direct connection between **desire machines** and the **Body Without Organs**. However, a gradually changing process and subtle relationship build up in different phases between the **desiring machines** and the **Body Without Organs** where the ultimate linkage to Marshall McLuhan's **Body Extensions** can be found in the following article: "Body without Organs". First, an apparent conflict arises because the **desiring machine** (an **organ**) tries to invade and break into the "**Body Without Organs**" which attempts to repel it. Afterwards, according to the article, "**in order to resist organ-machines, the 'Body Without Organs' presents its smooth, slippery, opaque, taut surface as a barrier**". Then, in the next phase, the "**Body Without Organs**" transforms itself into a smooth surface, recording the entire process of desire productions from each machine, thus forming a more intimate relationship between **desiring machine**(**organ**) and the "**Body Without Organs**". Eventually, "**...machines attach themselves to 'Body Without Organs' as so many points of disjunction between which an entire network of new synthesis is now**

woven, marks the surface off into co-ordinates, like a grid…no matter what two organs are involved, the way in which they are attached to the 'Body Without Organs' must be such that all the disjunction syntheses between the two amounts to the same on the slippery surface". (Deleuze, G., & Guattari, F., 2003) (Figure 1). To briefly summarize here, the "**Body Without Organs**" in the end becomes a smooth and slippery surface attached with all **desiring machines** (**organ**) which equally distributes onto the surface (the **Body Without Organs**) with no hierarchy and order.

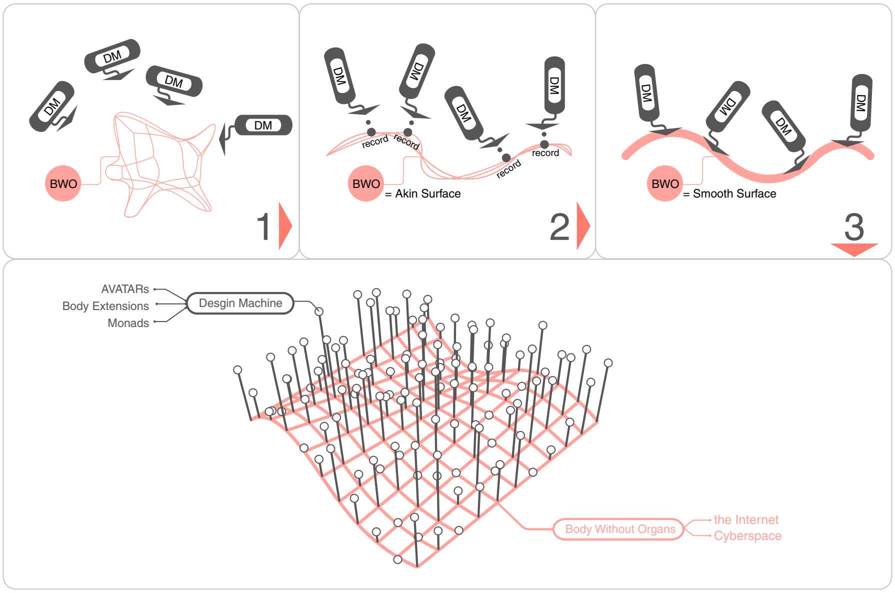


FIGURE 4.1 Diagram outlining the process of relationship changing between the desired machines and the Body Without Organs from left to right and to the bottom. DM = Desire Machine, BWO = Body Without Organs. Body Without Organs initiates with the action of repelling the Desire Machines but ends up morphing as a slippery smooth surface attaching with them as a boundless network.

After this process, a comparison can be made between the notion of the "**Body Without Organs**" not only with the "**Body Extension**" but also with the idea of "**Monadology**". **Desiring machines** here are transformed as monads that Gottfried Leibniz proposed in his Monadology (Leibniz, Monadology, 1714) which makes each **desiring machine** have equal impact and influence onto the ultimate grids/surface, the network of the "**Body Without Organs**." It might be difficult to understand with these philosophically abstract concepts, but within the content of the Internet, it can be relatively easy to explain. In a sense, the Internet is the new version of the "**Body Without Organs**", with people who connect to it acquire the form of the **desiring/organ machines**, and, the gadgets, servers, or other devices which are able to have connections to the Internet can be interpreted as **machines**. Then, regardless of how small an impact it would make, all the "things" connect though the web of the Internet, the **Body Without Organs**, will absorb the forces passing through the Internet surface. Referring back to the **Body Extensions** idea of Marshall McLuhan, under the context of the Internet, the technology/**Body Extensions** make people connect to the Internet which can be interpreted as a **desiring/organ machine** interplaying between other's body extensions. Under this pre-assumption, **Body Extensions** as **desiring/organ machines** can cling ubiquitously to the surface transformed from the **Body Without Organs** and blending the identification of the you and others, which means you might not be able to find your own Body Extensions since it will become more neutral than ever but you can still feel the influence from one another.

Another alternative interpretation can be related to the key notion of the "**Body Without Organs**", which is the attribute of "**schizophrenia**". Within the network of the Internet, people can easily have different identities with different characteristics as their **AVATAR**s. A male can easily pretend to be a female figure in an on-line game to fool people; a lower level employee can create a character living in the upper-class level to fulfill his/her implicit desire, etc. This is quite a common phenomenon with most of the people living in the current Internet era. In other words, people are revealing various attributes of their explicit personalities to somehow express their hidden emotions or satisfy certain desires from their not-too-successful lives. This phenomenon already classifies and qualifies people to be considered, "**schizophrenics**". One more quote from the section of "the Body Without Organ" in the publication of the "***Anti-Oedipus***" (Deleuze, G., & Guattari, F., 2003), **"...the surface of this uncreated body swarms with them, as a lion's mane swarms with flea**", and also consider the quote from Henry Miller in the introduction of the "***Anti-Oedipus***" by Mark Seem, "**We must die as egos and be born again in the swarm, not separate and self-hypnotized, but individual and related**". Once again, it refers back to Leibniz's philosophy of Monadology to treat each existing object/machine assembling with a simple substance, which matches not only the center stage of the "swarm" in nature but also the kernel idea/principle of this research. **"...a body without organs, like a spider poised in its web, observing nothing, but responding to the slightest sign, to the slightest vibration by springing on its prey**" (Deleuze, G., & Guattari, F., 2003). Each of us, as an individual could be the prey, or the substance falling on the web to make vibrations in order to create a synthesis impact to the spider (the **Body Without Organs**), but multi-directionally, the spider (the **Body Without Organs**) or the interrelation between each individual object can also influence with each other simultaneously, akin to a swarm of agents to create a collective intelligent-like creature from bottom up.

§ 4.2 You are in a Virtual Reality more frequently than you know

= Where the idea of interaction narratives has been initiated.

Virtual Reality as a terminology is connected with specific technologies with the help of which, artificial virtual environment can be exhibited either on a screen or through a glass-like device to make people experience a tangible journey where they think it is "real" like being in a parallel universe. But somehow, human beings have the imaginative capability to create their own virtual reality without any assistance from high-end wearables or simulating technological devices. For example, you must have had the experience of waking up with a nightmare which you almost felt was real. In this case, while people are dreaming, they are witnessing a virtual reality via their unconscious mind. A similar effect is felt while taking hallucinogenic drugs or while experiencing déjà vu. Each of the above examples is conditions that cannot be controlled and manipulated by our conscious mind. Another virtual reality example without technology involved or which can be controlled is "reading". **"...reading requires the mind to develop the visualization process as 'imagination'"** (de Kerckhove, 2001). After years of "training", not only a mysterious inner subvocalization voice will come out while reading a text, a sequence of images like a video recording can be created through the borderless imagination, which is an individual and unique virtual reality experience of one's own. While reading a fiction or a novel, such as "***Harry Potter***" or "***Alice's Adventure in Wonderland***", people set their imagination free to go along with the storyline created by the author and interpret the narrative with their own imagination based on their life experiences. Or novels like "***Sherlock Holmes***" will bring you back to the Victorian period in England, looking for evidence or testimonies and trying to figure out and reveal the truth of the story. Although "**the author is dead**" claimed by French literary critic and semiotician, Roland Barthes (Barthes, 1968), readers can in a sense find their own ways of realizing each narrative they read as a creative immersion through their mind. Kerckhove's in his publication, "***The Architecture of Intelligence***", states, "**As readers, we learn to represent and internalize the visual field by repeating it in our imagination. It is because of this simple process that quite literally, we 'make up our mind'.**" This mind is equal to the "**Mental Space**" described in the same publication, which has been further explained as a private, silent, personal, totally individualized visualized universe devoted to imagination and thought (de Kerckhove, 2001). Therefore, to a certain extent, can it somehow be interpreted that these inventive immersions are virtual reality experiences co-created by the authors and the readers? In the section of "**Literature and Virtual Realities**" of the publication "***On Literature***" the influential literature theorists, J. Hills Miller, writes that "**Right reading is an active engagement. It requires a tacit decision to commit all one's power to brining the work into existence as an imaginary space within oneself**"

(Miller, 2002). Hence, reading is quite private but requires an active manner to engage exactly to match with the aforementioned idea of "**Mental Space**" by Derrick de Kerckhove. In "**On Literature**", J. Hills Miller also tried to explain his observation of the connection between literature and virtual reality. "**Literature seizes me and carries me to a place where pleasure and pain join. When I say I am 'enchanted' by the virtual realities to which literary works transport me, that is a milder way of saying I am enraptured by reading those works**" (Miller, 2002). If simply replacing "literature" to "VR (virtual realities)", every single sentence can still remain valid. Long before the visual environmental technologies and the terminology had been invented, people had already known how to "project" themselves into an imaginary universe/world with literature and games by using their minds, in the "**Mental Space**". It's clear that **Mental Space** has similar effects but comes internally from people's minds, which is totally private and subjective. **The essential difference between "Mental Space" and "Virtual Reality (or Cyberspace)" is that the former one is made up by our minds with daily experiences which are extremely personal and the latter is an artificial product usually created by a third party which is comparably objective.** Within present technology development, people still cannot read each other's minds or copy and reproduce it. But VR(Cyberspace) is meant to be created as a repeatable product for more people to experience. You might argue that people can have individual experiences through the pre-set VR environment, but objectively, the invented environment remains the same for every participant to engage in. Nowadays, the ultimate goal and challenge for current VR simulation are to go beyond these unique imaginary immersions within mental space and to make an improvement to the "**tangibility**" aspect by implementing contemporary visual and sensing technologies. Having the assistance from different aspects of the current advanced technologies, the VR system can be more solid and to a certain extent bring one to a parallel universe/world with relatively more sensitive and accurate perception. **It is quite obvious why people intuitively tend to connect with interactivity using VR technology since this enables an entire immersive artificial environment which can fully embrace people to promote active engagement in real-time. Without interactivity, the VR system will work just as a film or TV program, which is relatively passive in terms of engagement akin to cold media defined by Marshall McLuhan.**

While speaking about VR (Virtual Realities), "Cyberspace" is the term that cannot be ignored. "Cyberspace" was coined by the well-known "cyberpunk"/science fiction author, William Gibson, first in his short story "***Burning Chrome***" in 1982 (Gibson, Burning Chrome, 1982), but later in 1984 in his novel "***Neuromancer***" (Gibson, Neuromancer, 1984), it gained extremely unprecedented popularity.

"Cyberspace. A con sensual hallucination experienced daily by billions of legitimate operators, in every nation, by children being taught mathematical concepts ... A graphic representation of data abstracted from the banks of every computer in the human system. Unthinkable complexity. Lines of light ranged in the non-space of the mind, clusters and constellations of data. Like city lights, receding...."

In "***Neuromancer***", William Gibson abstractly defines the meaning of Cyberspace. It is now extremely easy to understand if one replaces the word "Cyberspace" with "the Internet". At present, Cyberspace somehow is identified as a term representing on-line computer networks. Cyberspace had already been seriously taken as an actual space according to Anna Cicognani's five criteria to qualify "spaces" (Cicognani, 1998), which are: 1) possible interactions; 2) livability or occupy-ability; 3) a community-building capacity; 4) time management; and 5) space management opportunities. Cyberspace, in the form of Internet networks, can easily fulfill all of these criteria. Even simply considering Cyberspace as an on-line game like "Sim-City", people can, 1) definitely interact with each other; 2) buy a virtual house and have a second virtual life; 3) set up connections within social communities based on your personal habits; 4) schedule personal timeline compatible with your identity; and 5) even arrange space as virtual real estate through trading behaviors. Cyberspace creates an alternate universe where people can do all the activities in parallel to the actual world. Michael Benedikt, the author of "***Cyberspace: The First Step***" (Benedikt, 1991) states "**...with cyberspace, a whole new space is opened up by the very complexity of life on earth: a new niche for a realm that lies between the two worlds. Cyberspace becomes another venue for consciousness itself...**" claiming a brand-new world with at least 2 parallel universes that people have to engage and deal with. In another publication, "***V01D***" (Anders, 2001), which mainly discussed the topic of current digital space with the relationship to the network of the Internet, Peter Anders expressed his prediction of how Cyberspace will influence daily lives of humans if they understand technologies as sensory extensions, "**...we are increasingly dependent on such technologies to sustain our social cultural reality. They are part of being human in our time**". Since the Internet and World Wide Web were invented, humans have no capability to cease this inevitable trend and must start enjoying surfing on it. The fact is exactly the way how Peter Anders described: **this task of dealing with Cyberspace is a part of being a human at present.** This network of systems is everywhere you can imagine, economics, social communication, education, politics...etc. Cyberspace has reached a level of maturation that humans cannot ignore and one has to not only live in a materialized physical space, his/her own mental space with imagination, but also this network-like virtual reality space. Therefore, it makes people begin to explore ways in which one can integrate the virtual and physical universes. Before starting this topic, it is imperative to be more explicit and distinguish the essential difference between Cyberspace and Virtual Reality.

Cyberspace:

A network system, the current existing representation is the "Internet service". It is a Virtual Reality in a sense that people can project themselves and have multiple identities as AVATARS on-line. Through the screen and the Internet cable, people can basically navigate to each and every single digit/bit of the global Internet system.

VR (Virtual Reality):

A tactile and tangible environment creative with computer technology to invoke human's sensory system in real-time. It can either simulate existing surroundings or create a fantasy experience for people to examine and make people temporary enter an alternative universe by the constant electronic impulse to challenge human body senses.

A global networking system such as the Internet, which creates a relatively abstract virtual environment mostly through human sensory spectrum, where VR interprets senses more related to a local bodily perception, creating an engulfing experience and gives human sensory systems (with all senses) an immersive stimulation. In fact, the tasks for the spatial designers is even more crucial, namely, to find the connectivity between "virtual" and "actual", and to strengthen the relationship between "VR" and "Cyberspace".

An undivided relationship has been set up between physical and virtual space which had earlier been neglected. As Margret Wertheim pointed out in her publication, ***"The Pearl gate of Cyberspace***" (Wertheim, The Pearl Gate of Cyberspace: A History of Space from Dante to the Internet, 1999), "**Ironically, cyberspace is a technological by-product of physics. The silicon chips, the optic fibers, the liquid crystal display screen, the telecommunication satellites, even the electricity that powers the Internet are all by-products of this most mathematical science...**". Obviously, Cyberspace cannot stand alone without the support from all the prerequisite hardware devices. From the notion of the "**Body Extension**" point of view, humans expose themselves timelessly under the boundless information web, they might even unconsciously make connections to = Cyberspace as extending their nervous system without awareness. For instance, it has become quite common that with portable electronic gadgets, such as smartphones and tablet with their "WIFI" on, they can access to the surrounding Internet connection without explicit awareness. Suddenly, these portable gadgets, metaphorically/eventually connect to humans' bodies as new sensory organs pervasively searching for ways to connect to the holistic web-weaving Internet, the Cyberspace. A theoretical concept of "**Hyper-Body**" (Lévy, 1998) proposed by Pierre Levy can be introduced here, which refers basically to two aspects of this notion. From one aspect, it can be interpreted that humans literally transplant a new organ to replace one of the organs of the bodies of flesh, and the new organ can be biologically natural or artificially made. The purpose of the transplant surgery varies depending on each case, either to replace the ruined organs to repair it and retain the function of the bodies, for example, prosthetics, artificial hearts, or the devices like hearing aids; or to enhance and strengthen the sensory perception of the organs, such as telescopes and telephones. The other aspect is describing a notion of how humans plug into the Internet system and enhance and accelerate their capabilities and speed of acknowledgments and communications, which also makes the human body a hybrid "**Hyper-Body**" (Lévy, 1998) not a pure biological body. In other words, it can be said boldly that most of the humans are in a sense becoming a hybrid species, the "Cyborgs" which will be discussed later in this chapter. Another interesting idea called "**Global Communications Skin**" was raised by the experts in Bell Laboratory who made a prediction for 2025 back in 1999[30]. Their president Arun Netravali described the essential notion of this "**Web-like Electronic Skin**". "**We are already building the first layer of a mega-network that will cover the entire planet like a skin. As communication continues to become faster, smaller, cheaper and smarter in the next millennium, this skin, fed by a constant stream of information, will grow larger and more useful. That "skin" will include millions of electronic measuring devices - thermostats, pressure gauges, pollution detectors, cameras, microphones - all monitoring cities, roadways, and the environment. All of these will transmit data directly into the network, just as our skin transmits a constant stream of sensory data to our brains**". He simply suggested a skin-like network composed of constant data streams with all connections to the available device which provided data will cover the whole world. It is exactly akin to Gilles Deleuze and Felix Guattari's concept of "**Body Without Organs**" (**Global Communication Skin**), which initially cannot resist the desiring machines and eventually transform into a slippery and smooth surface accepting the connection from all desiring machines (electronic devices) as a network extremely influencing with each other by the desiring flux (data stream) passing through. This is probably the reason why the Spanish socialist, Manuel Castells, who specializes in the information society, communication and globalization stated that "**The global city is not a place, but a process**". With the assistance of this boundless Cyberspace, there is nearly nowhere that information cannot reach.

Until now, the concentration is more on the abstract surface of the Cyberspace at a global level which cannot be reached and touched. It is time to shift the discussion towards the tangible surface of Virtual Reality looking for the solution of connecting the physical and virtual, and especially for interconnecting Cyberspace with Virtual Reality. Although there's definitely a certain degree of interactivity within Cyberspace, Virtual Reality can literally stimulate a human's(user's) sensory organs and in an immersive

30 The whole paragraph of the "Global Communication Skin" prediction by Bell Laboratory in 1999 can be view with the link provided here: http://seclists.org/interesting-people/1999/Nov/56

environment, which, people can physically experience in real-time. The relationship between the user and the computer has been established since the time graphical displays and data visualization were initiated with the first personal computer, which, can also be considered as the birth of Virtual Reality. When Ivan Sutherland first demonstrated his pioneering computational tool for 2D/3D graphic design on screen with his magic light pen (similar to the stylus idea nowadays)[31], the interactivity between the physical and the virtual had been unconsciously realized. With his light pen as an input device, he could create points, make the line between points, even generate 3D primitives spinning in virtual space displayed on the 2D screen. This was an intuitive way of drawing and had real-time responsive interaction. After years of development, the input devices shifted to something everyone is familiar with: the mouse and keyboard. The whole operation system also became a graphic interface which was comparable to the mouse and keyboard. The keyboard was implemented earlier, much before the graphical user interface had been developed maturely. The mouse, which came later, attained a leading role owing to its intuitive navigation properties. Since then, people became eager to look for more tangible, flexible and intuitive user interfaces. **"…as we project mind and hand into screens, we are shifting from visual dominance to a tactile one**" (de Kerckhove, 2001). The mouse brought the sense of touching into Cyberspace or VR environment which enhanced people's engagement together with the vision and auditory senses. That is why Derrick de Kerckhove stated that "**…the mouse and the pointer (as like a direct extension of the eye) connection on the screen like a hand and the external mind digging, grabbing, pushing, replacing, removing and allowing a concrete operation followed closely by the eyes and the mind of the user. It is like touching idea**" (de Kerckhove, 2001). Referring back to Marshall McLuhan's theory of imbalance of human senses which are highly focused on the vision in the television era, VR (Virtual Reality) intended to address other human senses to bring the sensory balance back, for example, the multi-touch screen. The "Digi" of the word, "Digital", means "finger" in Latin which made it an interesting embodiment and connection between the technology, terminology, screen and the finger. It is either to say these devices bring the senses back, or these devices enhance senses as body extensions or embodiments. Although most of the people deny the notion that they are actually a true "Cyborg" now, but somehow with all of these portable and wearable devices as body extensions, the human is not anymore, the ones fighting against the world with their bare hands and feet. Eventually, the

31 A light pen detects a change of brightness of nearby screen pixels when scanned by cathode ray tube electron beam and communicates the timing of this event to the computer. Since a CRT (cathode ray tube) scans the entire screen one pixel at a time, the computer can keep track of the expected time of scanning various locations on screen by the beam and infer the pen's position from the latest timestamp: https://en.wikipedia.org/wiki/Light_pen

second definition of "Hyper-Body" by Pierre Levy has been fully demonstrated here. The first definition of "Hyper-Body" on one hand has been realized by differently abled or elder persons. But on the other hand, an Australian performance artist, Stelarc, seems to process himself into a literal "Hyper-Body" by experimenting with his body of flesh. All his projects push the limitations of the human body. His first well-known project is called "***Suspensions***" in 1976 which he did a couple of retro versions, and the latest is in 2012. In this project, he suspended his body from various apparatus by meat hooks embedded in his skin to test the durability under stress of the body. Then, he started to attach himself with electronic cables, the mechanical motorized structure as a "***Third Hand***" (as the project's title) to make himself as a combination of body and machine, and to see how to establish cooperation between the two. Stelarc tried various body experiments as his projects including swallowing capsule like sculptures and detecting the result by medical endoscopy or transplanting a cell-cultivated flesh with synthetic biological technology onto his left arm. One can say that Stelarc has a "Hyper-Body" or even has even become a total "Cyborg". He attempted to raise the issue: "**within advanced technologies, is there still a boundary between man and machine, virtual and physical body**?" in a relatively radical way, which he apparently responded to negatively. "**Technology is not only attached but is also implanted. Once a container, technology now becomes a component of the body…It is no longer of any advantage to either remain 'human' or to evolve as a species… Once technology provides each person with potential to progress individual in its development, the cohesiveness of the species is no longer distinction but the body-species split**" (Stelarc, 1995). At present, all humans should be considered as "Cyborgs" without awareness. It is only a matter of the proportion of technological attachments to the flesh body either holding in their hands or embedded into the human biological body. In the end, humans will inevitably become cyborgs and it's only about the degree of how addicted one will be to utilizing the technologies as one's body extensions.

After years of development, wearable technological gadgets like touch screens, movement detecting controllers, motion tracking devices, sensor gloves, optical displays such as Google glasses, and VR glasses or head-mounted displays …etc., have gradually threatened and replaced the common sets of input devices of the computer which used to be the screen, keyboard and mouse. To setup a VR environment, you need to have required software installed and animation(game) embedded (or streaming from the central computer) to the head mounted display device, then one can immediately start a VR journey with one's body senses connected to electronically controlled devices. Adding sophisticated devices, such as movement detecting controllers, motion tracking devices, or sensor gloves, to extract physiological data feedback to central computers can be harnessed for generating real-time visualization such in a game like setting. All devices basically transmit electronic impulses to create sensory stimulations a central machine. This kind of electronic circuit loop is akin to how the nervous system works in the human body. The nervous system is like a network of fibers omnipresent inside or attached to the human body. Performance wise, neuron cells can be categorized into Afferent(Sensory) neurons which convey the information and send to the central nervous system; Efferent(Motor) neurons which transmit the signal from the central to the effector cells to trigger movement; and Interneurons which connect neurons within specific regions of the central nervous system[32]. Basically, the natural routine of the nervous system starts with stimulation from the environment, senses through the afferent neurons, and transmits the information through interneurons to the central nervous system for judgement, eventually sending out the signal again through the interneurons to the efferent neurons to inform and trigger the required muscles or glands. Regardless of which kinds of neurons, they have to use the electronic impulses generated to transmit the information. This is the core principle behind the current advanced technologies of prosthetics that can link the artificial eyes, ears, arms or legs to a physical body and be freely manipulated by the differently abled person. Through the electronic impulses, the stimulation signal can be generated to make blind people see and deaf people hear. The electrical loop has literally passed through both the artificial and organic organs to create perceptions and trigger reactions. It's the brain which creates "feelings", making us human. Although the brain is a distributed networking system, which, can summarize an emotional sense of human feelings. Ideally, through the nervous system the brain enjoys sophisticated manipulability with external circuits of electricity, so one can mimic "**REAL**" feelings. Of course, this can also be claimed as a milestone of crossing/blurring the boundary between virtual and real. But the catastrophe of this scenario can also happen simultaneously, as the stimulation from the external electricity can accessible carry out a virtual universe for each individual person who believes this is an actual existing universe. Feelings and emotion can still be true in a virtual reality; it does not mean that the emotional senses in a "virtual" world are equally fake/artificial. Nor does such a Virtual World necessarily entail or alleviate alienation.

In his publication, "***Bergsonism***" (Deleuze, 1988), Gilles Deleuze stated that "**...the possible is the opposite of real, it is opposed to real, the virtual is opposed to actual... The possible has no reality; conversely, the virtual is not actual, but as such possesses a reality**". It should be less complicated after the interpretation here: if possible and real are in the same category representing the degree of reality, then virtual and actual are in another category labeling the degree of actuality. Virtual is not in the same category of real. Therefore, it is real but not completely actual. Furthermore, if another word, "materialized", replaces the term "actual" in the sentence, then it can clearly

32 Please check the webpage for more information and clear understandings about the neurons: https://en.wikipedia.org/wiki/Neuron

be concluded that "virtual is real but not completely materialized." We might find it difficult for the former generations to understand, but it is quite reasonable for the young generation who were born and raised in a digital age with their common senses. The intimate relationship you set up with your friends through the social media, the war that you fight against the orcs with your partners to win the victory, the bankruptcy of your virtual company when you've been cheated by your biggest opponent...etc., these can all be very true feelings and real experiences in terms of being in the Virtual world, but it is not materialized yet in a physical world. But since the Virtual engulfs more and more proportion of one's life, the "virtual" event can easily have "real" impact where you live. For example, the physical currency for paying the registration fee of the social communication networks and buying those virtual properties, weapons, and arms in the game is the perfect case of illustrating this circumstance crossing both the virtual and the real world that has to be confronted regardless of where you are physically present.

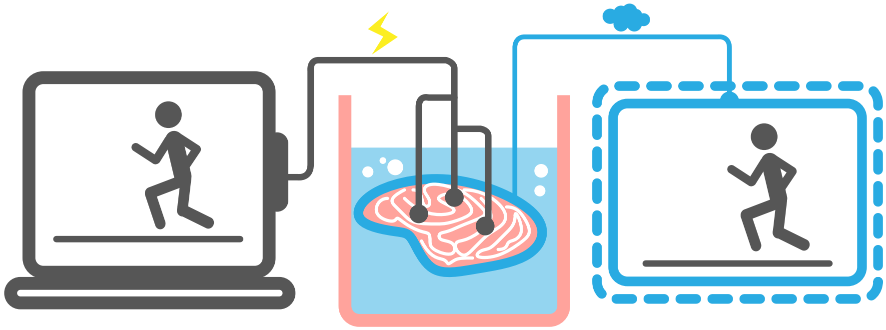


FIGURE 4.2 A diagram illustrating the conceptual idea of "Brain in a vat".

From another aspect, referring to the aforementioned electronic circuits which can to a certain extent be implemented in simulating the electronic impulse to stimulate the brain to generate all senses of humans, which is also extremely virtual, it makes the body totally useless but makes the brain sink/engage into an artificial universe and believe they are vividly living. This kind of hypothetical narrative is fully related to the theory of "**Brain in a Vat** (or Brain in a Jar)" (Figure 4.2) which has been applied to many Sci-Fi movie scripts. The most famous and popular example is "***The Matrix***"[33] series.

33 Please check the webpage for more information about the Sci-Fi Film, the Matrix: https://en.wikipedia.org/wiki/The_Matrix

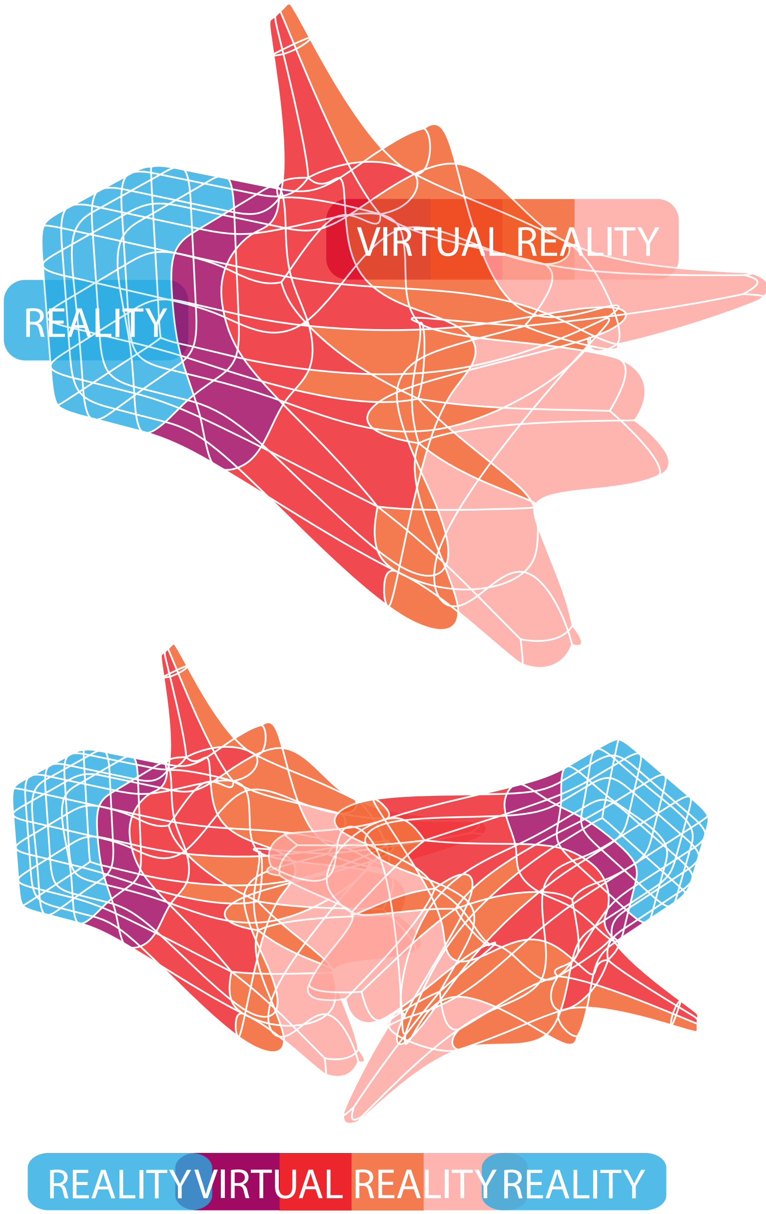


FIGURE 4.3 Diagram exhibiting the idea of space that in current condition has blended the virtual and the reality as a whole. In other words, there is no sharp boundary between VR and Reality within the omnipresent Internet.

“**Brain in a Vat**” is a theoretical hypothesis raised by the American philosopher, Gilbert Harman. It outlines a scenario where a mad scientist (machine, or other entity) takes out the brain from a body and suspends the brain into a vat of life-sustaining liquid. Afterwards, the neurons of the brain are connected to an extremely advanced computer which can provide electronic impulses identical to those the brain normally receives and simulate a “reality”. The brain in the vat without the original body of flesh’s physical container would constantly have access to the conscious experiences of those people who have their brain embedded [34]. In other words, even though the brain is in the body, with the constant electronic impulses provided as normal, the supercomputer can simulate reality as long as the body stays in a condition of life or being alive. This is a truly virtual life. In the movie “***The Matrix***”, most of the humans were ruled by AI (Artificial Intelligence) machines. These machines keep the biological human being alive with surviving-liquid in a capsule with cables attached to their brain simulating reality in order to gain the energy they need from those “cultivated” bodies. Most of the humans don’t know about this “reality” because they are enclosed and fed by the electronic impulses to make them believe they are alive. A series of nine extraordinary animation films, called “***The Animatrix***” including four stories written and produced by the director of “***The Matrix***”, the Wachowskis (Lana & Lilly Wachowskis), detailed the backstory of the Matrix universe. And one short animation film, “***World Record***”[35], created by Madhouse and directed by Takeshi Koike, with a screenplay by Yoshiaki Kawajiri, gave an explicit example of a “**Brain in a Vat**”. It is a story about a track athlete, Dan Davis, who set the 100 meters’ world running records in 8.99 seconds, but his subsequent gold medal was revoked for drug use. He anxiously wants to prove them wrong by competing again even with the possibility of a career-ending injury. Nevertheless, after a strong start, the muscles in his legs violently rupture, but with his incredible willpower, he ignores the injury and runs even faster than before. Suddenly, he sees the “**reality**” with numerous capsule-like pods, and he is in one of them and tries to rip off the cables plugged into his physical body. The machine around him pulls him back and gives him a violent shock of electric restraints to connect him back to “the world” (virtual/Matrix) in which he lives. Eventually, he does break the world record in 8.72 seconds, but his body cannot bear the high speed and makes him a differently abled person with a wheelchair. It is not now known if in the near future “***the Matrix***” like universe will emerge, but it is cogent to remind people that with current advanced wearable gadgets plugging into our body, and pushing it

34 Please check the webpage for the general theoretical description of “Brain in a Vat”: https://en.wikipedia.org/wiki/Brain_in_a_vat

35 Please check the webpage for more information about “The Animatrix” and “The World Record”: https://en.wikipedia.org/wiki/The_Animatrix

to extremes, it is possible to end up like living brains with abandoned bodies which can live forever. This is not, and must not be, the ultimate result of Virtual Reality. From the interactive point of view, it is even more fascinating and attractive to create a universal space including the actual and virtual world. "**We are entering an era of electronically extended bodies living at intersection points of the physical and virtual world,**" said William Mitchell, who pointed out the current conditions we are beginning to confront. Marcos Novak stated that "**it is possible to envision architecture nested within architecture**". The two architectures here relate to the physical and virtual spaces, which should be blended and fused into each other as a whole (Figure 4.2). As a result, there are two major topics for interaction at this time for the spatial designer to carry out: 1) Designing ways of setting linkages between virtual and real to become one integrated universe; 2) Creating multi-directional and sensory bodily interaction more akin to Marshall McLuhan's concept of hot media. Basically, the second topic could be the solution for the first topic, which makes the tasks concentrate on the notion of bodily interaction. The tragic outcome of "the Matrix" universe is alienation because there is no true interaction engaged within the Cyborgs. Most of the scenes are pre-set before experiencing them by the signals generated and sent from the Matrix, even the interaction is set by a program or lines of code. According to Marshall McLuhan, this accounts for cold media, which is the same experience as watching a movie. To prevent the future scenario of choosing the "red pill or blue pill"[36], it is crucial to shift the development of Virtual Reality toward a more intimate and tangible interactive scenario by intensively and actively utilizing all senses and full body movement. Fortunately, some contemporary projects are engaged with combining Virtual Reality and actual physical environments.

2016 is called the year of "Virtual Reality". "**Pokémon Go**", an augmented reality mobile game, just revealed its first release. Similarly, many on-going projects are also being developed with mounted headsets for Virtual Reality environments and are on their way to launch their products. An interesting observation is that some of the projects have already considered the marriage of physical and virtual space. For example, Samsung partnered with Six Flags amusement parks to build the first roller coaster where people have to wear VR glasses. While wearing the VR glasses on the roller coaster, the vision will calibrate with the physical environment but display unexpected surroundings, such as future cities with aircrafts passing by and attacking; By-products

36 The idea of "Red pill and blue pill" is derived from the line in the Sci-Fi movie, the Matrix. It happened while Morpheus was providing a chance for the main character, Neo, to escape or confront the real world by taking different colored pills. The red one represents the painful truth while the blue one means the illusion of ignorance. Please check the webpage for more detail information: https://en.wikipedia.org/wiki/Red_pill_and_blue_pill .

of the VR, such as **Virtrix Omni** and **Cyberith Virtualizer**[37], are physical motion platforms allowing players to conduct reaction like walk, run, jump and turn freely in every direction in a small footprint of area to create immersive gaming experience; "**The Void**"[38] is a 20-minute virtual reality journey in a 60 by 60 foot stage filled with dense foam walls as obstacles, and replete with effects like water and wind, which opened in Utah, in August of 2016. Multiple players wear VR mounted headsets with headphone embedded, arms with sensors, and a vest with hefty computer and batteries, while actively navigating and interacting by shooting zombies in a virtual temple inside of the physical environment which has a radio-frequency system for motion tracking. This is how Ken Bretschneider aims to marry the virtual and real through the game settings of "**The Void**". In this case, the Virtual Reality performance is like a decorated makeup of the physical space. On the contrary, the tangible physical objects enhance the immersive experience of the Virtual Reality. Such developing projects show proof that people are not satisfied with only a passive virtual reality experience, and they want to engage and be in the narrative to interact either with the environment or other people in Virtual Reality. It is not anymore like the scenario of VR rooms shown in the movie "***Minority Report***" where people lie on beds with sensor suits passively receiving and interacting with the visual effects as if watching a video[39]. Certainly, this is not the expectation people want from Virtual Reality in the future, people want to be "**in**" the movie, not just "**watching**" the movie. That is the obvious reason why computer games like to visualize their narrative perspective in the first-person perspective. In the same movie "***Minority Report***", there is the unforgettable scene where Tom Cruise, sophisticatedly moves his fingers controlling the transparent screen-like interface of the future computer showing other ways of interaction in life and space. It implies a way of communication besides the conventional triangle of the mouse, keyboard, and screen, or even a Virtual Reality interface, but embodying a relatively more bodily engaging possibility. This can be seen as a hint to escape from the phenomenon of the "**Brain in a vat**", and it simultaneously brings the balance of human senses while simultaneously enhancing the intimacy of the virtual and real. From another perspective, Google has invested more than 540 million US dollars in the company Magic Leap for developing hologram VR display without wearable devices to take

---

37 Please check these 2 webpages for more information about the physical motion platform of Virtrix Omni: http://www.virtuix.com/ and Cyberith Virtualizer: http://cyberith.com/product/.

38 Please check this webpage of MIT Technology Review reporting the information of "The Void": https://www.technologyreview.com/s/544096/inside-the-first-vr-theme-park/ , or check their official webpage for more information: https://thevoid.com/.

39 Please check this clip extracting from the movie, "Minority Report", on YouTube about the "VR Room" idea: https://www.youtube.com/watch?v=8tjOVOSqdQ0

augmented reality to the next level which can also be seen as an advanced approach towards weaving the virtual and real together. Furthermore, it brings forth the possibility of merging the concept of Virtual Reality and Cyberspace if the technology will be carried out in the near future. People can call each other and envision their figure through Magic Leap's hologram technology without wearing VR mounted headset. A system combining global cyberspace network with local VR displays is not far out of reach. What would a future party look like? There will be half of the participants joining the party far from the other side of the planet across time zones and the barrier of physical "space". In other words, people can be spatiotemporally present at different places at the same time visually across time and space similar to the Quantum Biology concept of Quantum Teleportation. On the other hand, there will be the risk of being hacked and losing one's identity as a real person or even as an authentic AVATAR.

FIGURE 4.4 Pokémon GO is an augmented reality game where the player as a Pokémon GO trainer has to catch the wild Pokémon monsters in order to battle with other players. The innovation of Pokémon GO is that it combines augmented reality technology and the GPS system to makes players sense the virtual monsters vividly as they actually live in Reality (source: Niantic/Nintendo, http://blogs-images.forbes.com/insertcoin/files/2016/07/pokemon-go-list1-1200x682.jpg).

Regardless of how and where the advanced technology can bring us, sensory engagement is the key to keeping the human aspect of people in order to make them feel alive and enjoy "tangible Interaction". In the movie, "***Her***"[40], directed by Spike Jonze, Theodore Twombly (the main character) gradually fell in love with "Samantha", which is an AI (Artificial Intelligent) operating system of his computer. In the end, he noticed that this AI system can have relationships with numerous people at the same time, which is not specifically unique to him, and he suddenly realizes the weakness of his relationship. Along with the departure of Samantha, he confronted his relationship problems about his ex-wife with his apology, acceptance, and gratitude. And in the end, he went to the rooftop and saw the sunset with his intimate friend, Amy who also lost her boyfriend as another operating system. One of the interesting things here is that the main character, Theodore, actually fell in love with an AI "voice", which rarely happens in any interpretation of novels or movies. And the other crucial point is that it foresaw a phenomenon of having an intimate relationship with a "virtual" system, with "real" feelings but somehow challenging the definition of "humanity". This, however, is happening, people are fascinated with developing artificial intelligence, machine learning, and quantum computing to improve computational speed and create human-brain like neuromorphic devices. For example, in the Google annual IO conference 2016, they revealed their own chip, the **TPU** (tensor processing unit), which is specific for deep neuron networks of hardware and software to learn specific tasks by analyzing the vast amounts of data. And they implanted it in **AlphaGo** to compete with one of the best professional Go players, Lee Sedol, in Go matches. If we keep concentrating on developing machine learning cooperating with neural network systems, then operating systems like Samantha in "**Her**" is not an unreachable goal in the future. Therefore, it is crucial to keep to our true self by keeping in touch with "real" people in whatever mediums we encounter whether physical or virtual. There is nothing wrong with virtual reality or technology or even AI, but humans have to learn how to get along with them without losing their true selves in their vague or aesthetic condition in virtual reality created by high-end technologies. Physical interactions with our intuitive sensory organs and movement could be the preventative/cue of this vague situation. If people lose their physicality and fully dive into the embrace of the virtual world, the body will eventually end up becoming useless like a shell without a soul or a brain in a vat scenario. Architects, working with such reified materialization whether virtual or real, have the responsibility to maintain not only the connections but also the balance between these two contrary universes. While extending one's body organs with technologies to plug into the body without organs network, we must be aware of our own will and consciousness to be freely hovering between virtual and real, but not

40 Please check the webpage for more information about the film, "Her": https://en.wikipedia.org/wiki/Her_(film).

to be fully amused or dissolve ourselves in the virtual, especially within the high-end technologies which can easily fool you. In other words, Virtual Reality can be seen as a starting point for implementing interactions in real space, but ultimately, it has to be the bodily interactions that keep us consciously acknowledging our own selves in the physicality of real space.

§ 4.3 From InterFACE to interACT: Merging Layers of (Sur)faces

= Architecture Skin (Realize Vitality) + Technological Glasses (Virtualize Reality):

Two layers of (sur)faces, which indicate two different scales of objects, two diverse approaches of viewing, and two kinds of interaction with the surfaces exist. One expresses the architectural skin, while the other, a wearable device, such as technological glasses; One is the outer-surface of the overall building body, the other is the screen in between the retina and the reality. One is the “Architecture Skin” which establishes a virtual interfere with reality via multiple display screens with animation running as a 3-dimensional black hole that attempts to take you to another universe. The other one, “Technological Glasses”, put a film of glass with information exhibited correlating to the human vision that tends to merge reality with the virtual, simultaneously. Somehow, these two surfaces should eventually merge into each other to create a changeable space with more intuitive bodily gestures.

First, let us have a glance at the development of the so-called “Architectural Skin”. Since architects will eventually merge the physical environment with virtual space, how can we confront the question of bringing Virtual Reality/Cyberspace into architecture? Through the common computer screens with Internet connections, space has already been plugged into the virtual world as Marco Novak said: “**Though the computer screen appears two-dimensional, it has a spatial-temporal dimension that allows it to interact with hypersurfaces created mathematically in the space of the computer**” (Emmer, 2004). Due to the Internet’s networking connections, the screen is not a simple monitor constantly displaying stop-motion graphics like television, instead, it has become real space with depth and time. Immediately capturing this surface-depth idea, the architects are eager to put their focus on the skin of the buildings akin to the fantasy scenes of city landscapes shown in Sci-Fi movies, which have capabilities for displaying graphics or animations as one of their answers as to how to marry the virtual and reality. Plenty of examples have realized such display skin ideas such as media façades in most of the world’s famous city locations, such as Times Square, New York, the Shibuya crossing in Tokyo, and the commercial signs all around Hong Kong. As a result, the skin of the building here represents a passive virtual medium (cold medium as Marshall McLuhan defined) to repeatedly transmit commercial information to people as a one-directional communication. Some architects, like Toyo Ito, want to bring the skin of the building to the next level of communication. The "**Tower of Wind**" is a silo-like technical sculpture sitting in the Yokohama railway station designed by Toto Ito as a public art. The color of the embedded lighting system of the tower's skin is determined by detecting the noise levels of its surroundings. This vital surface actively transmits the information of the noise level no matter if the passengers notice it or not, which, is akin to a cold medium but at least is initiated by a 1.5-degree communication between the building and the passer-by (Realized Virtuality). The awareness of the noise level comes from the sensors of the building which makes the skin, not merely an information deliverer but also an information receiver as well as loader. Therefore, the interaction in a sense starts between the building and the human in a relatively direct way though the message displaying on the Architectural Skins. Other examples are Al Bahar Towers in Abu Dhabi by AEDAS and Arab World Institute in Paris by Jean Nouvel. They all exhibit the light in that one is making shades to avoid direct sunlight and the other is opening holes for light penetration. Although the purposes of these two projects are totally opposite, by reading the patterns, it is immediately clear where the solar radiation is stronger which realizes information by communicating it physically through the architecture skin to the passerby.

FIGURE 4.5 Image captured from Keiichi Matsuda's animation project "Hyper-Reality" showing an augmented reality scenario in a supermarket.

TOC

Second, the technological glasses here indicate the technology akin to "Augmented Reality." "Augmented Reality" is a computerized vision correlated with the real environment through certain devices, such as cameras, special contact lenses, or see-through head mounted displays or eyeglasses like Google glasses. Basically, a layer of the transparent electronic film fits in with your vision and the true environment will display specific information at pre-set marks. Simply put, with a certain application and your smartphone's camera, you can see through the mobile screen by realizing a 3D animated object on the spot and match it to the existing environment as if it is literally there. This technology has been broadly applied in different realms of usage. In architecture, it can match the rendering effect on a real building to display the appearance when finished; in children's books, the animated characters show up through pages of markers as if you are watching a movie; in the military, useful information and potential dangers can be shown on the soldier's goggles to warn them on the battle field; or like Google's translator application that can not only translate the words but simultaneously map the results onto where the text is printed through the camera of the smartphone devices. The real-time data has been visualized and displayed on the "surface" to represent the real conditions (Virtualize Reality). Most of the applications are aiming to implement VR into daily life to assist people by exhibiting information of daily used objects, social data, and commercial advertisements as a virtual interface matching to the existing environment. If staying confined to showing information about objects, it would end up as the same as the architectural skin does for architecture, a mere information deliverer, a messenger. The interesting applications come from the idea of having a virtual interface which can control the physical objects in real-time by simple interactive hand gestures. In this sense, augmented reality shows its potential of inducing people's interactive movement. Keiichi Matsuda, a designer and a filmmaker, rendered this idealistic application with his series of animations called "**Hyper-Reality**[41]." One of the films rendered a kitchen scenario while you start entering the kitchen. In the film, with a first-person perspective, you will see plenty of commercials pop up into your eyes, and the wall above the tank just shows the episode you are watching in the living room. Afterwards, a search engine with screen and virtual keyboard shows up with hand gestures for you to search for information about making tea. Picking up a teabag on the side and putting it into the cup, tuning the temperature of the electric water boiler, you can check your status on social media by shifting the mode while waiting. He also had a version of Hyper-Reality showing how these virtual interfaces can be used in the supermarket by showing the gradient, the price, and the caloric information while you have a glance at the product. These easily understandable but effective animations

41 Please check this video, "Hyper Reality" by Keiichi Matsuda through his own website: http://km.cx/.

explicitly outline a future life with augmented reality being properly used. The bodily movements/free-hand gestures manipulate the virtual interface, in a sense, builds up an interactive relationship between our physical body and virtual environment correlating and matching back to the existing space.

FIGURE 4.6 A simulation image showing the navigating process by free-hand gestures with the sensor of "Soli" developed by Google ATAP (source: Google ATAP Soli project, https://2pobaduekzw9jt9a-zippykid.netdna-ssl.com/wp-content/uploads/2015/10/google-project-soli.png)

Not only is there extensive work underway on the improvement of Augmented reality, there are also quite a few emerging technologies looking for more intuitive and bodily movement as communication interfaces, which are implemented mostly in wearable devices as interfaces. For example, it is not news that Google has produced the Google Glasses along with augmented reality technology, but they also formed a group called ATAP (Advance Technology and Project) to draw attention to developing innovative devices with technologies. One of the projects utilizes radar detective technology, called "**Soli**". "**Soli**" is a sensor device which can analyze sophisticate hand gestures to replace the performance of a physical knob, button, slider, to create a virtual dial manipulating physical devices, such as alarm clocks, radios or watches[42]. Not only that, they also cooperated with world famous jeans brand, Levis, to develop a smart jacket, "**Jacquard**", which fuses into your daily life combining with the smartphone devices to either assist you with the direction of your destination, mixing companion music, or cancelling a phone call while you are biking on the street by simply touching the sleeve of this smart jacket[43]. This kind of bodily interaction is what should be retrieved, maintained, developed, and applied to our interactive environments. Furthermore, the responsive reactions to the surrounding environment are where most of the architectural interactive skins are carried out, but somehow the tendency of the interactions seems to draw more on users' requirements than before. "**Recently processors and sensors have shifted from strictly looking at environmental conditions outside the building and performance based aspects of the understanding and monitoring the changing needs of the users of space**", as cited from "***Interactive Architecture***" by Michael Fox and Miles Kemp (Fox, Michael, & Kemp, Miles, 2009). It is not to say that adaptive architectural skins are less crucial than interior changeable partitions, but since existing research efforts put more emphasis on external skins, it is time to draw attention to the reconfigurable scenario of the internal space according to the users' needs. The architecture skin represents a sensitive sur(face) reflecting the surroundings' information while the technological glasses show a virtual inter(face) inducing people's engagement more from the users' perspectives. Eventually, no matter whether it is an adaptive reaction to external environmental conditions or direct interaction for internal spatial reconfiguration of users' demands, they will have to ultimately merge into each other and find a perfect balance to have the interactive transition from the notion of **interFACE to interACT."**

§ 4.4 Body and Brain vs. Machine and Computer under the discourse of Interactive Architecture

After the steam engine had been invented, it not only led us to the industrial revolution but also raised the never-ending debates on the topics of "**men and machines**". Since there have been machines, they have always been treated as the replacement of human labor which can be seen as artificial bodies insofar as they are not in human figure shapes/forms. Same as with the computer, while it became mature in terms of

42 Please check the "Soli" project by visiting the website: https://atap.google.com/soli/

43 Please check the "Jacquard" project by visiting the website: https://atap.google.com/jacquard/

calculations, it has always been compared with the human brain (Interestingly that is why it was treated as a "machine" in the first place). When humans started to marry these two tremendous technologies, the "robot" was born. People are fascinated with making human-figures like robots (android) which satisfy their desire of being God-like. Before the computer was embedded into the machine, the machines could basically execute several pre-set tasks that had to be operated manually in the beginning by humans in order to initiate the procedure. However, after the computer was involved, the machine became the actuating **body** and the computer acted as the **brain** to receive the commands sent by operators who sat in a monitoring room at a distance from the giant machine. This is also when the research and terminology of "**HCI** (Human-Computer-Interface)" were initiated. HCI is essentially dealing with the operational interfaces between humans and computers. For example, the desktop application of computers, the software GUI (graphical user interface), the internet browser, and also the procedure, instruction, and error reports of the system in the computer. The ultimate goal of "**HCI**" is to make the interaction between humans and digital interfaces more efficient, intuitive, and easy to access. And the key point to make it successful is to make it understandable for the computer instead of improving the computational calculations behind the computer. Through these interfaces, people can operate the machines relatively easily than in the age of the steam engine. However, since the robot-kind of object was invented, the interaction interface no longer stayed on the screen of the computer, it became more tangible and became something which people had to confront. A crucial topic for interactive architecture is thus to do extensive research on HCI. To make a robot on one hand more sensitive to users' requirements, and on the other hand more intuitive for users to operate, all kinds of **sensors** with their compatible systems must be highly involved. Similar principles should be involved in developing interactive space/environment. Furthermore, akin to building a robot, interactive architecture/environment also need an actuating **body** and a neuron-like **brain** system to achieve the goal of "**interaction**". **An essential interaction can be interpreted simply as inputs from sensor organs, transmitting the input data to the brain for decision making, and passing the message to the actuating body to trigger the movement**. **It indicates the truth that the sensor, the brain, and the body are the three crucial elements in any interactive system.** At present, there is research both on **the body/the sensor** and **the brain** in interactive space/environment. From **the body** aspect, the research relates more to the physical materialization of the actuating mechanism, which can be motorized or bio-materialized; **the sensors** can be seen as **part of the body** and usually are attached along with the body (actuators) or even embedded in the body, such as simple distance sensors, sound, pressure sensors or relatively complex motion tracking systems, which mimic the sensory organs of a human; and from **the brain** aspect, besides making intuitive interfaces, it is highly debated as to whether the neuron system should be considered as a centralized control or a distributed system to drive the physical actuation. And last but not least is the question of how to integrate **the body**, **the sensor**, and **the brain** to realize a suitable environment for people to engage with. There has never been a serious discussion before the affordable price and techniques could be applied to architectural design. The day when Arduino kind of microcontrollers were released, marked a new era when people who had interest in realizing kinetic or even interactive architecture could pursue it more as a feasible prototyping project. Since the body can include the actuating body and sensory organs, they will be put together for a correlative discussion of their current developments. And the topic of **the brain** with neuron systematic communication will be discussed after that as the critical argument about whether it can make the interactive environment better.

FIGURE 4.7 Images of "HyperSurface" project by deCoi exhibiting the scale on the left, the details from the backside on the right top, and the component of each actuating element on the right bottom (source from left to right: http://fluxwurx.com/installation/wp-content/uploads/2011/01/PR_2003_hyposurface_001_p.jpeg, http://www.mediaarchitecture.org/wp-content/uploads/sites/4/2006/06/PR_2003_hyposurface_002_p.jpg, and http://www.mediaarchitecture.org/wp-content/uploads/sites/4/2006/06/digi1gn.jpg).

§ 4.4.1 Materialize the Body: "to Motorize or to Naturalize", that is the question

Starting with the actuated body part, there are two major directions which can be categorized here which also influence the definition of the sensor parts. One is fully motorized, which uses motors, gears, electronic devices, actuators, in cooperating with highly mechanistic approaches to drive the actuation. Like Da Vinci, the master of inventing classic mechanisms, designers try to realize actuated movement, while the other designers start to look into different material properties which trigger natural adaptive reactions in terms of changing shape. With the concept to "Materialize the Body", the discussion will be divided into two segments, which are "**Motorized**" and "**Naturalized**".

Motorized:

The machine here refers to what most people would intuitively think of, which has complicated operating systems with multiple size gears, several different thicknesses of electronic cables winding around, and can result in massive power compared to human force. Nonetheless, the purpose of using such a machine in interactive architecture is not to generate power, rather the kinetic movements are the value of using these machines. One well-known and one of the pioneer project is the **Arab World Institute** in Paris by Jean Nouvel. The sophistication of the camera-like shutter form of the modular façade serves to control the light penetrating into the interior space. This not only shows the beauty of the mechanism but also practically achieves the intended performance of the façade. More examples came afterwards with similar electronic driving motoring façades, including the **Al Bahar Towers in Abu Dhabi** by AEDAS with its triangular armor-like shading system, and the **One Ocean Thematic Pavilion EXPO 2012** designed by SOMA with its long thin aluminum stripes controlling the solar radiance of the building. Although the principles of the mechanism employed in these adaptive skin systems are not as complicated as any of the Da Vinci machines, it required a large amount of energy and massive prototyping to make it happen. Another crucial project in the interactive architecture domain is the "**HyperSurface**"[44] by deCoi led by Mark Goulthrope. It employed linear pistons in each single module of **HyperSurface** to generate radical morphing of the surface. The surface reactions based on contextual light and sound are actuated by the pushing movement of the piston influencing the triangular panel attached to achieve the performance. While looking at the backside of the installation, a huge steel frame with grids was employed to support all the individual actuator modules. Numerous pistons with electronic cables depict just how much electricity is required to drive the entire installation. Another example of this modular system is the **inFORM/TRANSFORM**[45] by the Tangible Media Group of the MIT Media Lab. Although it is not an architectural project, it points out most of

44 Please check the video for more understandings of "HyperSurface": https://www.youtube.com/watch?v=ANX-QRJ2zksI

45 Please check the official webpage for more details about the "inFORM/TRANSFORM": http://tangible.media.mit.edu/project/inform/

the advantages and disadvantages of building up an interactive space/environment. On the top surface of the **inFORM/TRANSFORM**, are grids of cubic sticks which can elevate up and down to create landscape shape-shifting effects for different purposes. This on-going project aims to make interactive furniture with a pixelated information display. Once again looking at the technical and mechanical setup of this project, it is surprising how much space it takes to hide/pack the required devices and equipment such as special sensors, electronic chips, actuators as pistons, power supplies, and maintenance devices like cooling fans. Nine-tenths of the space is used for either the electronic or mechanical equipment and only one-tenth of the space displays the extraordinary results. This makes it sound relatively inefficient in terms of space usage. And that's the major problem with these motorized spaces, even while making just a façade/skin of the building, it takes quite a large amount of facilitative space to achieve the interactive reactions. The sensory organs idea within the motorized options is also seen as electronic devices especially for the sensing system which has to be further integrated to make the "**Embodiment**". These sensory devices can replace the human senses as vision sensors, light sensors, sound sensors, temperature sensors… etc., which are available on the market at affordable prices. Avoiding the complicated integration of all these different sensor systems, some of the developers/designers in the interactive space/environment tend to look towards nature as biomimetic researchers to search for solutions, such as with Nano-scale modular elements or by harnessing natural material properties. Smart materials now tend to aid interactive architecture. But the associated problems remain hidden or neglected, while one obsesses over the advantages of this approach.

Naturalized:

"**Intelligent materials and smart materials are general terms for materials that have one or more properties that can be altered**". This is the major reason why designers are eager to take these materials and implement them into interactive design. In the publication of Michelle Addington and Daniel Schodek, "***Smart Materials and New Technologies: For Architecture and Design Profession***" " (Addington, Michelle & Schodek, Daniel, 2005), they separated smart materials into two categories: "**Type one materials undergo changes in one or more of their properties – chemical, mechanical, electrical, magnetic or thermal – in direct response to a change in the external stimuli associated with the environment surrounding the material…Type two materials transform energy from one form to an output energy in another form**". Type one materials are relatively more suitable for adaptive makeup, while type two materials are more beneficial from the sustainability point of view. Most of the smart materials applied in architectural design research are type one materials which mainly address adaptive performance.

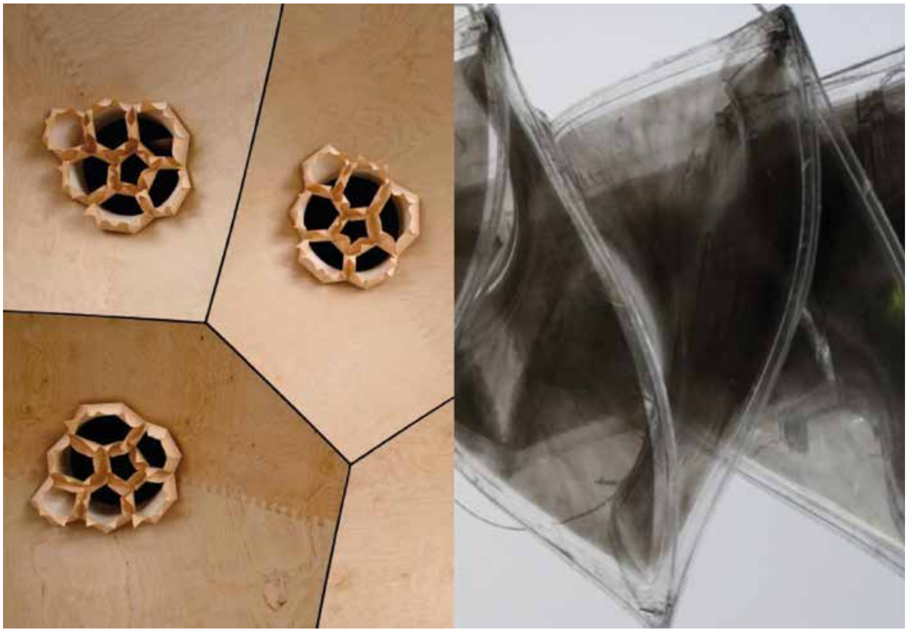


FIGURE 4.8 The images of the "HygroSkin" on the Left and the "ShapeShift" on the right (source from left to right: ICD: http://icd.uni-stuttgart.de/?p=9869, and see the Materiability Research Network: http://materiability.com/shapeshift/).

One explicit example was provided by **Materiability Research Network** team in the leading Swiss academic institution, ETHZ CAAD. Manuel Kretzer, the leader of the team, employed the eletro-active polymer (also known as EAP) thin films as a basic transformable unit while designing a shape-shifting project. The makeup of this EAP film is that while electrifying the film, this thin film will naturally bend with its unique material properties. Manuel Kretzer with his team took advantage of this property and applied them with different shapes for a series of morphing experiments from 2010, which includes, "SHAPESHIFT (2012)", "PHOTOTROPIA (2012)", "RESINANCE (2013)", and "RESINANCE 2.0(2013)" (Kretzer, 2014). The bending effect of this electrified EAP film is quite obvious and allows for successful transformation as expected. However, this EAP film seems to lack power to retain the complete surface with the force of its dramatic morphing. Not only do the resulting changes abolish the surface, during the process of making customized sheets with EAP, there are large percentages of broken sheets which have to be abandoned. This problem proves that the EAP is too fragile to be applied in architecture to achieve the ultimate goal of creating a changeable supporting structure. This is so even though the EAP was carried out quite successfully as an experiment as a morphing unit and could be manipulated individually to make a bottom up overall emergent effect. It is obvious that the EAP can be used as a responsive shading façade system, but can hardly be the key supporting structure for making real-time re-configurable space[46].

The other example is from ICD (Institute for Computational Design), Stuttgart University led by professor, Achim Menges, which is a series of projects employing wood film, which, responds to the surrounding's humidity (Menges, A., Reichert, S., & Krieg O. D., 2014). The team has been investigating biomimetic principles of spruce cones and applying them to an engineered material composed of thin wood film. The principle is the following: humidity change instigates the tissue of the wood cell film to correspondingly absorb or release the moisture and undergo significant morphing effects. The first experimental project using this technique was "**Hygroscope**", commissioned by and exhibited permanently in the Centre Pompidou, Paris, to represent an adaptive architectural skin, comprising of numerous wooden films as a basic unit[47]. The project was housed in a transparent glass case for artificially controlling the humidity, corresponding to the humidity in Paris. The second project is the "**Hygroskin**"[48] which involved robotic arms based manufacturing to materialize a pavilion. The robotic arm fabrication is essentially applied to making a Voronoi structure unit composing the pavilion. Within each of the units, openings were made using the thin wooden panels with an intention to change the amount of light penetration to the interior space in relation with the surrounding humidity. The local climate conditions thus actuate the openings to open up while sunny and close while raining. These material properties perform sensing and actuating roles at the same time. In the other words, within nature, material systems have always integrated sensing and actuation system in a fully embedded fashion. Such a way of utilizing material properties and natural principles seems to be a trend for replacing the relatively heavy and dirty mechanical actuation systems. However, in the case of the **Hygroscope** and **Hygroskin**, humidity can only produce dramatic changes if one manually alters the humidity fluctuations rapidly within the glass container. In the humidity change is not controlled artificially, then the adaptive morphing effect of the engineered wooden films can only change very slowly and makes it hard for the audience to observe. Consequently, there are arguments to choose between the options of using motorized electronic driven actuators or employing naturalized approaches such as utilizing the natural material properties.

46 Please check this video, "ShapeShift" for further understanding on the application of EAP by Materiability Research Network team, ETHZ CAAD: https://vimeo.com/15247128.

47 Please check this video to know more about "Hygroscope": https://vimeo.com/55938597.

48 Please check this video to know more about "HygroSkin": https://vimeo.com/73727749.

To conclude here, the **Motorized** solution can gain the benefits of making relatively rapid changing, having easier adjustment, and loading comparatively heavier objects or even people as supporting structures in a larger scale, which also refers to utilizing/wasting more energy of operating the machine, a separate sensory makeup/system is needed, and result in taking spaces for all these required equipment implemented to achieve the preset goal of kinetics/interaction; In the contrary, the **Naturalized** solution can take advantage by learning from nature and apply the existing natural chemical makeups in a smaller scale as a basic unit to realize the aim of adaptive/responsive performance. Unlike the **Motorized** one which needs the separate sensors for the input system, the **Naturalized** one has embedded the systems both from the sensing and actuating which enhances its benefits from the integration and light-weight points of view. But most of these smart materials are relatively fragile and embody the weakness of the long-term maintenance which makes it hardly be the candidate of creating reconfigurable structure. Therefore, the choices of **Motorized** and **Naturalized** solutions should be corresponding with the question to be solved, for example, to build up reconfigurable partitions of a smart interior space, no doubted the **Motorized** solution should be the option; and to develop sophisticate adaptive façade with the idea of reducing the energy waste simultaneously, the **Naturalized** solution should be the choice. In the near future, the combination of the **Motorized** and **Naturalized** solutions should all be both considered and integrated into a hybrid material while creating interactive architectures aiming for different performance goals.

§ 4.4.2 Build up the Brain: From Decentralization to Collective Intelligence

To step into the realm of Interactive Architecture, it is obvious that one must recognize that the soul of interaction is the control system. The control system defines the capabilities and the tasks of interaction. Although people might still remain the same while thinking, the "**brain**" is a centralized organ which tackles different tasks by this big intelligent machine in the head. But actually, the main components of the intelligence of the brain that makes one think, sense, and react are the brain cells or neurons. Based on different regions of the brain, neurons specialize themselves for specific performance such as movement, sensory processing, language and communication, and learning and memory. They are constructed nearby and form the cerebrum. However, this doesn't make the cerebrum a centralized controller. In the other words, even though the neurons of the cerebrum are located close to each other, they are assigned to conduct specific tasks through network communication and to eventually reach an ultimate decision, making it akin to a more de-centralized system in terms of its operational logic. Undoubtedly, the computer was invented by simulating how the brain works in terms of hardware and also the operational system. But the hidden information needed to be revealed is this "bottom-up" systematic approach. The neuron works as the smallest entity just like all the other functional cells in the body, performing properly as a CPU (Central Processing Unit) dealing with the given mission assigned to it by the embedded DNA. To a certain extent, human intelligence can also be interpreted as a result of collective intelligence gathered from each single neuron unit. There is an old saying in Chinese which translates to "The wisdom of the masses exceeds that of the widest individual" in English, which explicitly illustrates the condition of a distributed operating system in the form of collective intelligence. One of the major benefits of utilizing the distributed system idea in the form of a swarm is that even if one singular entity malfunctions, it won't affect the rest of the entities, thus keeping the whole system still operational. This can also be seen as the property of being "Resilient", as proposed by Kevin Kelly in his famous publication, "***Out of Control: The New Biology of Machines, Social Systems, and the Economic World***" (Kelly, 1995). According to **IEEEIEEE 802.11** terminology, "**a distribution system interconnects Basic Service Set (BSS) to build a premise-wide network that allows users of mobile equipment to roam and stay connected to the available network resources**"[49]. Similar circumstance occurs in nature, and there are plenty of examples depicting this type of system, such as, a swarm of birds, a school of fish, or a group of ants. All these examples work in a similar fashion to collectively form a relatively bigger and abstract object composed of numerous small but smart entities in order to conduct their mission efficiently. To learn from nature is one of the main principles this research obeys, and collective intelligence is one of the key to initiate this journey. Not only the inspiration from the birds, fish, and bees pertaining to their swarming character form an intelligent entity, but also the cells inside plants or animals with their communication protocols and embedded information literally form intelligent mature collectives. This principle should be examined for achieving the ultimate feature that Interactive Architecture should inherit when one speaks about learning from nature. "**There are many biological reasons for swarm behavior related to efficiency in foraging, hydrodynamics and aerodynamics, protection and reproduction...**" (Fox, Michael, & Kemp, Miles, 2009). The other benefit is that each of the single entity can afford to be less intelligent but with relatively simple relationship and communication abilities since they can eventually form an intelligence beyond what one singular entity possesses. "**The rules of response can be very simple and the rules for interaction between each system can be very simple, but the combination can produce interactions that become emergent and very difficult to predict. The more decentralized a system is, the more it relies on lateral relationships, and the less it can rely on overt commands**"

49 Please check the webpage of Webopedia: On-line Tech Dictionary for IT Profession for the definition of "Distribution System": http://www.webopedia.com/TERM/D/distribution_system.html.

(Fox, Michael, & Kemp, Miles, 2009). In accordance with this, the swarm behavior system is considered as strategic choice for developing Interactive Architecture to either sense and actuate locally, and to produce emergent behavior which affects the entire form from a bottom up perspective. This modular componential principle is extremely akin to how biological entities are composed. This is also the reason why "**agent based modeling**" is so crucial both from software simulation and hardware for developing interactive architecture. "**An agent-based model (ABM) is one of a class of computational models for simulating the actions and interactions of autonomous agents (both individual or collective entities such as organizations or groups) with a view to assessing their effects on the system as a whole**"[50]. Therefore, the notion of "**Space is computation**" has once again been brought forth here with the introduction of swarm behavior. By giving up the idea of making a powerful centralized computer taking care of all the adaptations of a building, the ultimate goal that Interactive Bio-Architecture should be composed is thus reformulated to hosting singular architectural components with specific assigned tasks, which embody simple intelligence aided cells. In this case, the body, the sensor and the brain are all integrated in one entity. Also, with its interactive capabilities of sensing, computing and actuating, this emergent architecture will become a holistic sensitive object which is akin to a true living architectural "**HyperBody**" in a relatively large scale.

§ 4.5 Conclusion

In this chapter, the discussions addressing philosophical, social, medium, technological, virtual/real, interaction, and distributed control system have been broadly covered within the context of establishing "**the relationship between body and space**". The idea of **Body Extensions** using artificial technologies, people become highly connected through the surface of **Body Without Organs** which also correlates to the **Cyberspace** notion where the omnipresent Internet exists. This inevitable trend with the development of advanced technologies has started to blur the boundary between virtual and real, making people co-exist in at least two parallel universes. The issue of interaction comes to the fore with the advent of virtual reality technology wherein the discussion around interaction, both in virtual and real spaces gains prime importance. Since space is always the major topic of architectural design, there is no

50 Please check the webpage to understand more details of Agent-Based Modeling (ABM): https://en.wikipedia.org/wiki/Agent-based_model

way to ignore the design requirements from both virtual and real counterparts and it has become a crucial task to create a transition in between. From the architectural design point of view, the interactions taking place have also shifted in scale. In the beginning, the skin (a surface) of the building was mostly used as an information vehicle transmitting messages in a one directional communication to the observer. With wearable gadgets like the Google glass (another surface), the interaction smoothly went to the next phase of "Augmented Reality" which combines virtual reality as a display and overlaying it in the real world thus bringing one close to real-life. With the new technological developments of such wearable gadgets, it potentially extends the possibility of bringing our natural instincts and senses back as Marshall McLuhan reminded us. Therefore, it is not only critical to focus on vision, but also the full sensory perceptions afforded by the body and human movements/gestures to reach the goal of creating tangible interactions in space to create an immersive experience. However, there was a long period of time when architects assigned more attention to adaptive skin systems and its relation with the surrounding environmental conditions. The local environmental condition was used as the input parameters to drive the opening or closing of façade elements in order to optimize the most suitable/comfortable environmental conditions. Although most projects focused on developing adaptive skins used electronic motorized solutions, people now tend to believe that smart materials will be the next ideal step for developing interactive/adaptive actuation systems. Meanwhile, the trend of interaction has shifted its focus from addressing environmental parameters to requirements of the users themselves. This enhances the possibility for people to own and effectively reside in an intelligent re-configurable space, which can adapt to their activity patterns and bio-rhythms. Following this trend, a distributed system both in terms of decentralized computational processing and modular componential assemblies become quintessential to materialize the next generation of Interactive Bio-Architecture. Cooperating with each low-level intelligent architectural component with embedded sensors and actuators for performing specific tasks, the whole architectural body can now become efficient, responsive, and interactive owing to a bottom up decision-making protocol instead of a fully centralized top-down demand based approach. This kind of collective intelligence based decision making is omnipresent in nature and it not only exhibits in the form of swarms of animal to perform variable tasks, but it also takes place inside the natural body for conducting sophisticated tasks by the living cells starting from the growth period of the embryo itself. The mystery behind a cell's emergent behavior relates to the embedded information in the DNA, and how these triggers and informs each other to produce proteins and take certain actions will be discussed in the following chapter.

References

Addington, Michelle & Schodek, Daniel. (2005). *Smart Materials and New Technologies: for the architecture and design professions.* Oxford: Architectural Press: An imprint of Elsevier.

Anders, P. (2001). Extending Architecture throgh Electronic Media. In C. Speed, & G. Grinsted (Eds.), *VO1D* (pp. 58-65).

Barthes, R. (1968). The Death of the Author. In S. Heath (Ed.), *Image, Music, Text* (S. Heath, Trans., pp. 142-148). London: Fontana Press.

Benedikt, M. (1991). *Cyberspace: the First Steps.* Cambridge: The MIT Pressed.

Cicognani, A. (1998). On the Linguistic Nature of Cyberspace and Virtual Communities. *Virtual Reality Society, 3*(1), 25-33.

de Kerckhove, D. (2001). *The Architecture of Intelligence.* Basel: Birkhäuser.

Deleuze, G. (1988). *Bergsonism.* New York: Zone Books.

Deleuze, G., & Guattari, F. (2003). *Anti-Oedipus: Capitalism and schizophrenia.* Londom: Continuum.

Emmer, M. (2004). *Mathland From Flatland to Hypersurfaces.* Basel: Birkhäuser.

Fox, Michael, & Kemp, Miles. (2009). *Interactive Architecture.* New York: Princeton Architectural Press.

Gibson, W. (1982, July). Burning Chrome. *Omni, 4*(10), pp. 72-77.

Gibson, W. (1984). *Neuromancer.* New York: Ace Books.

Kelly, K. (1995). *Out of Control: The New Biology of Machines, Social Systems, & the Economic World.* New York: Basic Books.

Kretzer, M. (2014). Beyond Performance. In M. Kretzer, & L. Hovestadt (Eds.), *ALIVE: Advancements in Adaptive Architecture* (pp. 72-77). Basel: Birkhäuser.

Leibniz, G. W. (1714). *Monadology.* (J. Bennett, Trans.) Continuum. Retrieved from http://www.earlymodern-texts.com/assets/pdfs/leibniz1714b.pdf

Lévy, P. (1998). *Becoming Virtual: Reality in the Digital Age.* (R. Bononno, Trans.) New York: Plenum Trade.

McLuhan, M. (1964). The Gadget Lover: Narcissus as Narcosis. In M. McLuhan, *Understanding Media: The Extensions of Man* (pp. 45-52). New York: McGraw-Hill.

McLuhan, M. (1964). *Understanding Media: The Extensions of Man.* New York: McGraw-Hill.

McLuhan, M., Fiore, Q., & Agel, J. (1967). *The medium is the massage.* New York: Bantam Books.

Menges, A., Reichert, S., & Krieg O. D. (2014). Meteorosensitive Architecture. In K. M., & L. Hovestadt (Eds.), *ALIVE: Advancements in Adaptive Architecture* (pp. 39-42). Basel: Birkhäuser.

Miller, J. H. (2002). Literature and Virtual Realities. In J. H. Miller, *On Literature* (pp. 24-45). New York: Routledge.

Playboy Interview: Marshall McLuhan. (1969, March). *Playboy*, pp. 26–27, 45, 55-56, 61, 63.

Stelarc. (1995). Towards the Post-Human: From Psycho-body to Cyber-system. *Architectural Design, 65*(11/12), 90-96.

Wertheim, M. (1999). *The Pearl Gate of Cyberspace: A History of Space from Dante to the Internet.* London: Virago.

5 Defining a Novel Meaning of the New Organic Architecture

"Machines are becoming biological and the biological is becoming engineered."

Kevin R. Kelly

§ 5.0 Current Developments and Trends of Bio-inspired/Organic Architecture.

Starting an overall investigation by categorizing current bio-inspired architectural design developments into "Material", "Morphological", and "Behavioral" to explore a novel definition of the "New Generation Organic Architecture".

At present, people are confronting the unprecedented unification of machine and biology which has been revealed by the means of advancing industrial processes towards the organic model. In his remarkable publication, "***Out of Control: The New Biology of Machines, Social Systems, and the Economic World***" (Kelly, 1995), Kevin Kelly makes an interesting observation that "***Machines are becoming biological and the biological is becoming engineered***". In other words, the clear boundary of machine vs biology is blurring through current technological developments. In "***Out of Control***", Kevin Kelly has further made several explicit points to support his views, that Industry will inevitably adopt bio-inspired methods:

- It takes less material to do the same job better.
- The complexity of built things now reaches biological complexity.
- Nature will not move, so it must be accommodated.
- The natural world itself—genes and life forms—can be engineered (and patented) just like industrial systems.

All the crucial points described above can be easily observed in the architectural industry as well. Each statement corresponds with material optimization, multi-disciplinary technologies, evolutionary processes, and genetic engineering which are all involved in current digital architectural design developments. After years of evolution, the developments of "Organic Architecture" have been now separated into various research focuses which are distant from the original idea coined by the well-known American architect, Frank Lloyd Wright. A group of followers still insist on maintaining Wright's original idea to develop buildings which are green and sustainable, they fit or even blend into the surrounding environment as a whole. But since the power of personal computers and sophisticated modeling software has become relatively easy to access and is employed in all aspects of architectural design, various experiments have been conducted in the last decade, which try to outline a number of new definitions pertaining to "**what are the essential ideas/principles of 'Organic Architecture'?**". Nature has undoubtedly always been the greatest inspiration for the manmade industry, technology, and architecture. This development has only escalated with the assistance from computational technology over the last few decades. The thesis will preview the pros and cons of current design developments under the big umbrella of digital organic/bio-inspired architecture. This discussion will be categorized into three major divisions: "**Morphological**", "**Material**", and "**Behavioral**" owing to the different focus of computational applications within each one of them.

§ 5.1 Morphological

§ 5.1.1 Morphological Development 0

Development pre and post computational assistance.

Instead of digging deeper into the level of thinking how natural objects, such as animal, plants, and landscapes, are formed, architects and artists begin with imitating the appearance of their shapes and analogously re-interpret and re-create them in the design industry. Early architecture examples depict natural forms on engraved layers of columns or rooftop as ornaments on facades. But things started to changes in the 19^{th}century, as people started looking towards mimicking the shape of natural entities and became curios about how these forms were made. For example, Ernst Haeckel as far back as 1866 (Haeckel, 1998), illustrated living creatures including animals and plants to study the morphology of natural entities, wherein he concluded that the morphological development is not only influenced by internal factors but is also impacted by the natural environment. Or consider one of the famous references in the domain of parametric architecture, "***On Growth and Form***" (Thompson, 1992), by D'Arcy Thompson, who focused on analyzing natural forms and studying how to generate them back in 1917. Through time, several newcomers, such as Antonio Gaudi, Buckminster Fuller, and Frei Otto all tried to re-generate natural shapes/forms and apply them into architectural designs from different aspects in terms of their material properties, geometry, and structure. At the time, there was no assistance from computational technologies yet, which made their dedication and contribution all the more admirable. Since the application of computational technologies in architectural design, architects have benefited heavily. However, during the initial phase of computer aided design (CAD), architects still fell into the trap of merely mimicking natural shapes by using the 3D modeling software. Nonetheless, interesting buildings were designed with this mentality of geometric modeling skill by architects during the "deconstructivist" movement. Some of the most prominent ones were designed by the Architects Coop Himm(l)blau, Zaha Hadid, and especially the projects of British architecture firm, "Future Systems". Almost all the projects of Future Systems take inspiration from the nature to design organically shaped architectures over many years. These have been published in two books: "***For Inspiration Only***" (Future System, 1996) and "***More for Inspiration Only***" (Future System, 1999). The skin of the Selfridges Department Stores in Birmingham[51] designed by Future Systems is one such example. The project is inspired by the eyes of a fly, which, is also the inspiration for their visionary project "The Earth Centre" (http://www.earch.cz/cs/future-systems).

§ 5.1.2 Morphological Development I

= Chaos Theory_ the initial phase of computer aided bio-architecture design.

After years of exploration in the field of 3D modeling, Greg Lynn, an architect who has both an Architecture and Philosophy background, developed a parametric thinking approach by using computational techniques based on D'arcy Thompson's analytical logic stated in "***On Growth and Form***" (Thompson, 1992). Lynn used this to generate

51 Please check the Wiki page for more details about the Selfridges Department Store by Future System: https://en.wikipedia.org/wiki/Selfridges_Building,_Birmingham

a parametric model of a house, called the "**Embryological House**". As a metaphor of DNA, 12 control points were able to flexibly manipulate to generate various curvilinear shapes (**Blob**) using different combinations of control point positions. After this, an inevitable wave in both digital and bio-inspired architecture realms to push this parametric thinking to new heights began. Not only in architectural design, but all other sciences are working hard on discovering benefits by following the principles of nature: for deciphering the hidden code behind structures in nature, such as the ways a plant grows, or the generation of a panther's fur patterns...etc. People intent on implementing algorithms discovered from nature to efficiently complete their tasks developed genetic algorithms. The same holds true for architectural design, as architects now attempt to introduce various technological tools like parametric modeling and applied algorithms to architectural design, especially after the development of "**Chaos Theory**" and its implications on computational design. Since Chaos Theory was discovered, multiple useful algorithms have been applied in architectural designs for generating 2d and 3d patterns with the assistance of computational techniques which could hardly be down with manual 3D modeling skills. Alan Turing who had been seen as the inventor of the contemporary computer had a lifetime interest in biological morphogenesis. Although Turing could not witness it himself, but years later, his ultimate dream seems to have come true since the relationship between computation and biology has been tightly bound. Fractals, cellular automation, multi-agent systems...etc., which all work through complicated mathematics algorithms, are able to be easily re-invented using current computational technology. So, pioneering architects have taken these computational techniques as an inspiration and are implementing them into their design projects.

§ 5.1.3 Morphological development II

= flourish developments amongst the young generation of architects implementing computational techniques within algorithms extracted from nature as a new organic Bio-architectural design.

Biothing, founded by Alisa Andrasek, with her colleague, Jose Sanchez, has been heavily experimenting with fractal algorithms, multi-agent systems and embodying them in their design projects (Figure 5.1). These biological principles give the architects chances to design generative rules from a bottom-up perspective similar to how natural objects grow. "**Code sequences generate 'immaterial forms of intelligence... coalescence between the organic and the inorganic**" (Andrasek, 2012). In accordance with Alisa Andrasek's thought, computational technology bridges not only the material and immaterial but also helps with blurring the boundary between biology and the artificial which is again akin to Kevin Kelly's statement that "**Machines (Architecture) are becoming biological**". **THEVERYMANY** can be seen as another pioneering group established by Marc Fornes using computational simulations with recursive logic to generate coral-like, vaporous membranes as a form-finding process. Incorporating the use of CNC machines, laser cutters, **THEVERYMANY** mostly built 1:1 pavilions using sheet-like materials with bending or folding techniques to reinforce the structural supports with simple plug-in/out assembly methods. Like a living plant, the structure was built up through materials as structure without any redundancy making the pavilion have a sense of being an organism. **Michael Hansmeyer** mainly uses recursive computation as well as subdivision methods to not only create several large-scale organic but also slightly Baroque-like architectural elements, such as columns and grottos, and stated that "**we are not seeking to imitate forms of nature in a figurative manner, but instead we reference the processes of their evolution**" (Brayer, Marie-Ange, 2013). Michael's point actually emphasized the major advantages in this phase of morphological development that even when the logic was once taken from nature, it is not simply a matter of reproducing exactly the same what already exists in nature, on the contrary, the logic with the assistance of computational techniques should be able to assist people to generate unexpected, optimized, but also beautiful forms and shapes akin to natural objects. In other words, designers should shift their focus to designing the principles of growth in architecture rather than sculpting the external form. **Nervous System**, another young design group was formed in 2007 by Jessica Rosenkrantz with both architecture and biology degrees and Jesse Louis-Rosenberg whose major is Mathematics. Their biology and mathematics backgrounds make them a relatively strong team of researchers working on the design of natural patterns. They focus heavily on the topic of "**Pattern**"; not only patterns seen in natural organisms but also patterns of growth. Coupling with their professions, they executed digital fabrication techniques, such as 3D printing to realize their industrial design projects from jewelry, lamps, the midsoles of sneakers, and even to a series of 3D printed necklaces and dresses called kinematics, which are all based on the natural growth patterns they researched.

The aforementioned groups are heavily experimenting with digital computational techniques in architectural design. More groups can be listed here under this digital form-finding umbrella with utilizing natural algorithms in architectural design, such as Andrew Kudless' **MATSYS**, Matias del Campo's **SPAN**, Iain Maxwell and David Pigram's **Supermanoeuvre**, who are making numerous fascinating contributions in this field of design exploration.

FIGURE 5.1 Turing Pavilion by Biothing (Alisa Andrasek + Jose Sanche) cooperating with Dshape Italy based on the Reaction-Diffusion algorithms (source: Biothing, https://vimeo.com/20873694).

One of the common points between the above pioneers in computational design is that they use their knowledge to develop/modify the algorithms to fit their designs, and most of them consider materialization as a post-design process, which is totally opposed to how natural organisms develop. Although they have heavily employed digital fabrication to realize their prototypes and mock-ups, this process is unintentionally akin to finding a materialization solution after generating the code in a non-physical simulated universe. In other words, the approach of utilizing algorithms in architectural design in this case is without considering material applications from the very beginning. The positive aspect of this is that there is more freedom for architects to visualize their designs via form-finding techniques and to focus on spatial quality rather than worry too much about construction problems in the early design stage. But, on the other hand, this is exactly the point where there has always been challenges and doubts with their designs because they look more like visionary projects than practical ones which can be actually built. It is not an easy task for architects to solve these practical construction tasks in the early stage of design, but it is potentially feasible to start putting the material or environmental factors as input values like information of a biological embryo to build or even grow with the material properties from the beginning as initial constraints. It is understandable that the above-listed architects are confronting so many different difficult design questions and so they pick their own focus on form-finding process with computational techniques without worrying about applied materials and solving practical issues cleverly with their later design stages. However, young architectural students might take their methods as a given and misuse them with their designs only for generating theatricality, monstrous, complicated forms and claim their projects are organic in nature. "Algorithm" seems to be the magic term to convince people their projects were based on logical translations from organisms to architecture, but as a term of art or nomenclature algorithms in current architectural parlance are totally abusing the essence of mathematics derived from living creatures. If one is not acknowledging the essential idea before applying a specific algorithm, then it is relatively risky in architectural design and fears of reducing the process to a sophisticated method for merely generating "Good Looking" appearance for outer aesthetic purposes become very high. "Algorithms" must be seen as a growing pattern/principle of any organism to be respected and also intensively included in the "design process", not just some random formulas for making organic shapes. In this case, the morphology is truly a process of morphogenesis instead of morphological mimicry. "Genetic algorithm", as another almost magical term, has always been seen as another ultimate solution to all the above doubts when utilizing them in architectural design. Since a "Genetic algorithm" is a relatively special topic closely related to this research's design methodology, it will be intensively considered after the discussions of three divisions of organic/bio-inspired architectural design along with the major inspiration of this research as regards biological aspects.

§ 5.2 Material

§ 5.2.1 Materialization with Algorithms

From the material aspect, several directions are inclusive to this special realm with different focuses but highly related to the material system and also to digital fabrication technology used here. Several experiments can be seen as an extension of the **Morphological** approach which takes materials as a factor along with the development of its unique generative algorithms. Take **EZCT** for example, in their project of "Chair Model", 25 prototypes were generated by the evolutionary algorithm as a biological formation process with natural selection concerning both the material and functional aspects. Later on, with the "Studies in Recursive Lattices" project, they kept exploring the combination of developing the unique generative algorithm. In their study, the recursive algorithm, collaborated with fiber-reinforced concrete as a material system to reduce the redundancy of the useless volume of the materials. A similar idea came across with **Joris Laarman** Lab's project, "Bone Furniture", collaborating with Adam Opel's International Technical Development Center is based on the inspiration of Claus Mattheck's research on the growth of plants and bones.

A series of 3D optimization algorithms in charge of both constructing the main structure lines and conducting the form optimization were employed in the design process which is way beyond the mere imitation of the natural form in the Art Nouveau period (Brayer, Marie-Ange, 2013). By considering the qualities of the applied materials, the algorithms here aren't merely used as a form-finding tool without physical constraints but rather become a relatively reliable process engulfing fabrication and construction.

FIGURE 5.2 Bone chair by Joris Laarman (source: Joris Laarman LAB, http://www.jorislaarman.com/work/bone-chair/, the optimization process can be observed in the same webpage.).

§ 5.2.2 Materialization with Real Organs

FIGURE 5.3 Image on top is the design project "Syncretic Transplants" of Tobias Klein under the guidance of Marcos Cruz. The bottom image is the "gaming console" derived from the film, the "eXistenZ" (source from top to bottom: UCL Bartlett, https://www.bartlett.ucl.ac.uk/architecture/research/projects/neoplasmatic-design, and http://acidemic.blogspot.nl/2015/01/death-to-realism-existenz-oculus-rift.html.

The title of "materialization with real organs" applied in architectural design might sound awkward or even too much science fiction, but it is somehow the simple interpretation of "Neoplasms" (Cruz, 2008) as claimed by **Marcos Cruz**, professor of Innovative Environment in UCL. Also known as the Director of the BiotA LAB in UCL, **Marcos Cruz** revealed his idea of utilizing "Synthetic Biology" technology to transplant real organs/flesh onto architecture bodies to make architecture eventually become a semi-living object. In other words, the real flesh/tissue of an organ is the new innovative material for building up purposeful bio-architecture. It is obvious that "Neoplasms" (Cruz, 2008) is a cross-disciplinary research involving diverse experts, such as biologists, physicians, and engineers to realize his visionary idea. He implied his “Neoplasms” (Cruz, 2008) idea by taking the movie “eXistenZ”[52] as a reference where the organic virtual reality game consoles called game pods have replaced the electronic ones and have to be attached to “bio-ports” inserted in the player’s spine. These game pods have a flesh-like appearance which can be seen as the new material which would be connected to the building through Marcos’s perspective. In the movie, with the bio-port inserted to the player’s spine, the organic game pods gradually become parts of the player, which have three different phases which can be seen as an evolving process also for the buildings of “Neoplasms” (Cruz, 2008). Within the steps of “having flesh”, “being flesh”, and “becoming flesh”, the biologic transplanted flesh emerges as a new material which will gradually blend into each other from both biological and architectural angles to generate a so-called “semi-living” architecture which actually responds as a living body instead of utilizing electric mechanisms to imitate the makeup of living organs. Hypothetically speaking, taking animals lungs for examples, through advanced synthetic biology, numerous lungs can be implemented onto the building’s façade to filter the air penetrating the façade and literally turn the whole building into a semi-living space. This is the philosophical and advanced vision of “organic architecture” from Marcos Cruz’s point of view.

“***Protocell Architecture***” can be seen as an alternative branch of the “Neoplasms” but is relatively more practical in terms of its research approach. A series of experimental projects entitled “Protocell Architecture” in the Architecture Design journal guest-edited by Racheal Armstrong and Neil Spiller explicitly showed several different interpretations of the design idea of “what is Protocell Architecture?”. “**Protocell do not operate within the realms of biological processes that are associated with living systems, but are driven by primordial organizing forces—the laws of physics and chemistry**” (Spiller, Neil & Amstrong, Rachel, 2011). Some try to culture artificial cells to implement the sustainability of the space, for example, synthetic cells generating energy for cultivating the electricity or heat of an interior space in a relatively natural way (applied in Philips Beesley’s ‘the Hylozoic Series’ and his later series of projects); some look into natural principles of physics and chemistry for the solutions from the material world, such as development of inventing self-healing concrete (for example, self-healing concrete by bacterial mineral precipitation of TU Delft’s Micro Lab)[53]. “**The ‘protocell architecture’ can be thought of as an alternative arrangement of terrestrial chemistry that ultimately results in a new living system that has been ‘midwifed’ into existence by human design and technological innovation**” (Spiller, Neil &

52 Please check the webpage for more information about the film, eXistenZ: https://en.wikipedia.org/wiki/Existenz

53 Please check these webpages for more understandings about the “Self-Healing Concrete”: http://www.citg.tudelft.nl/en/research/projects/self-healing-concrete/ and http://www.microlab.citg.tudelft.nl/.

Amstrong, Rachel, 2011). As in Protocell Architecture, they address a lot of the existing technology and attempt to push them to the extreme with the material, or to discover new ways of scientific marriage generating a living system, unlike what Marcos Cruz with his "Neoplasms" (Cruz, 2008) idea was trying to do with an uncertain cyborg-kind of surgery between human and buildings. In the end of the introduction article by Neil Spiller and Rachel Armstrong for the ***Protocell Architecture*** issue of the AD (Architectural Design) journal, they even wrote a manifesto for Protocell Architecture to fight against biological formalism. Rachel Armstrong believes that imitating nature is not the ultimate approach, but to reproduce architecture should be akin to the way a plant produces its fruits in nature.

§ 5.2.3 Materialization, Biomimicry, and digital fabrication technologies

FIGURE 5.4 Neri Oxman's Gemini (source: Neri Oxman, http://www.materialecology.com/projects/details/gemini#prettyPhoto).

Two major series of experimental researches described here as examples are those by Professor Neri Oxman and Professor Achim Menges who coincidently both have similar ideas/interests not only on materiality but also on the logic of organisms' growth as well as integration with architectural application by means of digital fabrication technology. In other words, they both look into the ways of growth of natural organisms and apply these principles in architectural design as fundamentally based on reproducing material' properties along with compatible digital fabrication technology. Of course, they both have their own bio-inspired narratives and specific approaches of digital fabrication.

Ms. Neri Oxman, a professor, is known as the director of the **Mediated Matter Group** with the MIT Media Lab, where she started her preliminary transdisciplinary research between biology and technology from 2006. By extracting bottom-up principles of how natural living creatures grow, she utilized computational techniques to simulate growth pattern and employed digital fabrication methods, such as 3D printing and robotic arms based additive fabrication, to experiment with several prototypes of synthetic materials. In the project "Gemini" (Figure 5.4), a semi-anechoic chaise lounge, Neri Oxman translated the geometry of the Ornithogalum dubium's flower's seed which has a star-like cellular shape interlocking with each other to tessellate the overall form of the lounge, and with the distribution weight simulation ensuring ergonomic comfort for a typical person's weight, each of the generative cellular star-shapes reformed constantly to reach the gradient equivalence of the load bearing as an optimization process. Corresponding with the existing 3D printing and CNC milling techniques, each unique and complex generative cellular unit can relatively easily be fabricated in accordance with the distributed loading simulation result. Against the existing architectural industrial production method of staying homogenous by composing items of homogeneously defined forms and parts, Neri Oxman coined the term "**Digital Anisotropy**" to denote the ability of the designer to strategically control the density and directionality of material substance in the generation of form as nature normally does (Oxman, Neri, Firstenberg, Michal, & Tsai, Elizabeth,, 2012). Based on the above notion cooperating with rapid prototyping methods such as 3D printing technology of Object Ltd., Neri Oxman with her team developed several intimate wearable art pieces corresponding with growth principles of related body parts. For example, by simulating the approach of how hard tissue (skull) and the soft tissue (skin and muscle) interact with each other to construct the head part of a figure, an anisotropy helmet was generated with different thickness and density of material composition to resemble a human organ. The thought of linking the material and the production with the goal of functionality is somehow relatively common but brilliant in nature. While the growth of an organism in nature, the material is always considered in association with its' functionality to adjust the density it will inherit and how this would accommodate the method of producing it. This is core to what Neri Oxman would like to deliver to not only architects but also the general public in order for us to re-think the means of design concerning the choice of materials, the suitable fabrication methods of construction in terms of material properties, and the ultimate applied function by fully utilizing the existing digital techniques.

Achim Menges, Professor and the head of ICD (Institute of Computational Design, Faculty of Architecture and Urban Planning, University of Stuttgart), also a pioneer in the bio-inspired design field has looked into both biology and material science with the integration of digital fabrication technology for years. Since 2011, Achim Menges with his research team began to deliver a research pavilion each year within the bio-inspired notion of morphology which has intended to transfer the idea from a theoretical paradigm to real construction practice. The morphogenesis idea of Menges is the linkage between the ecological capacities of material systems and environmental modulations. "**Contemporary architectural design is still characterized by a clear separation and hierarchical conception of the creation of form, space and structure and its subsequent preparation for materialization. In contrast, the approach presented here seeks to employ computational processes for a higher level of integration of form generation and materialization**" (Menges, 2013). It is akin to Neri Oxman's notion of integration concerning space, structure, and material as a whole while designing a building like a natural organism. With the knowledge of morphogenesis and the skills of computational technology, Achim Menges took advantage of material properties and the constraints of Robotic fabrication techniques to experiment profoundly with the combination of biology and design. Every annual research pavilion has a unique biologic/morphological principle and is translated into actual construction by utilizing specific application methods of robotic arms as a unique fabrication process. For example, with the research pavilion in 2011, Achim Menges and his team, took the morphological principles of a sea urchin's structure, and with numerous pressure bending testing of plywood strips as the applied materials, and the computed calculations of the structural stability, eventually, the research pavilion was merged into an integrated design. Examining the exoskeleton of a lobster, instead of normal hot-wire cutting, or 3D printing techniques, in 2012, their team developed a customized tool/head for robotic fabrication to weave the carbon and glass fiber onto a temporary steel frame to build up the pavilion. In 2015, the latest version of research pavilion, Achim Menges and his team investigated the natural segmented plate structure of a sand dollar as a shell structure. Taking timber plates as an essential material, the challenge is to have a further understanding of its bending limitations both theoretically and practically, and the applied linkage to the research of shell structure. The other profound challenge is from the manufacturing point of view. For this, the team invented novel robotic fabrication methods of sewing in order to connect each bending plywood component to eventually compose the resulting timber shell pavilion. Wood and the fibers are the two major materials Achim Menges and his team mostly addressed with their current robotic manufacturing experiments. Moreover, with his essential focus on material, Achim Menges also stepped into the exploration of adaptive architecture. In his other two worlds, renowned projects of Hygroscope and Hygroskin (discussed in Chapter 4), by implementing the properties that the wooden film can absorb and release the moisture in the air to morph its shape (inspired by the pinecone), they developed moisture-driven openings, which, automatically adapt to the surrounding environment without any electricity and mechanics.

"**Nature as model. Biomimicry is a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems**" (Benyus, 1997). Broadly speaking, most of the bio-inspired designs can be viewed as "Biomimicry". This is especially true of Neri Oxman or Achim Menges who attempt to take their inspiration and learn from natural materiality and digital fabrication perspectives to reveal the potential of implementing them into their designs. Their approach not only imitates the natural logic but also translate them in accordance to natural materials selected. This, doubles the layers of complexity but simultaneously increases the depth of their biomimicry based approach unlike those who just literally use such approaches to mimic the appearance of natural organisms. Regardless of whether we consider Neri Oxman, or Achim Menges, and their followers, they all seem to walk on a path searching for a perfect architecture body optimally composed of natural materials with properties selected with the assistance of simulations and digital manufacturing. This, is already a huge step in bio-inspired architecture with one conflict as compared with living entities in nature. First, let's rule out the possibilities of self-division, self-replication based production logics which can be found in nature, since, these can hardly be achieved by using current artificial approaches in the physical architectural domain. The real paradox thus lies in neglecting "the embedded dynamics of natural systems"; the external dynamic property of the environment and the internal dynamics of metabolism and circulation which all living creatures possess and confront. From this point of view, Achim Menges has realized some ideas with his engineered wooden film experiments in relation to moisture absorption, but to reach a fully adaptive body, it is still a relatively long process of development. This is the key point to be considered: how do we enhance our buildings to evolve from being statically optimized to dynamically optimized akin to living organisms. So, to explicitly work on reversing this contradiction, some architects have shifted their focus towards an autonomous swarm based thinking in architectural design, intent to be relatively closer to the way in which natural entities operate. Instead of sculpting the natural form or taking certain natural mechanisms applied as artificial technologies, this section has brought the bio-inspiration and its implementation to a whole new level than merely studying the principles of the natural system and re-creating the system with its nature-inspired design principles.

§ 5.3 Behavioral

§ 5.3.1 More Than Form Finding

A swarm behavior should be more than just a trajectory of virtual agents meant for form finding in architectural design.

When talking about "autonomous" applications in architectural design, one important example is that of Swarm behavior based design process of **Kokkugia.** Co-founded by Roland Snooks and Robert Stuart-Smith, Kokkugia mostly use swarm behavior logic as a form-finding tool to generate 3D complex geometric space. By coding the swarm with specific principles, an emergent self-organization process is initiated, which, frequently results in a frozen fibrous tracing patterns. This is a common approach utilized by the young generation of architects experimenting with autonomous behavior logics in architectural design which, opposes theories of Marcos Novak's Liquid Architecture with its attempts to liquidize otherwise frozen architecture. Although swarm behavior as a form-finding process seems to now be mainstream in architectural design, the section here will outline a different approach by literally harnessing architectural elements as the agents of a swarm. This notion of designing an architectural component as an agent of a swarm composing a building from a bottom up perspective is in its initial phase and is not yet embodied completely in practice, but has great potential to do so using the ongoing trends in technological development.

§ 5.3.2 A Swarm of Smart Autonomous Entities

Swarm behavior, in the case of this research implies activation of agents to promote processes of self-organization and self-assembly driven by a set of collective principles followed by numerous smart autonomous entities.

§ 5.3.2.1 Autonomous as Transportation and Assembly

FIGURE 5.5 Flight Assembled Architecture by Gramazio & Kohler (source: ETHZ, Gramazio & Kohler Research and Institute for Dynamic Systems and Control, http://www.idsc.ethz.ch/research-dandrea/research-projects/archive/flying-machine-enabled-construction.html)

One of the pioneering swarm simulation based projects was called "**Flight Assembled Architecture**" by Gramazio & Kohler in 2011. Gramazio & Kohler was founded in 2000, and later in 2005, they found the first robotic laboratory in the renowned Swiss Federal Institute of Technology (ETHZ, Zurich) which started experimenting with transdisciplinary computational design, new material exploration and 1:1 prototyping with digital fabrication. Although they are mostly known recently by their projects of robotic arm manufacturing experiments, the "Flight Assembled Architecture" can be seen as the first autonomous robotic assembly project which took robotic applications to the next level in architectural design. Cooperating with Raffaello D'Andrea, the Professor of Dynamic Systems and Control in ETHZ, also the co-founder of the KIVA system, they developed a hi-end system with a scenario of assembling a non-standard building using hundreds of autonomous drones (Gramazio, F., Kohler, M., & D'Andea, R., 2014)[54]. The flying drones were akin to a flock of birds picking up bricks one by one and putting them precisely on location in 3d space to sequentially construct the building. In the prototyping process, they used 4 flying drones which managed to reach to 6 meters' height with polystyrene modules which in reality should be 100 times larger in scale to afford 30,000 inhabitants homes in the residential tower. This project showed great potentials for mimicking natural group activities as a physical swarm instead of simulating the behavior behind the computer screen for generating static/frozen building bodies. The drones were used as transportation and assembly robots/tools but it implied near-term development of making each architectural component as a drone-like module. In other words, each of these drones should be treated as smart entities and as architectural components rather than just a device for transportation and assembly. Simply speaking, here the flying drones should "BE" the architectural components, like a bird in a flock to form a collective living form.

§ 5.3.2.2 Autonomous as Mobile/Transformable Components in Architectural Design

Spending years in developing programmable material, Skylar Tibbits set up his **Self-Assembly LAB** under the MIT Media Lab. The Lab now has a great reputation, and is known for its 4D printing technology worldwide. Skylar Tibbits' ultimate goal is to find a way to merge the physical and digital as one that you can simulate but at the same time program with the existing physical materials so as to match the resulting simulation with the physical outcome. But here, it is interesting to look into his early stage of research, which is relatively more akin to the componential and autonomous modular idea while still using the process of self-assembly. From their Self-Assembly Units of 2008, Macrobot, Decibot, even their Logic Matter, a clear evolutionary process can be observed. Skylar Tibbits at the time attempted to develop a modular component which has automatic transformable mechanisms based connections in between. It is a bottom-up idea to create/generate complexity out of simple geometric transformation occurring in each component's connection parts. Akin to scaling-up a Rubik snake, each triangular shape could twist in any angle on every connection to make different shapes. In other words, all of his projects including the Self-Assembly Unit, Macrobot, Decibot, or Logic Matters, have a regular default shape (the figure of a bird) and with some freedom from the designed transformation mechanism (a function of flying) regardless of whether they are electronic or manual, operating under certain principles (a separation distance in order not to crash into each other), they can self-assemble,

54 Please check the video for the generic idea of "Flight Assembled Architecture" project: https://vimeo.com/33919488

resulting in various expected and unexpected formations (a flock of birds dynamically composing variable forms). Even though Skylar Tibbits has contributed toward the development of programmable materials, but in his C-strain project as a playable reconfigurable sculpture structure or even one of his latest project's, Aerial Assemblies, which are like flying balloons, one can still trace how his autonomous assembly ideas are realized in his projects. His experiments in materials are crucial to him because it is possible for him to develop natural mechanisms/robots without any electronic devices. The morphing effects acquired from programming material properties are however, still relatively fragile to be implemented as supporting structures employed for spatial reconfiguration purposes (the most difficult challenge in Interactive Architectural designs). But if these natural mechanisms were applied to relatively smaller modules as a componential system, then the ultimate form can be potentially more effective in terms of their reconfiguration and self-assembly following a bottom-up logic akin to the proposal of replacing bricks by flying drones in Gramazio & Kohler's Flight Assembled Architecture.

§ 5.3.2.3 A vision of Autonomous Emergent Systems

Theodore Spyropoulos and his brother Stephen founded "**minimaform**" in 2002 and since then have dedicated themselves to researching on computational, parametric, and interactive design exploring intimate relationships amongst things, objects, and people. In 2012, with the "Petting Zoo" project, they intended to mimic an animal-like object formed as an elephant trunk hung from the ceiling as an interactive installation. Owing to the approaching movements of the visitors detected by the camera on top, the microcontroller made decisions based on pre-set code to trigger the movements of the 3 trunks to produce an emotional and ambiguous reaction in the visitors. They are among a few architects who have started to bring the topic of emotion into spatial design. In "Petting Zoo", the atmosphere of interaction between people and life like objects created vivid impressions of the space to enhance the idea of communication between space and people. This innovative notion of creating spaces with emotions will be further discussed in the next chapter. Other than discovering the possibilities of mimicking natural living things and the trend to transform the space into a relatively sensitive and emotional environment, Theodore Spyropoulos as a Director of AADRL (Design Research Lab, Architecture Association) has educated and delivered a notion of bio-inspired modular componential system to his supervised students since then. In recent years, Theodore's studio has several innovative experimental projects akin to Skylar Tibbit's early phase of research that worked with modular systems with mechanisms to build a self-assembly system for architectural design from bottom up.

"ROTO", "Anti-Bot", "HyperCell", "noMad" and "OWO"[55] are all projects conceived with the notion of mobile/transformable architectural components following self-assembly logic to construct "Zero-Occupied Spaces". Instead of the traditional brick-like architectural components, the essential components of these project either have the ability to be transformable or mobile and can geometrically re-configure to construct immediate response. Zero-occupied implies that when needed, the architectural components can move to the required location to achieve the task but can be dismissed afterwards. All these mobile/transformable components can be once again interpreted as agents of a swarm which have relatively simple intelligence with certain freedom of movement following a set of emergent rules. The only critique of their project is that almost all the projects appear in a pixelated fashion to regenerate a typical shape of an object or building without further geometrical explorations.

When speaking of "Robotic Buildings", people might directly refer to robotically "**Manufactured**" projects, however, autonomous swarm based robotic componential systems applied to architectural design should be seen aptly as "**Robotic Building**". With the development of current technologies, such as artificial intelligence, it is to be expected that these small entities can become even smarter and dynamic and a lot more efficient while they act like real living entities. "Bio-inspired" design and its implications can thus be now seen from a very different perspective, wherein, the collective intelligence of physical agents can now truly mimic processes of natural growth, self-organization, and emergence. Kevin Kelly in his publication "***Out of Control***" has already stated that "**these same principles of biologics are now being implanted in computer chips, electronic communication networks, robot modules, pharmaceutical searches, software design, and corporate management, in order that these artificial systems may overcome their own complexity**" (Kelly, 1995). In terms of bio-inspired or organic architecture, there should be more and younger and bold architects ready to contribute their talents in this cross-disciplinary realm of bio-inspired architectural design. "**When the Technology is enlivened by Biology we get artifacts that can adapt, learn, and evolve. When our technology adapts, learns, and evolves then we will have a neo-biological civilization**" (Kelly, 1995). It is this cutting-edge future where there is no clear boundary between biology and mechanisms/ artificial like a cybernetic community that people are heading towards.

55 Please check the AADRL website to have a glance of "ROTO", "Anti-Bot", "HyperCell", "noMad", and "OWO": http://drl.aaschool.ac.uk/projects/.

§ 5.4 From Static to Dynamic Optimization

From Static (Genetic Algorithm based form finding approach) to Dynamic (Living creature-like Interactive systems).

Following up from the previous discussion about the application of implementing natural algorithms in architectural design for optimal form-finding, using Genetic Algorithms instead, for mimicking natural evolutionary processes to arrive at an optimal form could be seen as a more convincing approach. However, the research, instead, attempts to illustrate a few critical points concerning the use of Genetic Algorithms especially in the field of interactive architecture.

A Genetic Algorithm[56] is defined as a heuristic search that mimics the process of natural selection using mathematical optimization processes. Since D'arcy Thompson started looking into the relationship between mathematics and morphogenesis, experts like him from diverse research fields have attempted to decipher codes in nature using Math, to see how living things are formed. Ultimately, John H. Holland with his team was able to translate Charles Darwin's ideas on "natural selection & survival of the fittest" in his influential publication "***On the Origin of Species by Means of Natural Selection***" (Darwin, 1859) into a computational algorithm, which is since known as the "Genetic Algorithm". The Genetic Algorithm is the one focusing on the purpose of obtaining the efficient "**optimizing solution**" by learning from nature.

"**Genetic algorithms initiate and maintain a population of computational individuals, each of which has a genotype and phenotype. Sexual reproduction is simulated by random selection of two individuals to produce 'parents' from which 'offspring' are generated. By using crossover (random allocation of genes from the parents' genotype) and mutation, varied off springs are generated until they fill the population. All parents are discarded, and the process is iterated for as many generations as are required to produce a population that has among it a range of suitable individuals to satisfy the fitness criteria**" (Weistock, 2004). Michael Weinstock, one of the pioneers addressing natural morphogenesis has written this explicit description of the Genetic Algorithm. Simply said, the algorithm is running a process that keeps looking for a solution relatively close to the defined "fitness" criteria via iterations through a constant generational production process of selection, crossover, and leaving a small proportion of mutational chance as a disturbance. The searching process terminates either by

56 Please check the webpage for more information about "Genetic Algorithm": https://en.wikipedia.org/wiki/Genetic_algorithm

the pre-set maximum numbers of generations produced (terminating searching), or converge into a certain value (result not close to the optimal fitness), or ultimately a satisfactory fitness level is reached. In terms of architectural applications, the Genetic Algorithm has been broadly utilized in searching the optimal solutions for well-defined form-finding problems, such as sustainability, reducing the materials used, structural analysis, and thermal and lighting performance, which are easier to set up with the required fitness in each of these individual cases. Nonetheless, these problems are pre-embedded in constructing static buildings, which, is not quite relevant, when it comes to designing "Interactive Architecture". Even discussing designing static buildings by using Genetic Algorithms, seems to work the opposite way of how nature operates. It is understandable to take advantage of computational technology to accelerate evolutionary processes. But buildings are like plants and animals which are all highly related to their environment. It is thus not convincing to have a "fitness" criteria which is fixed within a given environmental context. A building is a complex object which has many demanding requirements, and a designer using Genetic Algorithms has to select a certain number of these criteria as fitness values in order to achieve Multiple Optimization. However, the number of fitness parameters which can be assigned has its limitations in order to manage computational speed. If one considers all the demands surrounding the design of a building as fitness criteria, then it might result in the production of a relatively average geometric solution, such as spheres, and thus the outcome loses out on the production of unique architectural qualities.

It thus sounds relatively "objective" to use Genetic Algorithms to do calculations and produce an optimized solution, while, in fact, most of the demands are still designed subjectively following the designers' intentions (such as the maximum population of individuals in the first generation, the number of iterations, and the crucial selections of the fitness parameters). Moreover, the so-called optimized results are relative optimizations, not absolute. Genetic Algorithms here provide a method of creating a relatively optimized body(building) suitable for handling a certain number of fitness requirements, which is perfect for optimizing construction and controlling material usage. However, in terms of interactive architecture, with its inherent need to be dynamic in nature, it is not suitable to use this bio-inspired algorithm, since an interactive construct would need real-time optimization based on the slightest change in its context. In terms of "interactive building design", this is also the reason why this research would rather investigate the role of "genes" as the fundamental building block which regulates morphogenesis. In "***Deleuze and the Use of the Genetic Algorithm in Architecture***" (DeLanda, 2002), Manuel DeLanda pointed out a crucial issue pertaining to the role of an architect in algorithm-driven-design: "**Thus, architects wishing to use this new (computational) tool must not only become hackers (so that they can create the code needed to bring extensive and intensive aspect together) but also be able 'to hack' biology, thermodynamics, mathematics, and other areas of science to tap into**

TOC

the necessary resources" (DeLanda, 2002). As interpreted, architects should not only remain fixated to extracting principles from other scientific fields and applying them directly for generating forms. Instead, they should further understand the essential notions of applied sciences and translate them into design strategy. The other issue brought out here is that this research does not oppose the idea of optimization, but suggests that optimization should address the context of the dynamic environment. In other words, rather than running heavy calculations to obtain a singular optimized result, one should seek for dynamic/real time optimization of designs to deal with a constantly changing environment and the diverse individuals which live in it. Real-time interactive architectures, which address issues of sustainability and diverse spatial requirements, can actively sense and adapt to the environment and user's needs. Eventually, dynamic optimization/customization can be potentially achieved with the development of computational and mechanic technologies within architectural design. And this is why architects will eventually "hack" into other related fields.

§ 5.5 EVO-DEVO (Evolutionary Development Biology), the Inspiration of New Organic Bio-Architecture

EVO-DEVO (Evolutionary Development Biology), the hidden secret of morphogenesis and the inspiration of new organic Bio-architecture.

Instead of directly extracting and applying principles from genetic engineering into architectural design without any further interpretations and translations, this research attempts to focus more on extracting hidden secrets behind genes to understand natural Morphogenesis. Genes, shall be studied and decoded **to develop a novel design framework for living creature-like interactive Bio-architectures**. Evolutionary Development Biology (Evo-Devo) is a genre of biology, which, looks into the diverse developmental processes in different organisms and discovers how they evolve according to gene regulation principles, unique to them. By revealing a great deal about the otherwise invisible genes and the simple rules that shape an animal form and its evolution, Evo-Devo introduces the keys to understanding form and its development via a process initiated from a single-cell egg to a complex, multi-billion-celled animal body. There was a long period of time that people could only discover that forms do change, and that natural selection is the driving force, but there was nothing to outline how forms change (Carroll, 2005). After decades of research in embryology and evolutionary biology as two separate sciences, the discovery, that similar structures in animals, such as eyes, limbs, and hearts, were governed by the same genes, made these two disciplines eventually came together to create a new discipline called Evolutionary Development Biology (Evo-Devo). This idea that all animals share the same master gene toolkit is comparable to parametric design thinking which has caught much attention from architects who are eager to learn from biology and nature. This research can be seen as a similar effort, which attempts to extract the most crucial and inspiring principles from Evo-Devo to create a new organic Bio-architecture paradigm.

This research gained a clear insight and numerous interesting inspirations from the publication, the "***Endless Form Most Beautiful***" by Sean B. Carroll, who is at the forefront of evolutionary development biology. The title, "***Endless Form Most Beautiful***" was a quote from Charles Darwin's biological classic, "***The Origin of Species***" (Darwin, 1859), which gave an explicit paradigm of Darwin's pioneering belief back in 1860 that the descent of all forms arise from one (or a few) common ancestor. This, has been further proven and supported by the evidence of the current research from Evolutionary Development Biology. This leads us to the crucial and fundamental idea propagated by Evo-Devo that all animals share the same gene toolkits but have differences in terms of the number of genes and their regulations, which is responsible for the diversity of animals worldwide. Based on this essential fundamental notion, this research is able to extract several useful and logical principles, which are interpreted and listed as three major and interrelated topics: "**From Simple to Complex**", "**Geometric Information Distribution**" and "**On/Off Switch & Trigger**".

§ 5.5.1 Simple to Complex

In terms of results, every complex organic body is composed of numerous amounts of simple and self-similar elements based on information obtained from the gene's regulations (which is the on/off mechanism which will be mentioned later in the section of "On/Off Switch &Trigger"). It is apparent from observation of the spine structure of the vertebrates which can be varied in numbers from a dozen in frogs, thirty-three in humans, to a few hundred in a snake (Figure 5.6, left); and diverse in similar shapes of the cervical, thoracic, lumbar, sacral, and caudal vertebrae. This modular design with repeated assemblages of similar parts, according to Sean Carroll, is the success of evolutionary diversification in biology. This principle can be applied to architectural designs to initiate a radical design revolution. People are easily trapped into believing that complex objects should be composed of complicated elements, but taking a closer look at living objects in nature, it becomes apparent that they are all composed of relatively simple and self-similar elements, a core principle behind: "**from simple to complex**". The "**complicated**" and the "**complex**" have slightly different interpretations here in that the **complicated** leans towards a confusing and puzzling situation where it is hard to find the solution while **complex** is more akin to a logical combination of simple elements. This "**Simple to Complex**" principle relates to Kas Oosterhuis' "**One Building One Detail**" idea in architectural design; "…**any building should have only one single parametric detail mapped on all surface, subject to a range of parameters that render the values of the parametric system unique in each local instance, thus creating a visual richness and a variety that is virtually unmatched by any traditional building technique**" (Oosterhuis, Towards a New Kind of Building, 2011). Here, one can trace a common idea, seen both in nature and Kas's notion of architecture; simplicity is not only applied to the shape of a basic element but also to the logic of the system from how the elements were generated and how the ultimate body was assembled. "**Simplicity is thus intrinsically tied to multiplicity**" (Oosterhuis, Towards a New Kind of Building, 2011). With the differences in the numbers, and diverse but similar morphological elements, there are plenty of geometric outcomes which can be generated within this "**simple to complex**" logic from an architectural design viewpoint. Furthermore, if the Evo-Devo idea of all animals sharing the same gene toolkits is taken as an inspiration, then it is easy to relate to the current parametric world in architectural design. However, it would be a better fit if we consider this from a modular/self-similar componential design perspective. Such a simple systematic approach will be further discussed in the "**On/Off Switch & Trigger**" section, which clarifies how architectural designs can learn from the morphogenesis of an animal gene's intelligent mechanisms.

§ 5.5.2 Geometric Information Distribution

The process of several cleavages, gastrulation, progressing into forming three main layers of the embryo; the innermost(endoderm), middle(mesoderm), and outer layers, eventually leads to the development of establishing regions within these layers to form localized tissues and organs in the embryo's body based on the "**Fate Map**" (Figure 5.6, middle up). Like an instruction, a "**Fate Maps reveals that, at some point in development, cells 'know' where they are in an embryo and to what tissue or structures they belong**" (Carroll, 2005). Like making a geographical map, through a precise dividing process of defining poles, axes, longitudes, latitude as a coordinate system, a **Fate Map** will let the genetic switches make marks on the precise coordinates as a GPS system defining the body segments and divisions of diverse cell types, where different organs and tissues belong. Repeating the subdivision process, each organ and body part will be refined with more details, locally generated via cell interactions besides the global specifications of the **Fate Map**. The formation process of an organism is relatively simple than what most people think, in terms of logic, which fits exactly the quotation from the physicist Jean Perrin, "**to explain the complicated visible by some simple invisible**". As mentioned before, to directly extract principles from biology and reuse them in architectural design without translation is not the approach of this research. Besides, it is not the ultimate goal to re-create a new species of animal. Although the geometric formation process is quite fascinating and intriguing, this research rather focuses on how the information process behind formation is assigned and distributed. A **Fate Map** works as a global information protocol for cells as regards the kind of cellular differentiation and specialization tasks they need to undertake by demarcating different functional zones. This can be seen as several power-/guide-lines in an initial stage of design to define certain areas for specific functions either based on internal functional influences or physical external environmental impacts. After this, the local information distribution mostly happens while building up the pattern of the hair, scales, fur or feathers. A quick and simple example from the publication of "***Endless Forms Most Beautiful***" can clearly explain this bottom-up idea: in an initially uniform field of cells (Figure 5.6, mid-down 1), two cells assigned by the **Fate Map** begin to differentiate and inhibit cells in contact with them from doing so (Figure 5.6, mid-down 2). Cells in other regions begin to differentiate and inhibit their nearest neighbors (Figure 5.6, mid-down 3), which eventually establishes a regularly spaced pattern of cells (Figure 5.6, mid-down 4) (Carroll, 2005). Regardless of the self-assembly or self-adaptive applications in designing interactive architectures, this kind of bottom-up information distribution protocol can be perfectly implemented by referring back to the aforementioned logic of simple-complex modular componential idea while designing an intelligent interactive architecture based on a swarm logic.

§ 5.5.3 On/off Switch & Trigger

The gene switch (On/Off Switch & Trigger), plays an important role in regulating the formation of an organism. For example, the switches inside the category of the Hox gene tell an organism where and when to evolve different body parts in time. The Hox gene is a collective term including several different types of genes holding a specific morphological task to turn on the gene switches. For example, the Dll(Distal-less) genes are in charge of limb formation, Pax-6 genes play crucial roles in eyes development, Tinman genes are dedicated to the formation and patterning of the heart, and the UBX genes control the differences of the arthropods' forewings and hindwings. But these Hox genes can also play roles in different development of the formation process and that is the reason why the body becomes complex. Take Dll genes and butterflies for example, the major task of Dll genes are generating the limb formation, but a moment later, while it goes to the development of the fur on the wings, the Dll genes will shift their tasks to regulate the pattern of the wings. In other words, these genes switches hold a major and other additional tasks and precisely switch them on and off to generate different cells and proteins through time to sculpt the ultimate body. Taking a closer look at the switch control, "***Endless Form Most Beautiful***" once again gives a great example of how this gene switch works. The switch is basically controlled by "lactose". When lactose is absent, the gene switch is off, because the lac repressor binds to the switch and represses gene transcription. In contrast, when lactose is present, the gene switch flips on and the repressor falls off the switch to trigger the transcription and translation for the enzyme production. This is the exact process of how DNA transcripts to mRNA and translates it for producing demanded proteins (Carroll, 2005)(Figure 5.6, right). These gene switch turn on and off to trigger the enzyme production process in a highly efficient manner. Surprisingly, only around 3 percent of the DNA regulates an organism's formation process through time to produce the intricate complexity of mature animal bodies. This switch, on and off trigger is on one hand akin to the 0 and 1 calculation logic of computational technology. There is another instance of the on/off switch to exhibit how simple but powerful this intelligent mechanism can be through the expression of the Hox6 gene. The on/off regulations of the Hox6 genes defines the neck length of different animals. For example, the position of Hox6 in a goose is longer than a chicken and a mouse, and there is no space between Hox5 to Hox6 gene in a snake which makes a snake have no neck in its morphogenesis. It is because of the layering of nested combinations of the gene switches that make all animal bodies refined and sophisticated in terms of ultimate shape. "**It is by 'computing' the inputs of multiple proteins that switches transformation complex sets of inputs into the simpler outputs as three dimensional on/off patterns of gene expression...**" (Carroll, 2005), which can be seen as a simple-to-complex expression in terms of an organic generating system. One more crucial morphological idea of this on/off logic is that it takes dynamic movement of the body after they were built into account. In other words, the gene switches are not only taking care of the formations but also considering the functions, which the forms will afford afterwards. Ubx gene is the gene which regulates the difference between the hindwing and forewing of a fruit fly. The Ubx gene turns off during the formation of the forewing making it larger, flat, venated and powerful which is beneficial for flight, while the Ubx gene turns on making the hindwing to balance by sensing and correcting yaw, pitch and roll during flight (Carroll, 2005). This particular principle of taking animating movements of the forms into account makes it even more intriguing and fascinating, when we try applying it to interactive Bio-architectural.

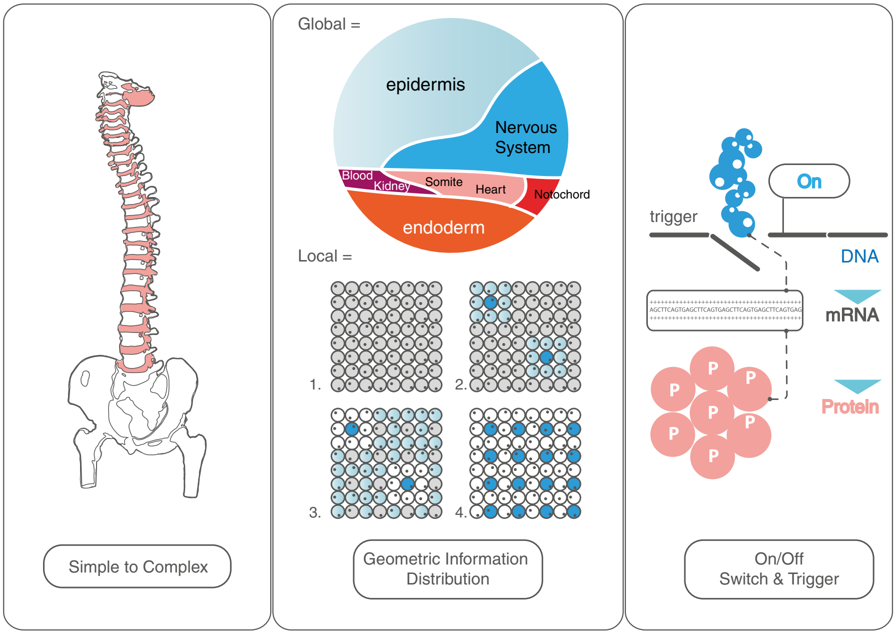


FIGURE 5.6 Diagrams illustrating the fundamental principles extracted from Evo-Devo by this research. "Simple to Complex" referring to the modular elements idea of constructing animal bodies; "Geometric Information Distribution" indicating the internal communication globally as a Fate Map system, or locally as neighboring distribution protocols; "On/Off Switch & Trigger" implying the essential logic of building complex animal bodies by following relatively simple rules as an On/Off (0 and 1) logic to produce proteins as demanded.

§ 5.6 Conclusion

This chapter starts with a discussion of how the gap between the domain of biology and engineering is diminishing and how this helps in addressing the question: "**what is the definition of the organic Bio-architecture**". The chapter further looks into diverse developments in the realm of bio-inspired architecture design, especially the ones utilizing contemporary computational technology, but hold different unique design perspectives. Some of them focus on generating forms with algorithms inspired from nature, some work on material properties with digital fabrication techniques, some want to push swarm robots further as architectural components, and some literally utilize genetic algorithms as an optimized form-finding process. This research takes its' bio-inspiration mostly from a novel biological field, the Evolutionary Development

Biology (Evo-Devo) to see what are the crucial and fundamental principles behind natural morphogenesis of animal bodies. Instead of literally/directly employing the technology from Evo-Devo, it seeks to take the inspiring principles of Evo-Devo and re-creates the useful parts and rules applied to architectural design with the assistance of computational technology. This concept will lead to a summary of all the aforementioned ideas of each chapter by generating the design framework for the bio-inspired interactive architecture entitled "HyperCell" which will be thoroughly illustrated in the next chapter. This research believes that the ultimate goal of Interactive architecture is to become an authentic organic architecture which can pro-actively adapt and react to the environment as well as the users demands. To achieve this goal, it is inevitable to understand the morphological principles of living creature. By learning from Evo-Devo, based on the fundamental idea of all animals sharing the same gene toolkits, this research has extracted three major directions/principles awaiting to be deployed into new organic and interactive Bio-architectural design: "**Simple to Complex**", "**Geometric Information Distribution**", and "**On/Off Switch and Trigger**". Akin to the parametric idea in today's digital architectural design, it is relatively easier to understand the idea of taking the gene regulations as the combinations of parameters for generating architectural design. Furthermore, "**Simple to Complex**", "**Geometric Information Distribution**", and "**On/Off Switch and Trigger**" can be simplified and interpreted as essential characteristics of modular componential systems, bottom-up information protocols, and 0/1 switches for triggering formation assembly logic. In other words, the design framework developed by this research should lead to an intelligent componential idea compatible with the swarm behavior logic in terms of self-assembly and bottom-up local communication protocols, and its ultimate geometric form should be generated with simple on/off logic considering the movements which need to be animated.

References

Andrasek, A. (2012). Open Synthesis// Toward a Resilient Fabric of Architecture. *Log, 25*, 45-54.

Benyus, J. M. (1997). *Biomimicry: Innovation Inspired by Nature*. New York: HarperCollins Publishers Inc.

Brayer, Marie-Ange. (2013). Natur and artifice: Affects and artifacts in naturalized architecture. In M.-A. &. Brayer, *Naturalizing Architecture* (pp. 14-37). Orléans: Edition HYX.

Carroll, S. B. (2005). *Endless Forms Most Beautiful: the New Science of Evo Devo*. New York: W. W. Norton & Company, Inc.

Cruz, M. (2008). Synthetic Neoplasms. *Architectural Design: Neoplasmatic Design, 78*(6), 36-43.

Darwin, C. (1859). *On the Origin of Species by Means of Natural Selection*. London: J. Murray.

DeLanda, M. (2002). Deleuze and the Use of the Genetic Algorithm in Architecture. In N. Leach (Ed.), *Designing for a Digital World*. New York: Wiley-Academic.

Future System. (1996). *For Inspiration Only*. New York: John Wiley & Sons.

Future System. (1999). *More for Inspiration Only*. New York: John Wiley & Sons.

Gramazio, F., Kohler, M., & D'Andea, R. (2014). Flight Assembled Architecture. In M.-A. &. Brayer, *Naturalizing Architecture* (pp. 136-137). Orléans: Edition HYX.

Haeckel, E. (1998). *Art Forms in Nature: The Prints of Ernst Haeckel* . Munich: Prestel.
Kelly, K. (1995). *Out of Control: The New Biology of Machines, Social Systems, & the Economic World*. New York: Basic Books.
Menges, A. (2013). Morphospaces of Robotic Fabrication. In S. n. Brell-Çokca, & J. Braumann (Eds.), *Rob | Arch 2012: Robotic Fabrication in Architecture, Art, and Design* (pp. 28-47). Berlin: Springer.
Oosterhuis, K. (2011). *Towards* a *New Kind of Building*. Rotterdam: NAi Publisher.
Oxman, Neri, Firstenberg, Michal, & Tsai, Elizabeth,. (2012). Digital Anisotropy: A Variable Elasticity Rapid Prototyping Platform. *Virtual and Physical Prototyping (VPP)*, 261-274.
Spiller, Neil & Amstrong, Rachel. (2011). It's A Brand New Morning. *Architectural Design: Protocell Architecture, 81*(2), 14-25.
Thompson, D. (1992). *On Growth of Form*. London: Cambridge University Press.
Weistock, M. (2004). Morphogenesis and Mathematics of Emergence. In M. Hensel, A. Menges, & M. Weinstock (Eds.), *Architectural Design, Emergence: Morphogenetic Design Strategies, Volume 74, Issue 3* (Vol. 74, pp. 10-17). New York: Wiley.

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

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

Michael Fox & Miles Kemp

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

Marcos Novak

§ 6.1 Architecture as Body

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

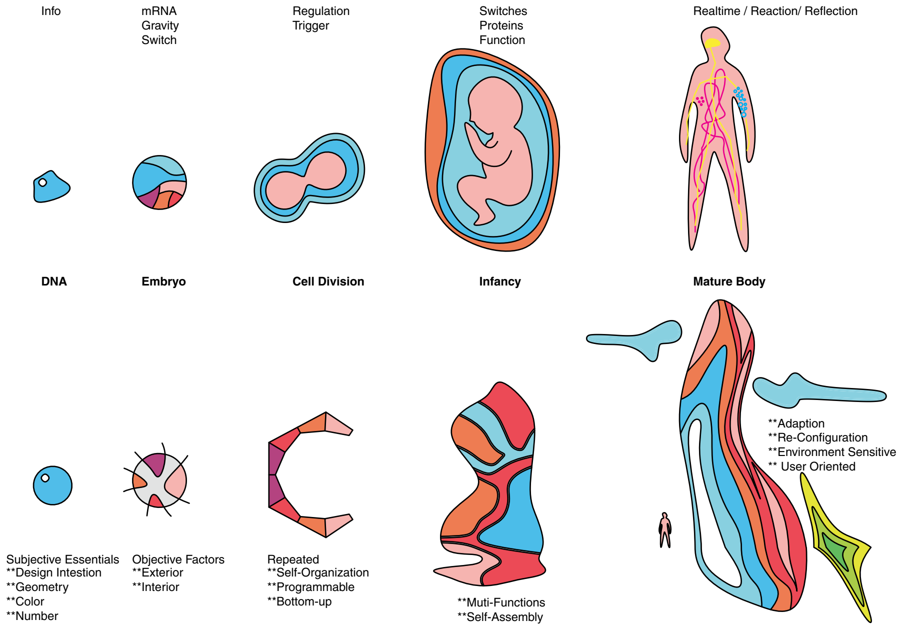


FIGURE 6.1 Diagram illustrating the analog comparison as a conceptual design idea of having an "Evolving Architecture" akin to natural growing processes. The mature architecture body would be as a human figure ultimately interacting with the surrounding environment and additionally fulfilling the user's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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

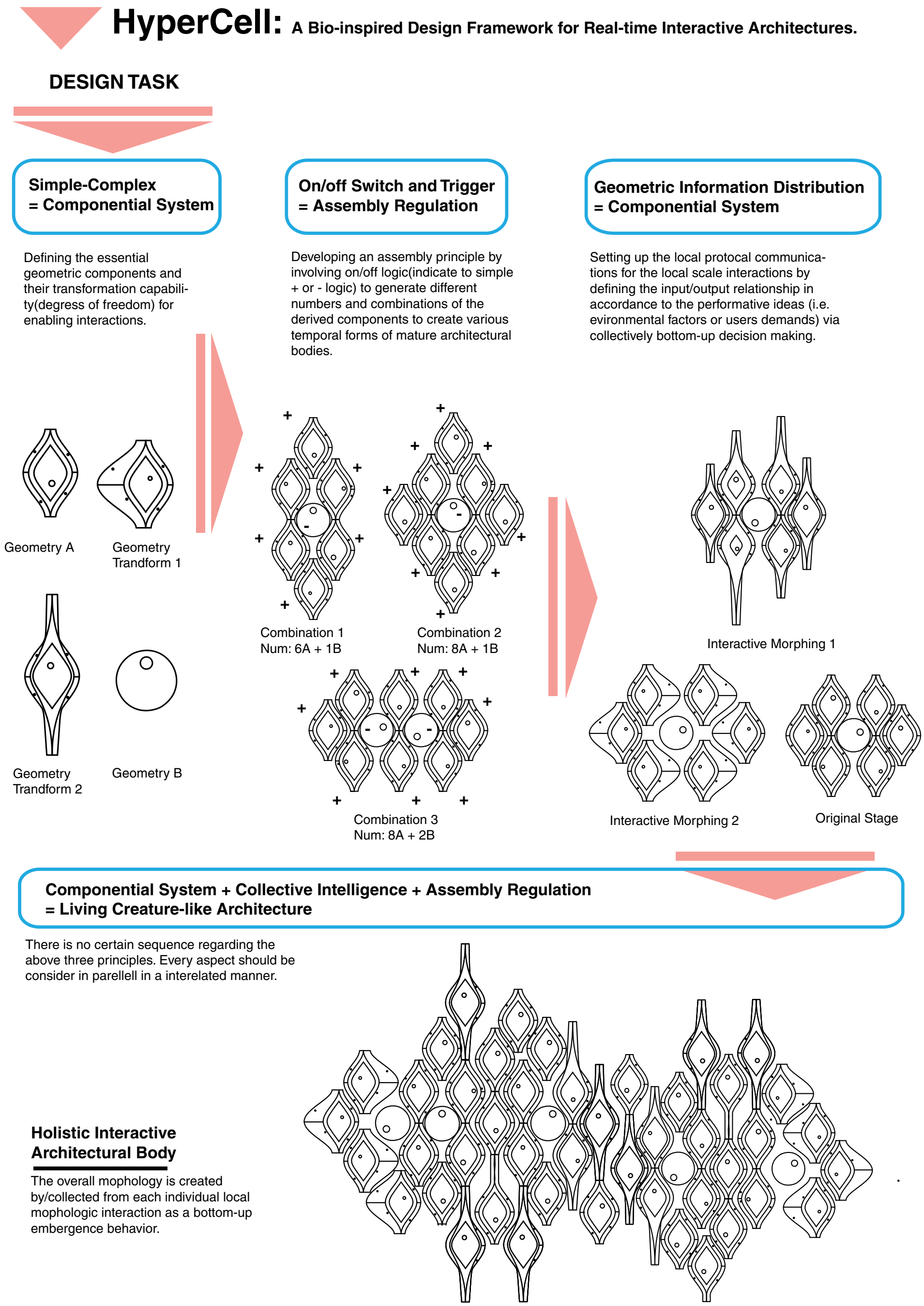


FIGURE 6.2 Diagram detailing the generic idea of HyperCell: A Bio-inspired Design Framework for Real-time Interactive Architectures.

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

= Defining the basic geometric component.

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

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

= Setting up local information protocols and individual interactive transformations.

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

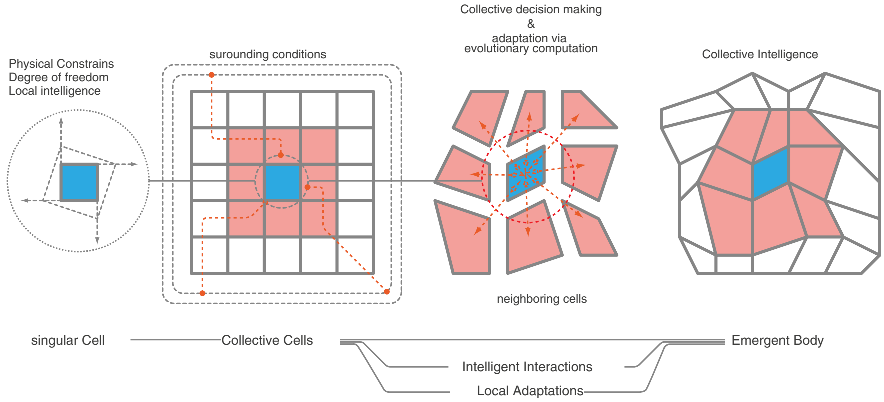


FIGURE 6.3 Process of collective decision making through local level adaptive components to the emergent optimized body for the information distribution idea within the logic of self-organization and swarm intelligence.

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

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

Rather than addressing production processes, while addressing the principle of "Growth", this research instead focuses on defining assembly logic. The morphologies of animals are well defined by the mysterious and relatively complex layers of on/off triggers, which result in simple output commands. The research attempts to follow a similar, yet, simplified version of using on/off triggers to generate an assembly logic for interactive architectures. Even with the degrees of freedom to transform, it is necessary to define the generating rules for resulting bodies according to certain principles, which include the on/off makeup, extracted from Evo-Devo. As the notion of all animals sharing the same gene toolkits but only with different numbers and regulation of the genes turns out to have a diversity of species in nature, the research tests the idea of having self-similar geometric components cooperating with different numbers and combinations of the "On/Off" regulation. Multiple resulting forms can thus be generated according to environmental conditions or user based demands. Once the basic geometry of the components is defined, the simple logic (on/off) can be applied to further construct the assembly logic in this phase of design.

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

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

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

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

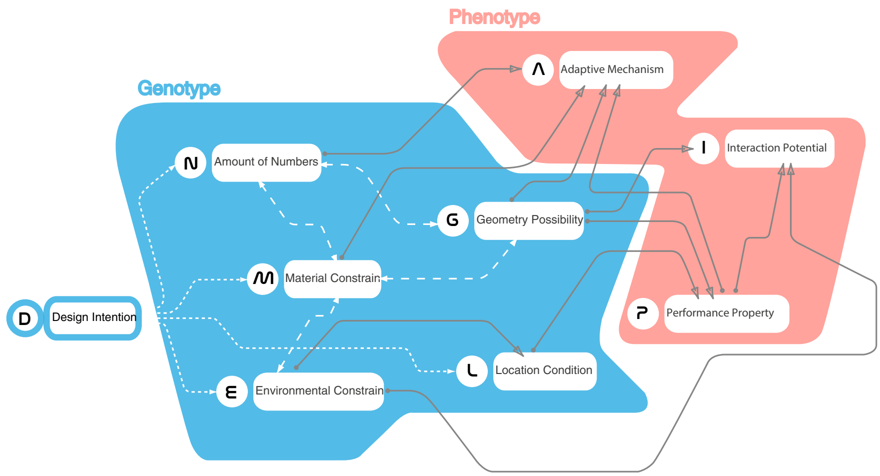


FIGURE 6.4 Diagram portraying possible DNA logic implemented in architectural design as a set of relationships instead of parameters merely for form generation.

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

It has been observed that genetic processes and evolutionary strategies in natural systems are easily misunderstood and misused by designers in architecture. Geometric form-finding processes are at times deduced by considering a DNA code as a metaphor for fixed formal attributes while completely ignoring the deeper relational processes that exist between encoded genetic information and the resultant phenotype. This dissertation categorically opposes the much-simplified literal translation of A-C-T-G sequences within the DNA into datasets of spatial vertexes, edges, transformation factors, and other geometric relationships for deriving a shape. On the contrary, the research premise establishes that all genes in cells should unavoidably interact with each other as a relational system in a non-linear process in order to successively grow an organism using cellular differentiation and specialization-based tissue formation into a holistic body. This necessitates a systematic relationship between genes as a vital area of research in order to extract rules for generating information driven performative form. In other words, the research proclaims that designers should build bottom-up spatial formations by setting up genetic rule sets within the design process. These will be inherited within the smallest unit of the proposed space; the spatial component (similar to the cells in organisms). The number of such cells, their material make-up, their communication protocols and data exchange routines (gene expression and signal processing) while interacting with their immediate context in order to arrive at individual cell specialization (in terms of form and ambient characteristics) result in the generation of emergent morphological phenotypes (Figure 6.4).

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

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

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

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

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

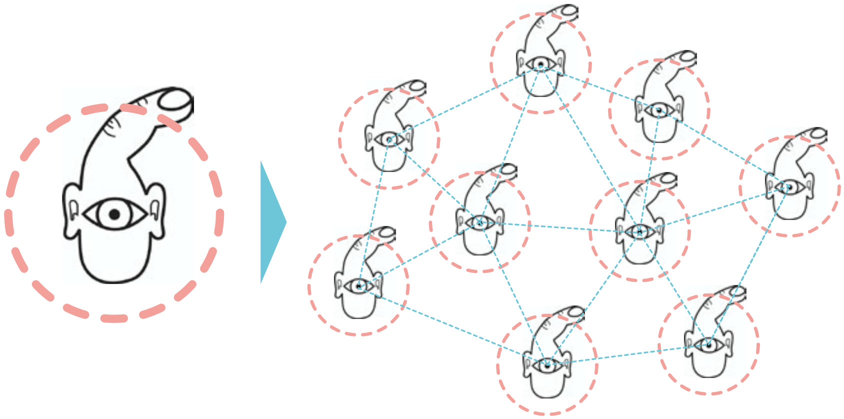


FIGURE 6.5 Diagram illustrating how the computer sees us from the left derived from the publication of "Physical Computing: sensing and controlling the physical world with computers", and on the right-hand side exhibiting how this research would like the HyperCell components to possess essential intelligence.

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

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

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

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

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

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

§ 6.5 A Series of Experiments with the HyperCell System:

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

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

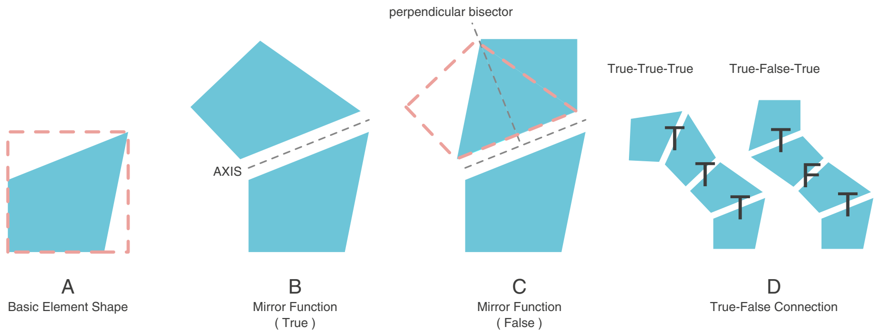


FIGURE 6.6 A) Degrees of freedom in terms of dimensions. B) True mirror function. C) False mirror function. D) An Example of True & False regulation between cells.

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

62 Please refer to the following papers of the authors for more detailed information:
Biloria, Nimish & Chang, Jia-Rey. (2012). HyperCell: A Bio-Inspired Information Design Framework for Real-Time Adaptive Spatial Components. Proceedings of the 30th eCAADe Conference (pp. 573-581). Prague: eCAADe and Czech Technical University in Prague, Faculty of Architecture. (http://papers.cumincad.org/cgi-bin/works/Show?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)

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

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

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

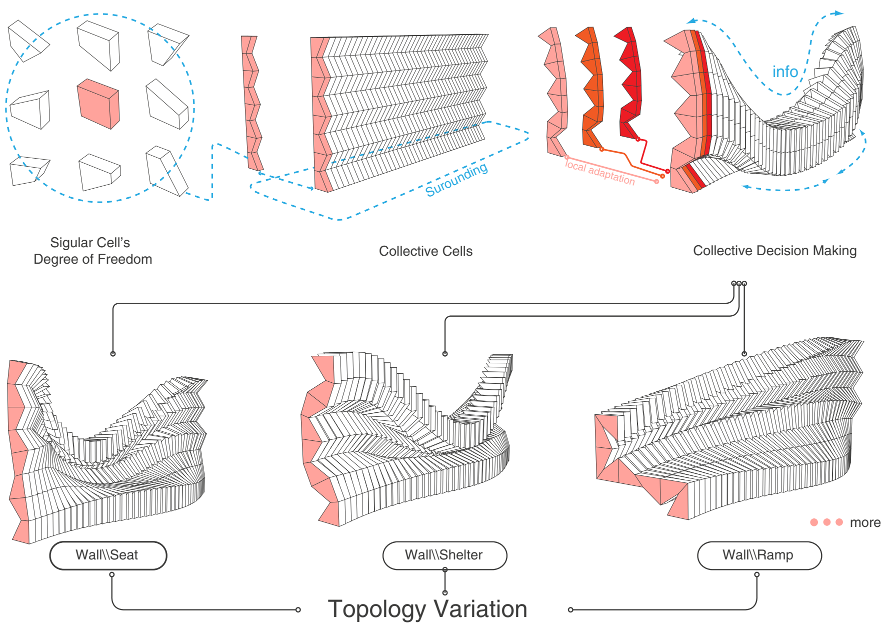


FIGURE 6.7 Diagram illustrating the bottom-up communication protocols and how it influences the real-time morphology of the architectural element (wall in this case) owing to users' demands using the swarm intelligence logic.

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

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

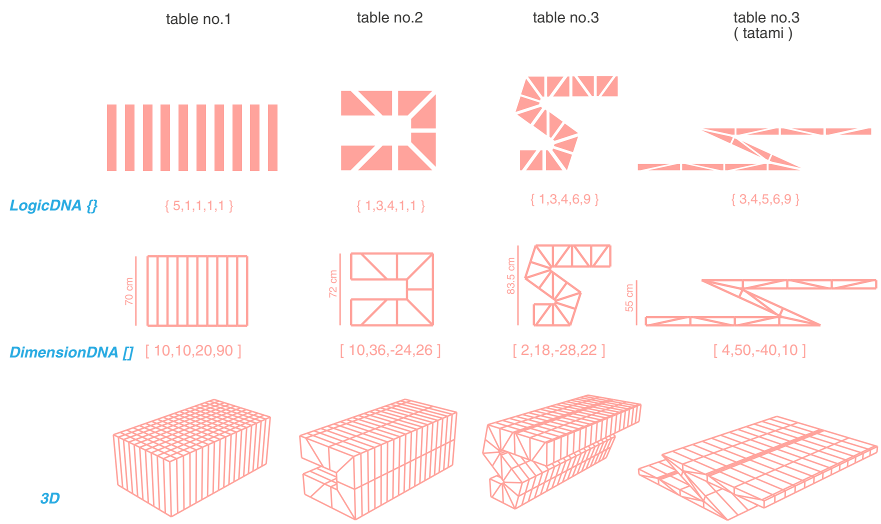


FIGURE 6.8 Diagram showing types of table variations also as an example for forming the furniture in accordance with the logic of Logic-DNA and Dimension-DNA as this research developed.

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

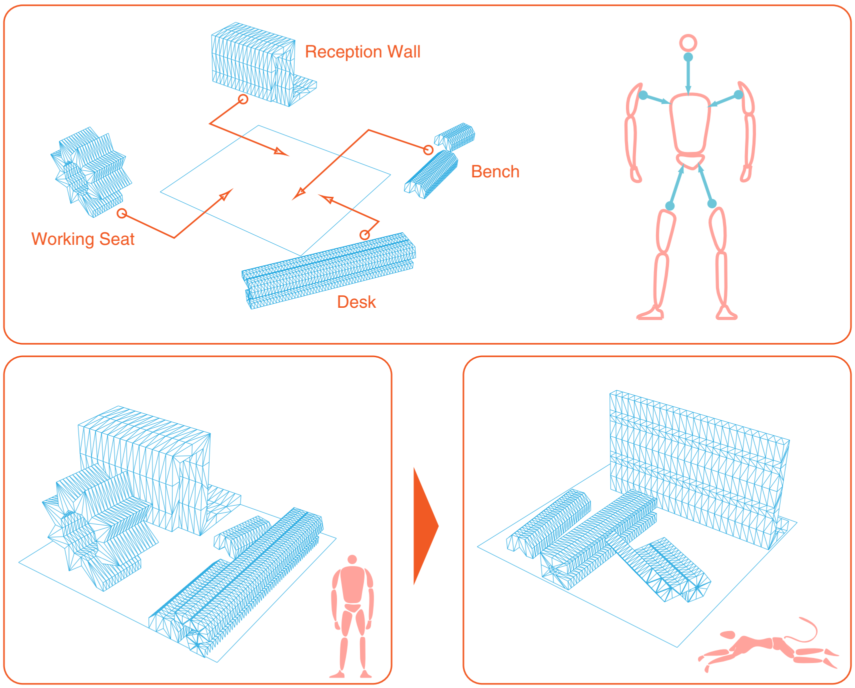


FIGURE 6.9 Diagram illustrating the conceptual idea of having different reconfiguration and combinations of the furniture system as various spatial usages metaphorically representing different species. (I.e. From left to right: private working space to office space; Human being to Panther).

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

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

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

§ 6.5.3 A Series of Developments with HyperCell

1 HyperCell: Geometric Experiments:

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

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

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

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

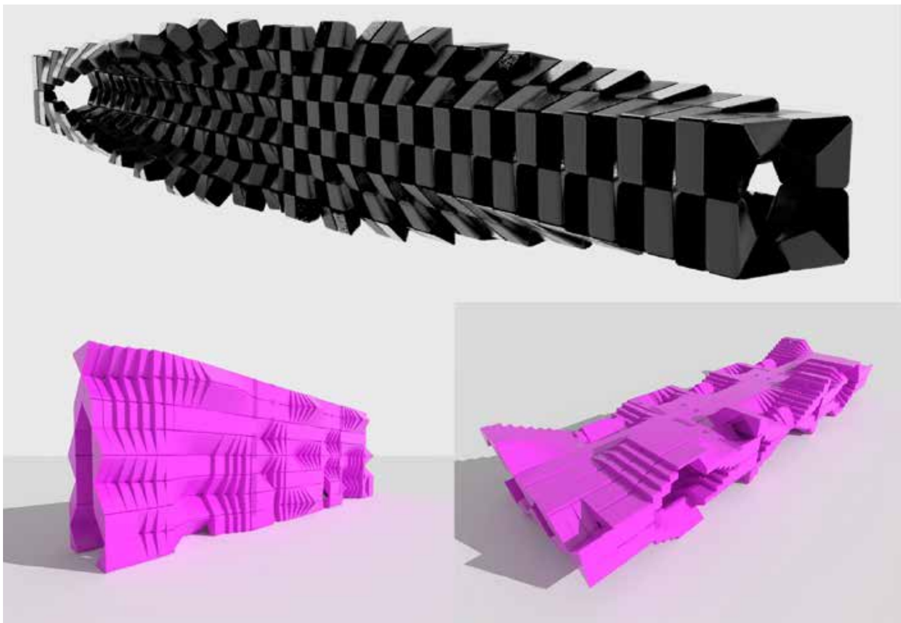


FIGURE 6.10 The first generation of HyperCell component on top, and a Duchamp Wall project following the same logic with more diversity of the morphing patterns.

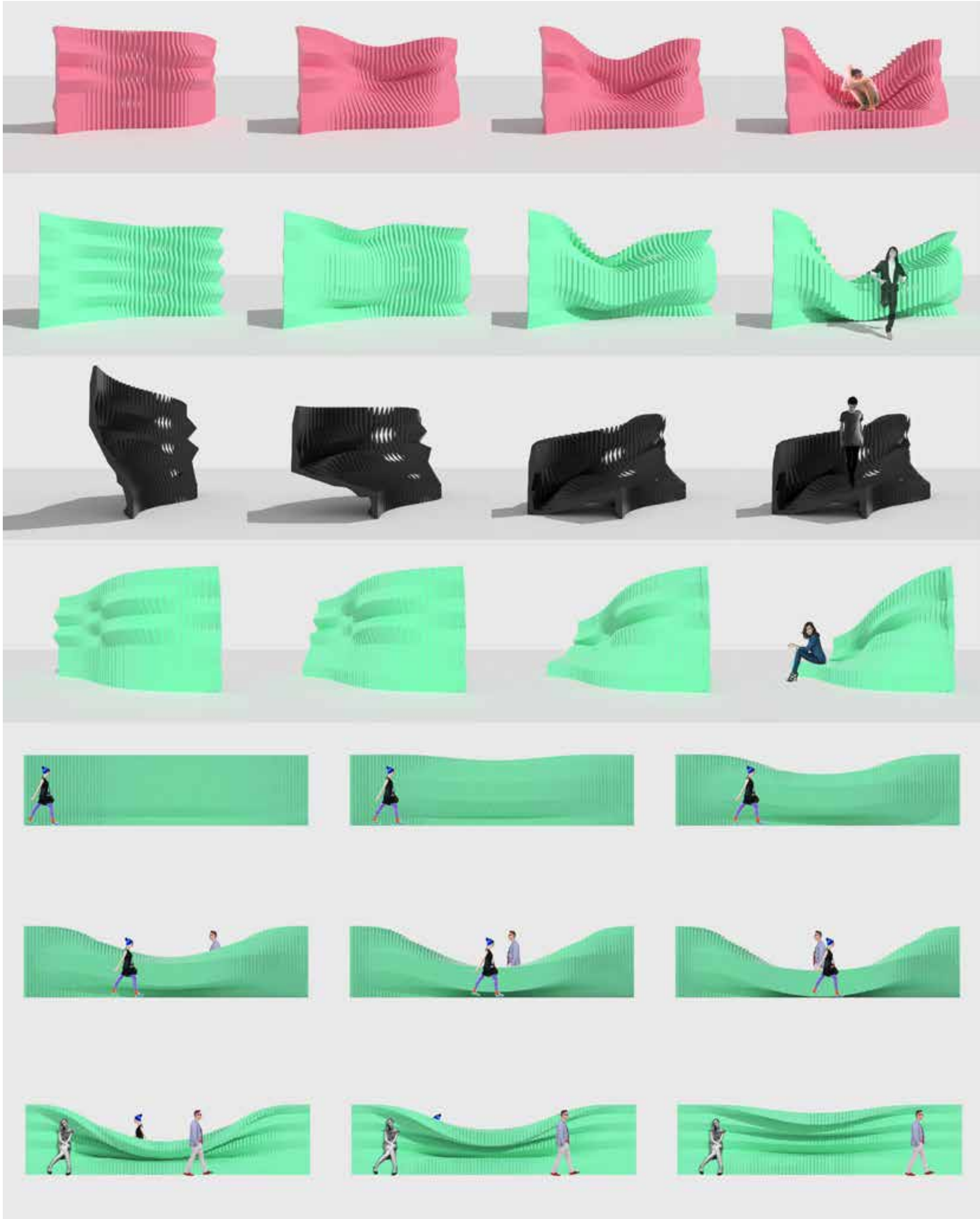


FIGURE 6.11 HyperCell 2.0 Furniture applications such as HyperCell Walls that can reconfigure (transform into) Seats, Counters, Ramps, Waiting Partitions, and Encountering Meeting Spots as multi-functional partitions owing to diverse time slots and users' demands.

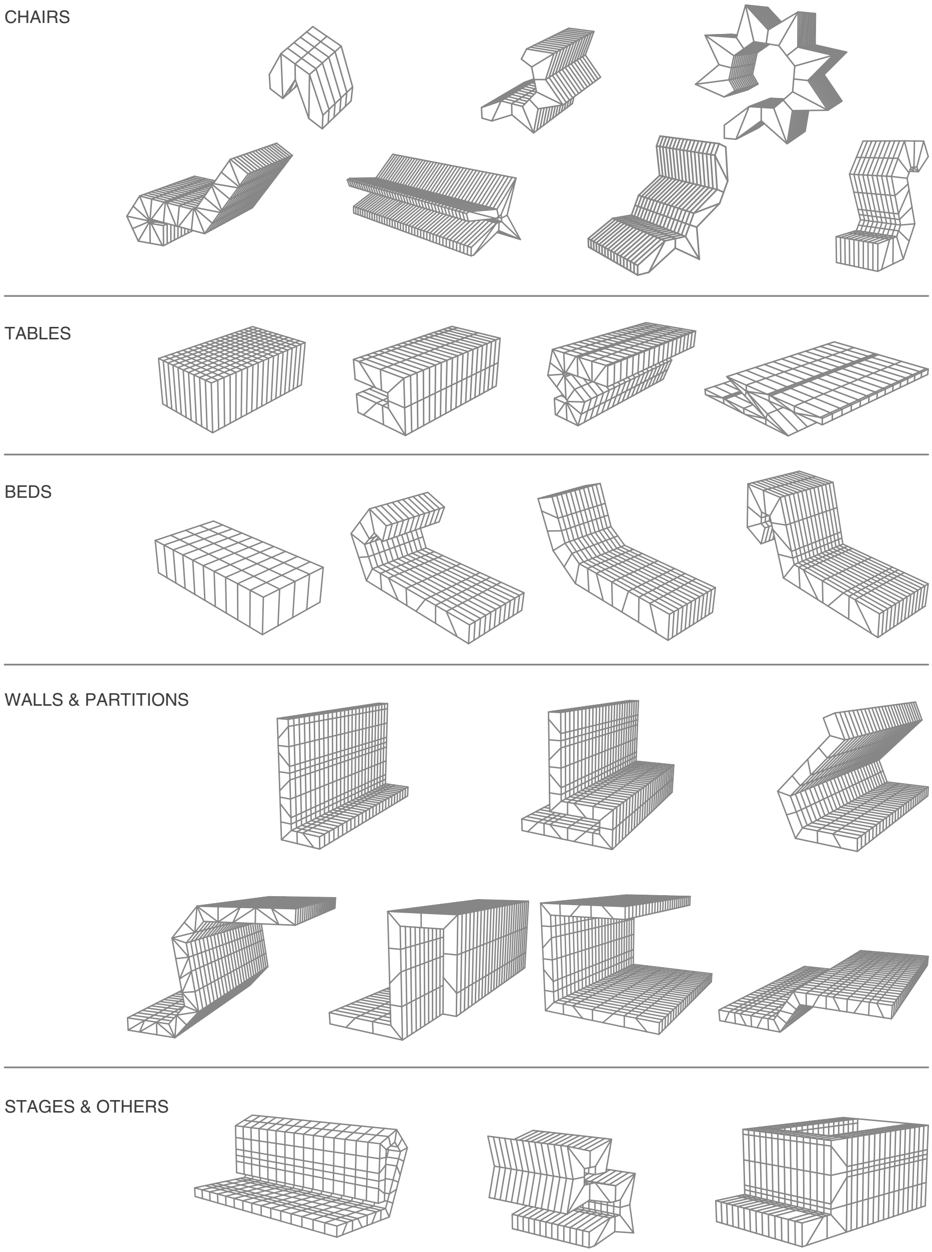


FIGURE 6.12 A 3D Diagram exhibiting the collections of the transformable furniture system made of "HyperCell" components as a catalog. These are variations but can include more diversity in terms of form and usage. The catalog with L-DAN and D-DNA is found in Appendix i.

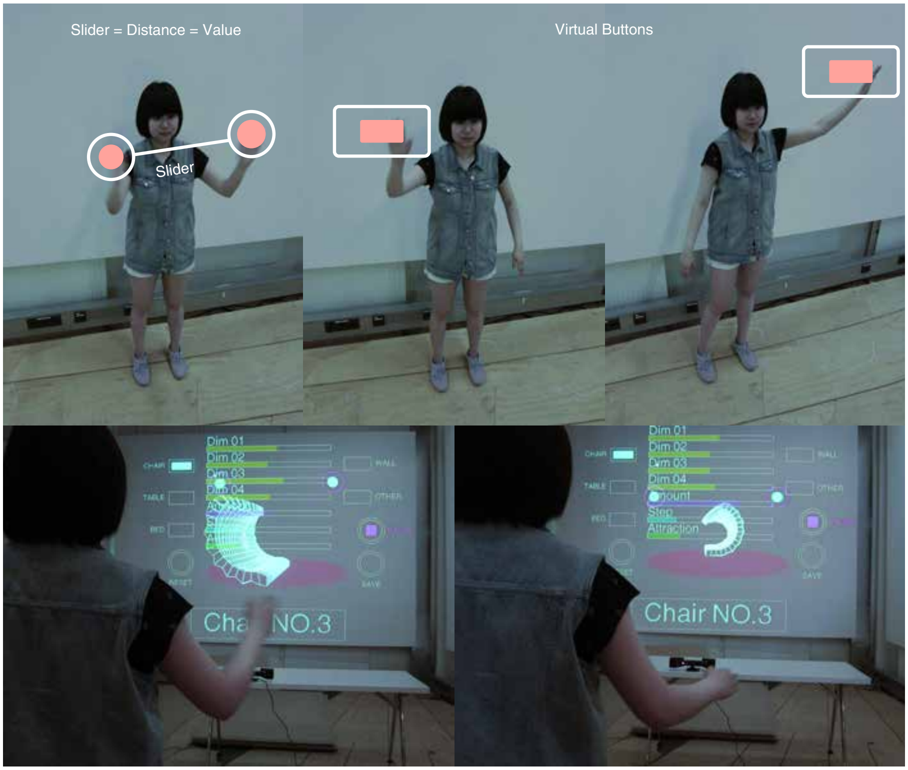


FIGURE 6.13 Top image shows the concept of virtual slider and button in accord with hand gestures. Bottom image records the utilization of the HyperCell interface in real physical space (see the video here: https://vimeo.com/68836252).

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

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

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

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

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

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

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

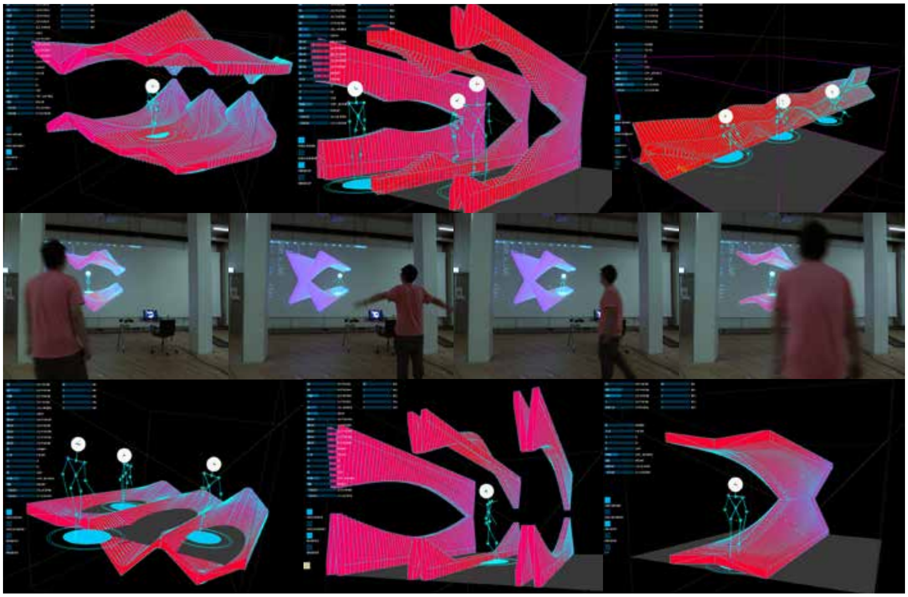


FIGURE 6.14 Images exhibiting the Virtual Reality Space built up by transformable HyperCell components which is able to interact with the users in real-time as an immersive spatial experience by utilizing the Processing real-time simulation and motion tracking technology cooperating with Microsoft Kinect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

§ 6.6 Brief Conclusion

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

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

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

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

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

§ 6.7.1 Ambiguous Topology

FIGURE 6.15 Image of "Ambiguous Topology".

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

Ambiguous Topology Introduction

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

Volumetric Projection System

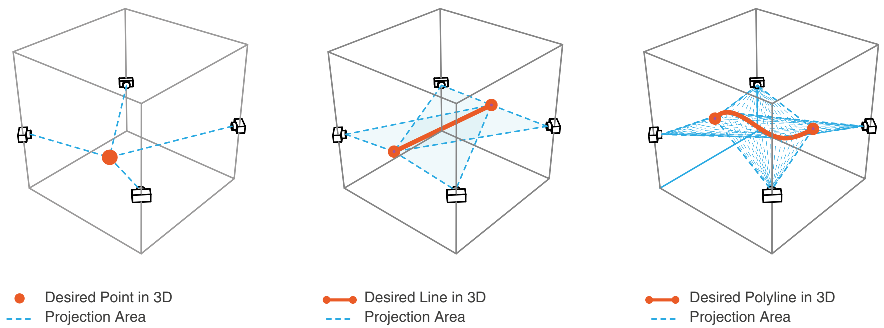


FIGURE 6.16 Diagrams showing basic principles and setup for 3-Dimensional geometry realization based on the volumetric projection system.

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

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

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

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

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

Swarm Behavior Premise:

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

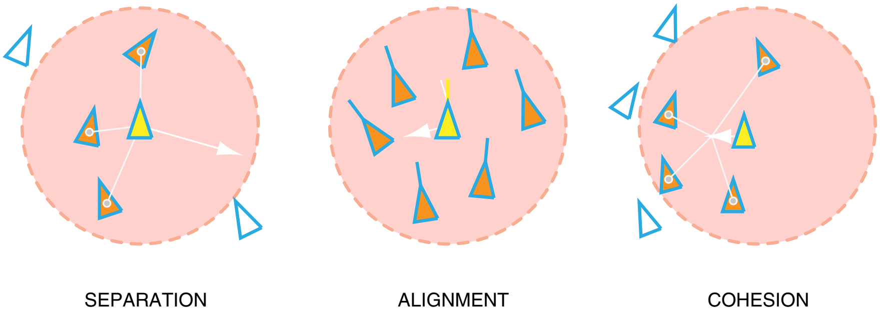


FIGURE 6.17 Diagrams of Craig Reynold's swarm behavior principles for the flocking simulation; separation, alignment, and cohesion. (http://www.red3d.com/cwr/boids/).

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

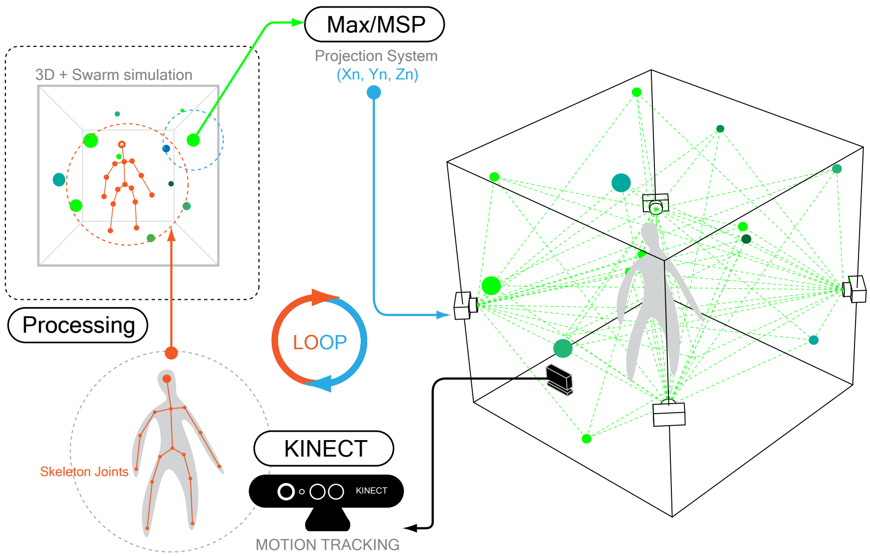


FIGURE 6.18 Diagram showing the interactive loop of data streams.

Technical Interpretation:

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

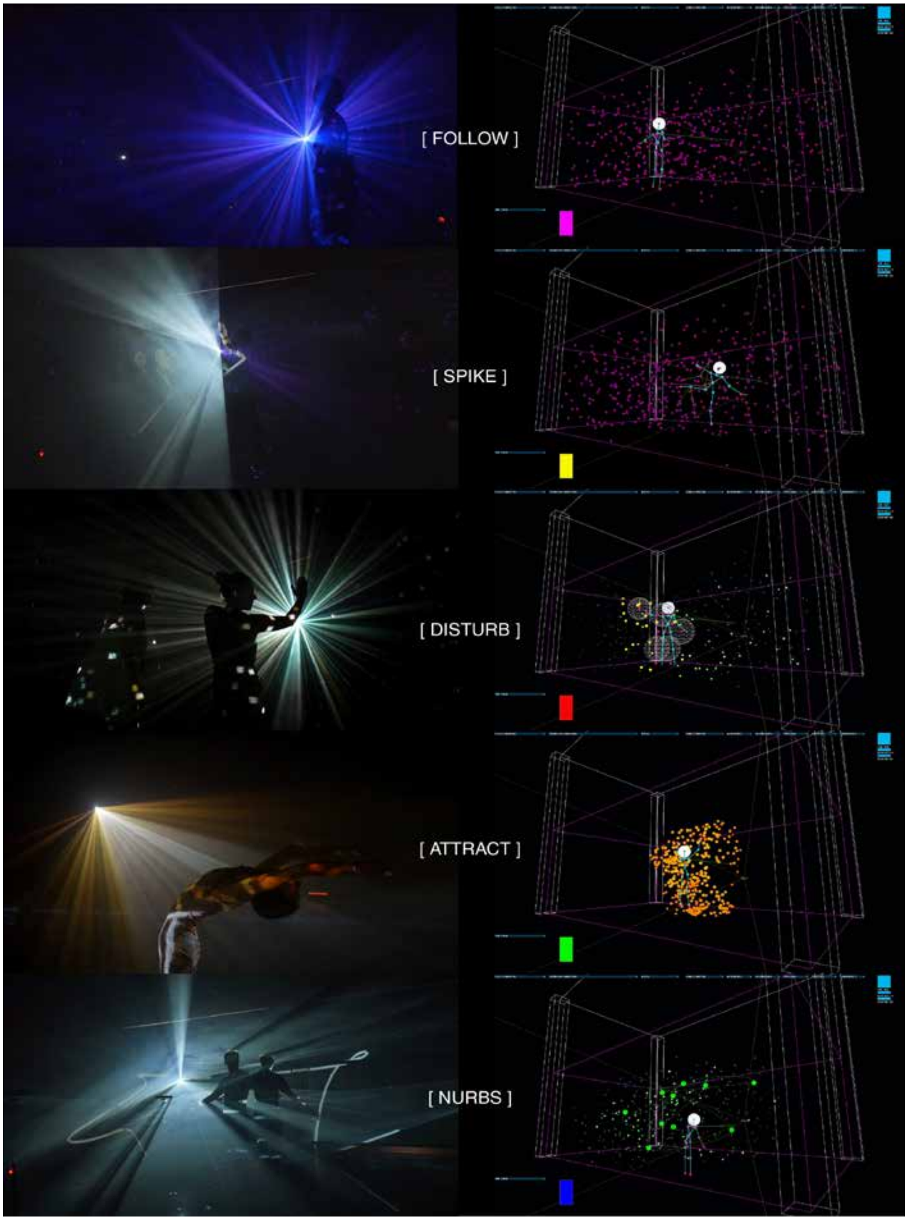


FIGURE 6.19 Images showing different modes of the Ambiguous Topology experience with scenes of "Follow", "Spike", "Disturb", "Attract", and "Nurbs" mode from top to bottom with photos taken on the left and simulations on the right side.

Settings and the Narrative:

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

Rain Mode:

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

Follow Mode:

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

Spike Mode:

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

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

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

Nurbs Mode:

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

Rain-Up Mode:

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

Ambiguous Topology Conclusion

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

§ 6.7.2 HyperLoop, an Intra-active Pavilion

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

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

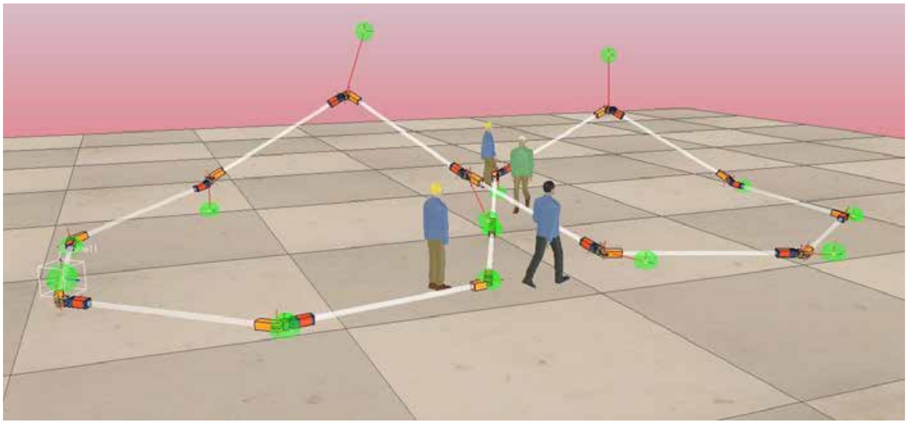


FIGURE 6.20 HyperLoop pavilion simulation by V-Rep.

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

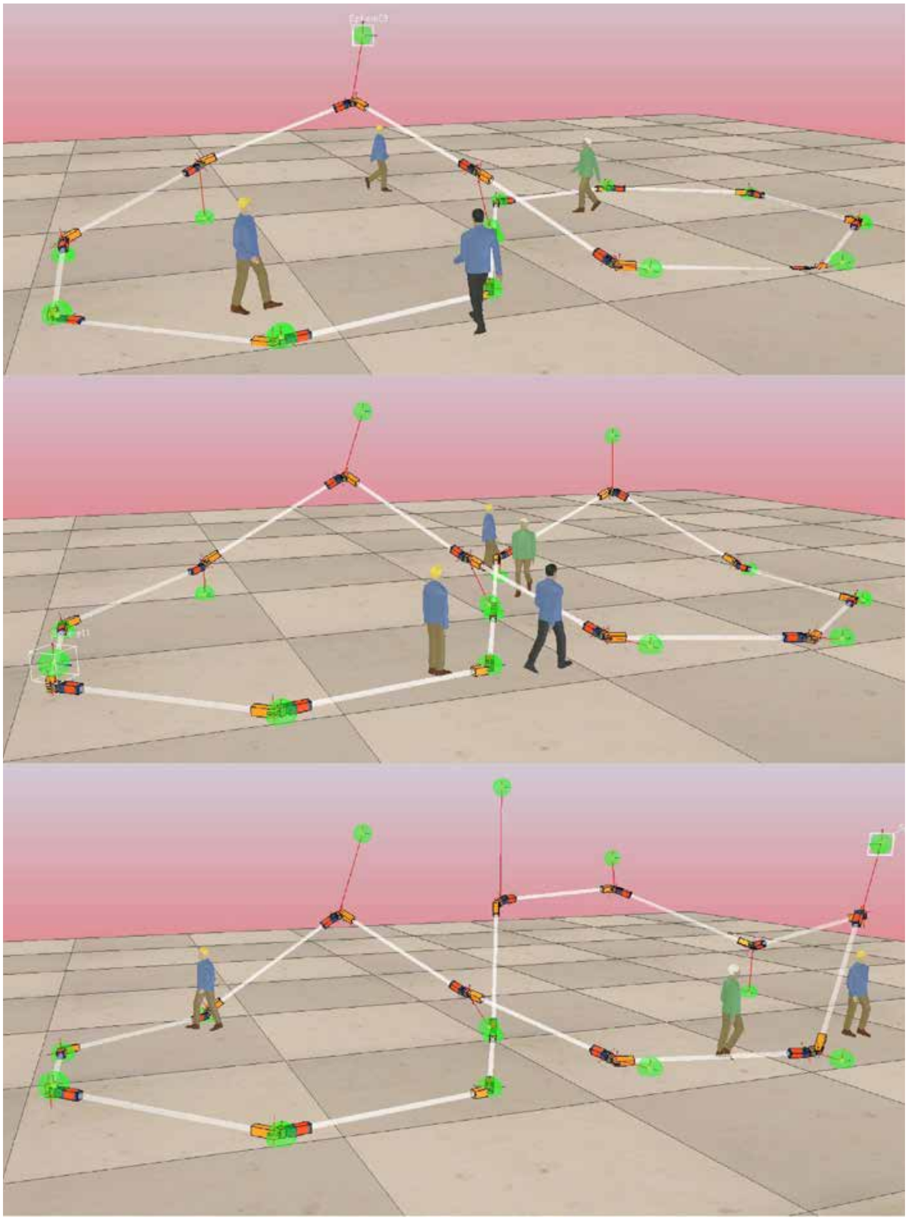


FIGURE 6.21 The real-time morphology simulation of HyperLoop acting by embracing and repelling movement among the people surrounding it by V-Rep.

= Mechanical Make-up + Consensus Algorithm

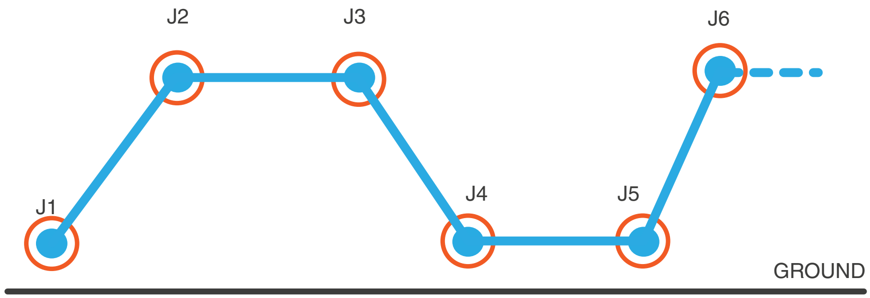


FIGURE 6.22 Diagram explaining the mechanical loop structure concerning the capability of the joint against gravity: NO.1 joint staying on the ground can possibly hold NO.2 and NO.3 joints in the Air but NO.4 joint would have to stay on the ground in order to support the structural stability.

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

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

Joint Design Developments

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

Initial Thought:

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

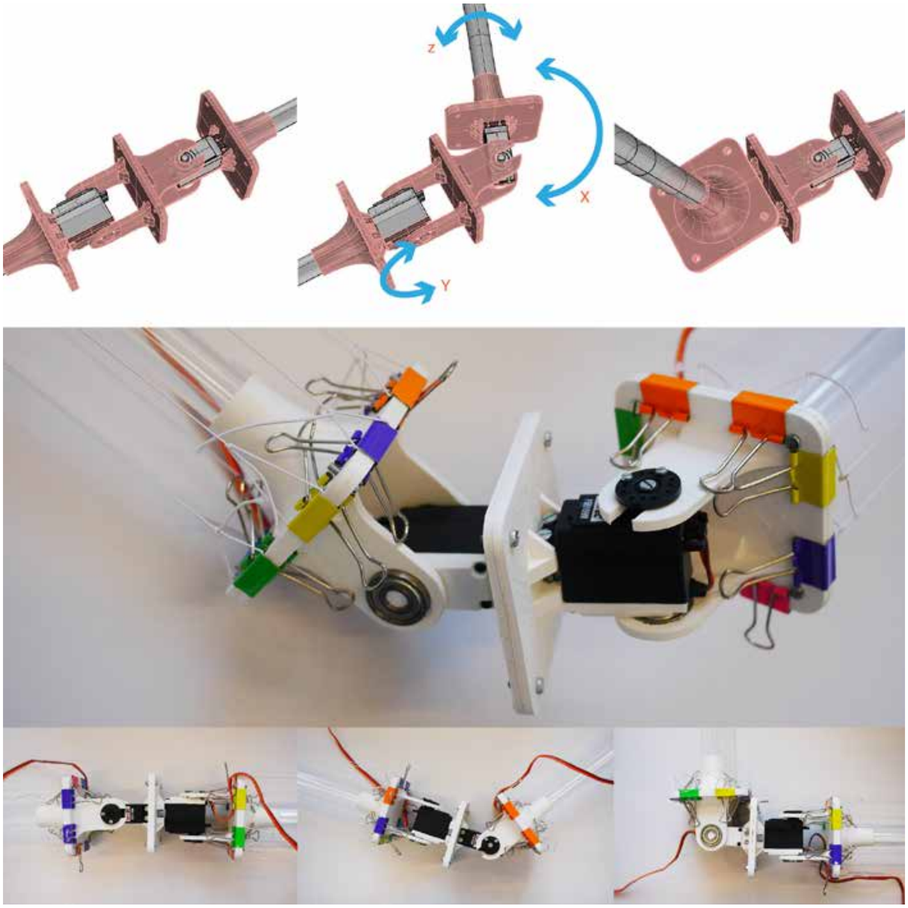


FIGURE 6.23 Diagrams illustrating the flexibilities and the rotation axis of the joint design at the initial experiment stage. The bottom is the photo of the 3D printing prototype embedded with 2 servo motors as the rotating actuators.

Idea Proposal:

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

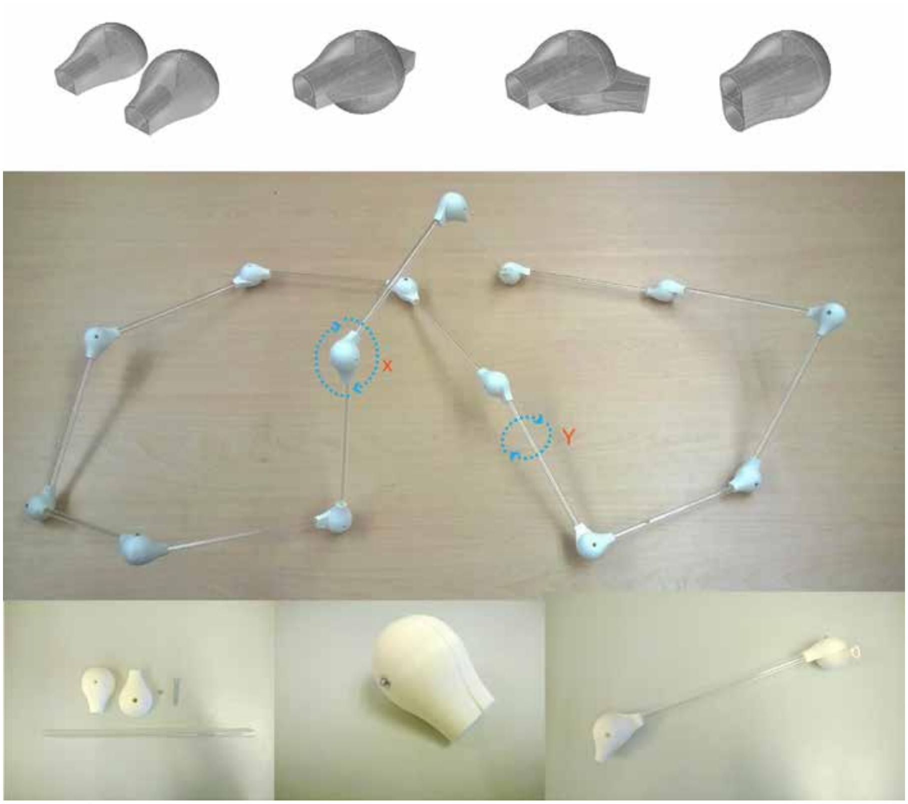


FIGURE 6.24 Images exhibiting the simulations and the photos of the 3D printing joint as scale models for examining the flexibility of the pavilions. The sphere shape of the joint reduces one directional rotation to make it functionally more impactful and efficient and also relatively more protectable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

Physical Prototype:

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

TOC

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

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

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

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

§ 6.8 Conclusion

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

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

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

References

Benyus, J. M. (1997). *Biomimicry: Innovation Inspired by Nature.* New York: HarperCollins Publishers Inc.

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.

Deleuze, G., & Guattari, F. (2003). *Anti-Oedipus: Capitalism and schizophrenia.* Londom: Continuum.

Engelbart, D. (1962). *Augmenting Human Intellect: A Conceptual Framework.* Washington DC: Stanford Research Institute. Retrieved from http://www.dougengelbart.org/pubs/papers/scanned/Doug_Engelbart-AugmentingHumanIntellect.pdf

Fox, Michael, & Kemp, Miles. (2009). *Interactive Architecture.* New York: Princeton Architectural Press.

Leibniz, G. W. (1714). *Monadology.* (J. Bennett, Trans.) Continuum. Retrieved from http://www.earlymoderntexts.com/assets/pdfs/leibniz1714b.pdf

McLuhan, M. (1964). *Understanding Media: The Extensions of Man.* New York: McGraw-Hill.

Novak, M. (1991). Liquid Architectures in Cyberspace. In M. Benedikt, *Cyberspace: First Step* (pp. 225-255). Cambridge: The MIT Press.

Oosterhuis, K. (2003). *HyperBodies: Towards an E-motive Architecture.* Basel: Birkhäuser.

O'Sullivan, Dan & Igoe, Tom. (2004). *Physical Computing: Sensing and Controlling the Physical World with Computers.* Boston: Course Technology Press.

Palumbo, L. M. (2000). *New Wombs: Electronic Bodies and Architectural Disorders.* Basel: Birkhäuser.

Price, C. (2002). Generator Project. In *Cyber_Reader: Critical Writings for the Digital Era* (pp. 86-89). London: Phaidon Press Limited.

Reynolds, C. W. (1987). Flocks, herds and schools: A distributed behavioral model. *Compute Graphics, 21*(4), 25-34.

Reynolds, C. W. (1999). Steering Behaviors For Autonomous Characters. *Proceedings of Game Developers Conference* (pp. 763-782). San Francisco: Miller Freeman Game Group.

Thompson, D. (1992). *On Growth of Form.* London: Cambridge University Press.

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.hyperbody.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.

References

Deleuze, G., & Guattari, F. (2003). *Anti-Oedipus: Capitalism and schizophrenia*. Londom: Continuum.

Frazer, J. (1995). A Natural Model for Architecture/ The Nature of the Evolutionary Mode. In J. Frazer, *An Evolutionary Architecture*. London: Architectural Association.

Leibniz, G. W. (1714). *Monadology*. (J. Bennett, Trans.) Continuum. Retrieved from http://www.earlymoderntexts.com/assets/pdfs/leibniz1714b.pdf

Negroponte, N. (1975). Soft Architecture Machine. In *Computer Aided Participatory Design* (pp. 102-123). Cambridge: MIT Press.

Pask, G. (1969). The Architecture Relevance of Cybernetics. *Architectural Design*, 494-496.

Appendix

Appendix I

HyperCell Furniture Catalogue_

Before you read the catalog, you should know the form driven logic behind it. The catalog displayed here only defines the default settings of the HyperCell transformable furniture. There is no limitation to explore more potential possible topological, Tatami, Origami or Tangram-like applications following the design principles.

// L-DNA

= The Ultimate Type and Shape.

= {N,N,N,N...}

The logic extends the "True/False" mirror geometric transformation to determine the assembly regulation of the furniture piece.

// D-DNA

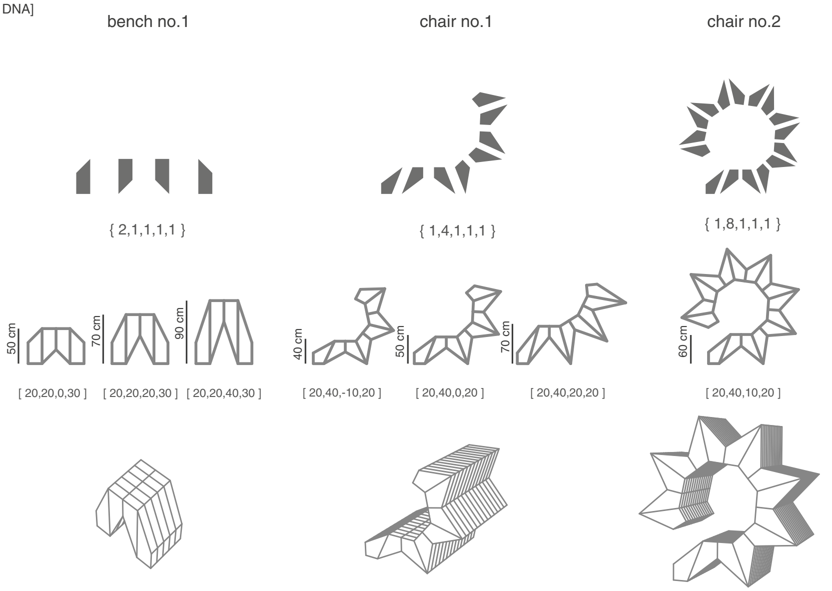
= The Interactive Movement Possibilities.

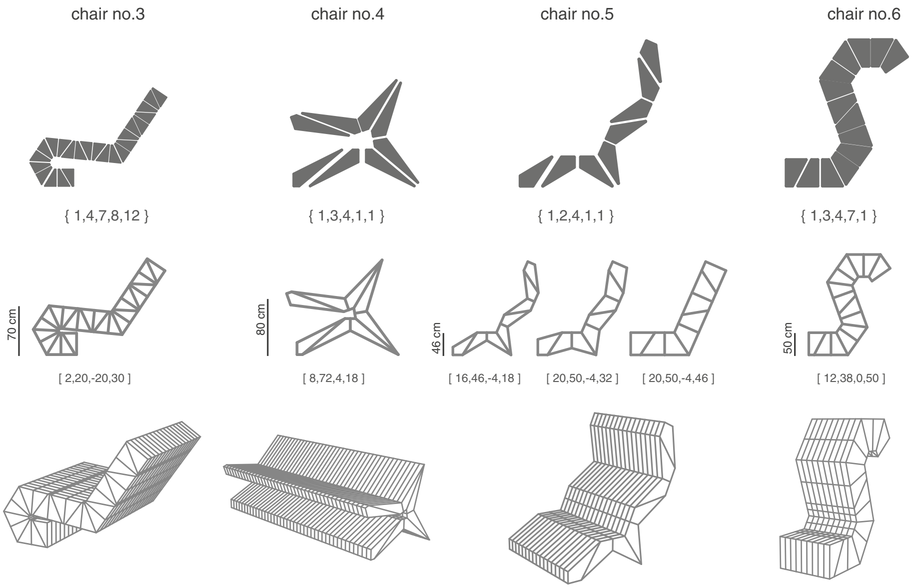
= [N,N,N,N]

The logic defines the basic component's shape as well as the degrees of freedom of the physical constraints of the component in order to interact with the users and make the transformation as a behavior emerging bottom-up.

CHAIRS//

{Logic DNA}
[Dimension DNA]





TABLES//

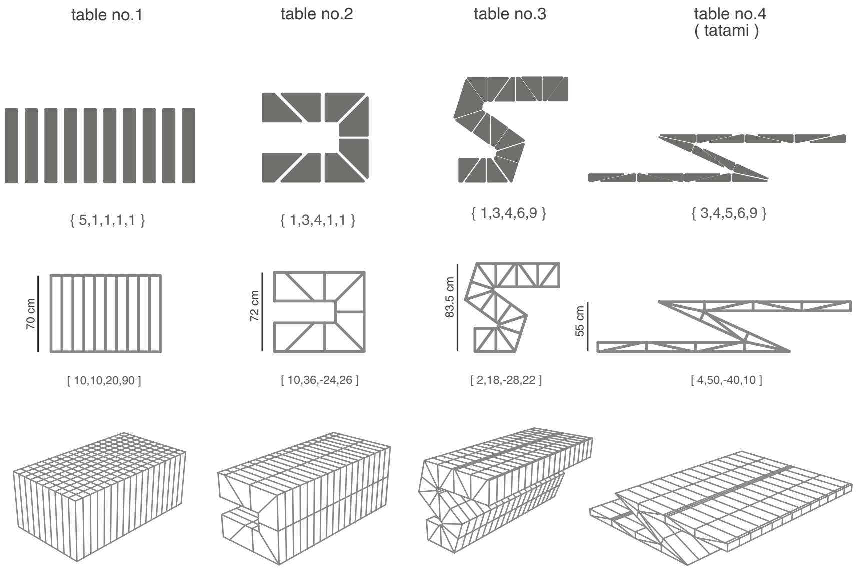
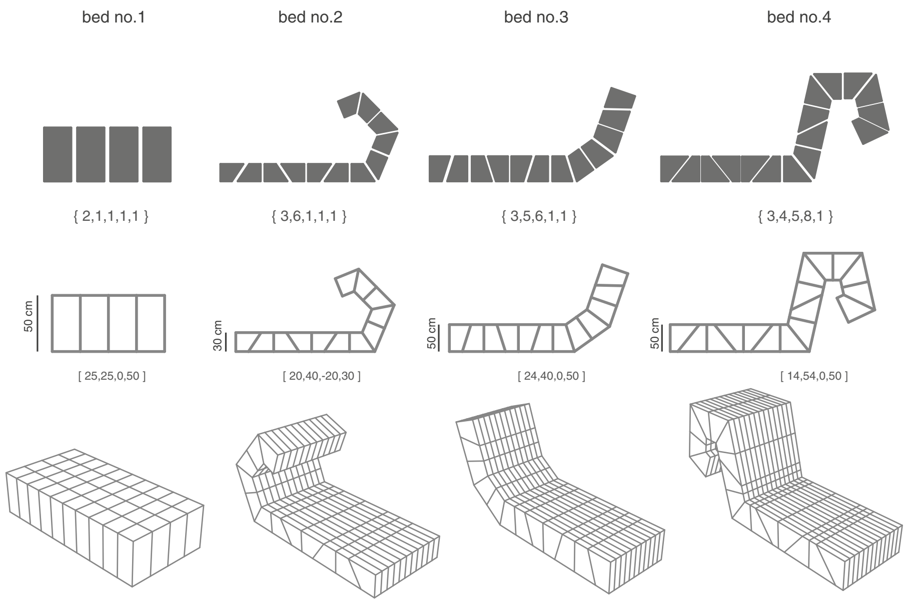
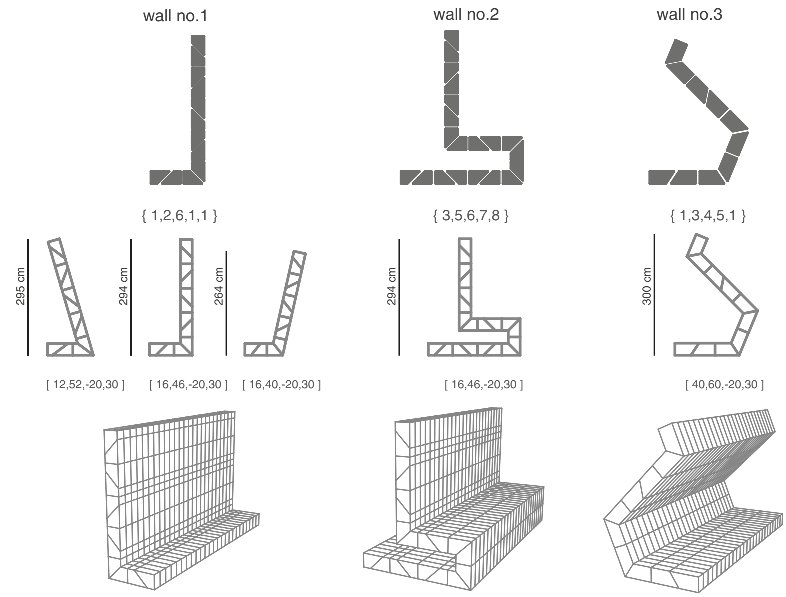


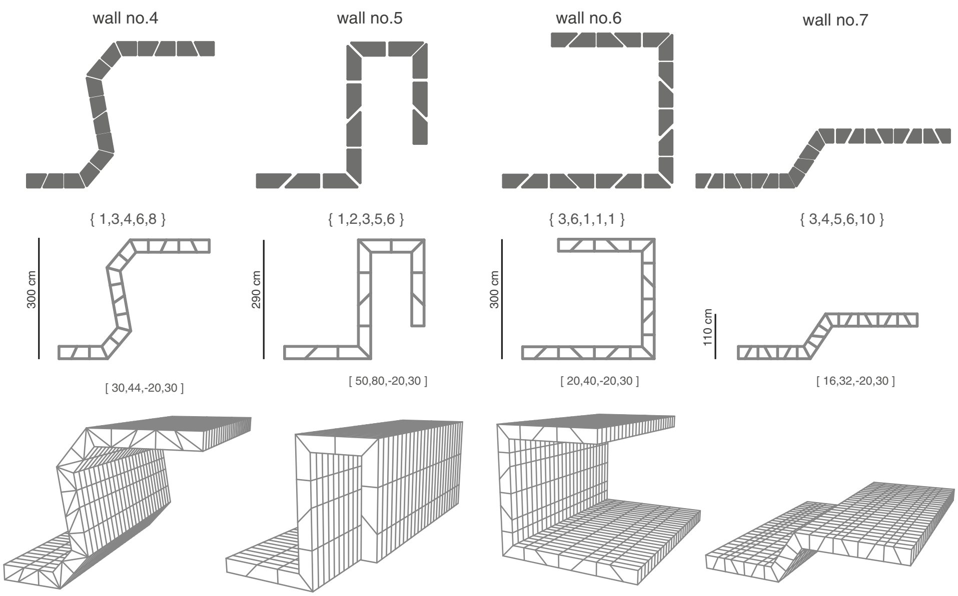
table no.1
table no.2
table no.3
table no.4
(tatami)
{ 5,1,1,1,1 }
{ 1,3,4,1,1 }
{ 1,3,4,6,9 }
{ 3,4,5,6,9 }
70 cm
72 cm
83.5 cm
55 cm
[10,10,20,90]
[10,36,-24,26]
[2,18,-28,22]
[4,50,-40,10]

BEDS//

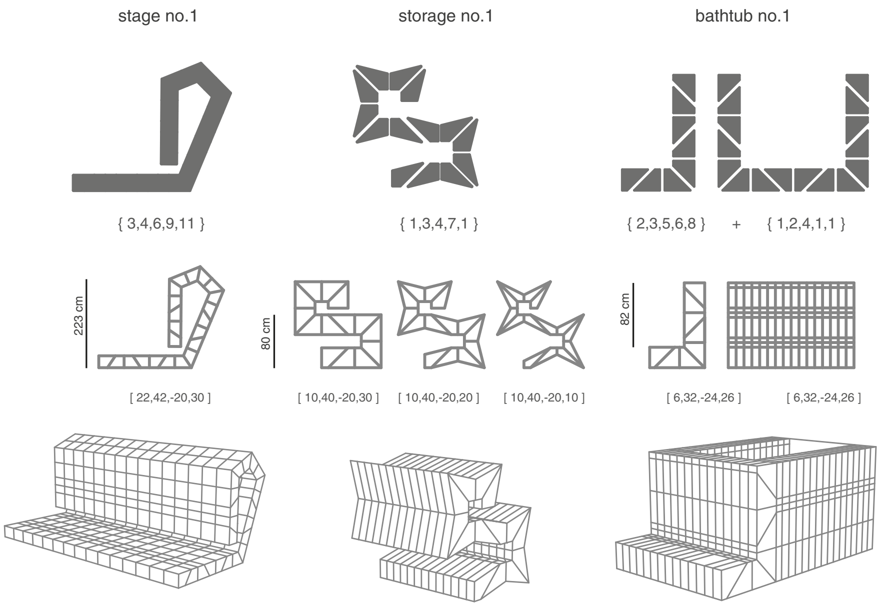

bed no.1
bed no.2
bed no.3
bed no.4
{ 2,1,1,1,1 }
{ 3,6,1,1,1 }
{ 3,5,6,1,1 }
{ 3,4,5,8,1 }
50 cm
30 cm
50 cm
50 cm
[25,25,0,50]
[20,40,-20,30]
[24,40,0,50]
[14,54,0,50]

WALLS & PARTITIONS





STAGES & OTHERS



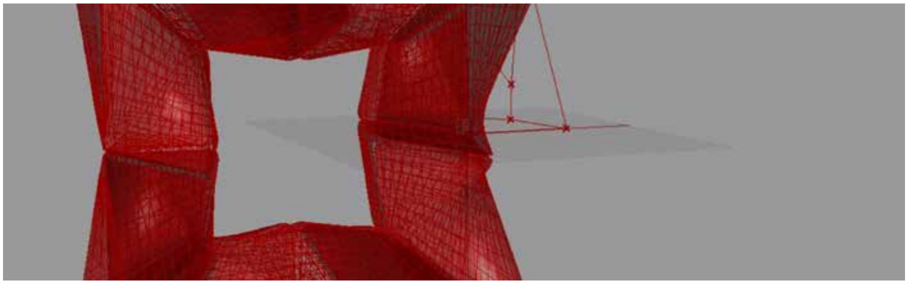
Appendix II

||Videos & Images Links_ 2011-17:

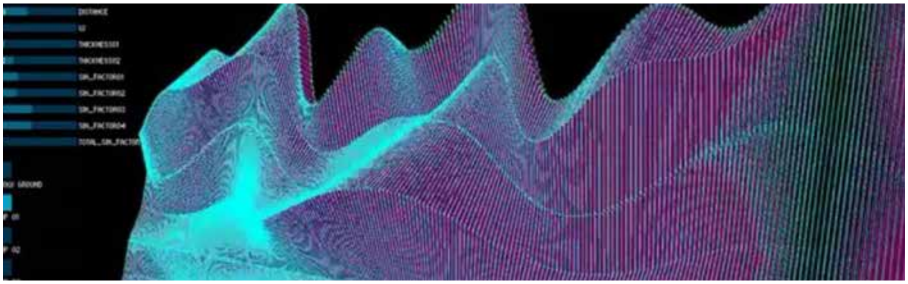
The videos exhibit the simulations, prototypes, studio & workshop results and other projects:

//RESEARCH RELATED

HyperCell Series:

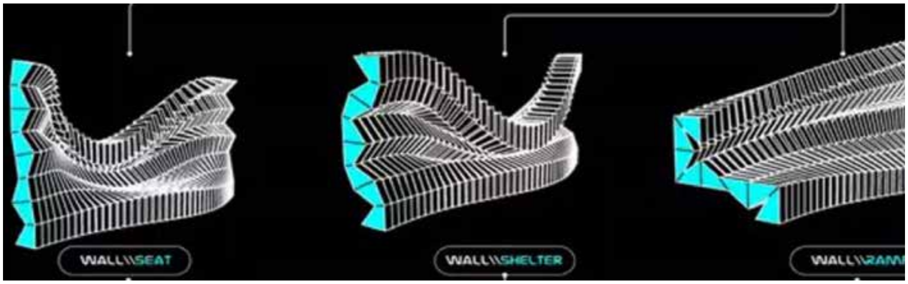


HyperCell 1 HyperCell Geometric Concept Simulation: https://vimeo.com/34121883.

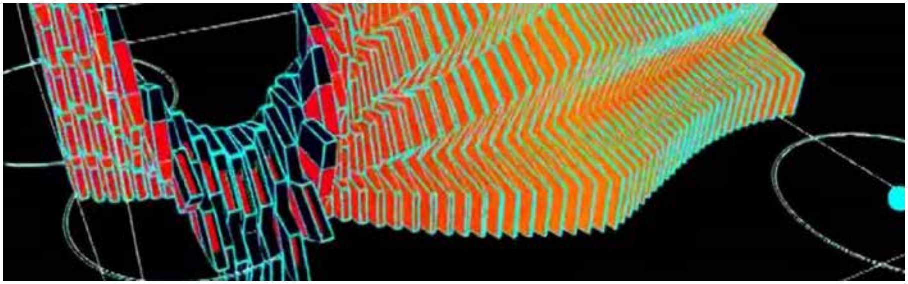


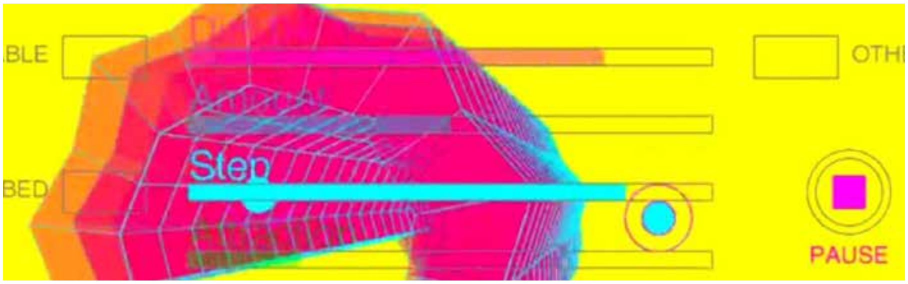
HyperCell 2 HyperShell Processing Experiment: https://vimeo.com/50818076.

HyperCell 3 HyperCell SmartPhone Wireless Control: https://vimeo.com/41069182.

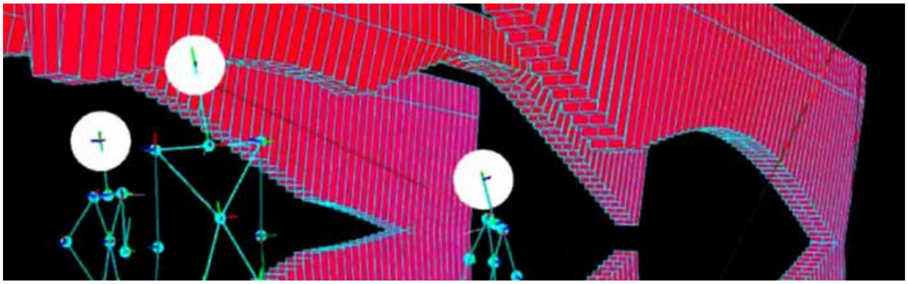


HyperCell 4 HyperWall/Furniture: https://vimeo.com/55289946.


HyperCell 5 HyperCell Processing Real-Time Simulation: https://vimeo.com/61828421.



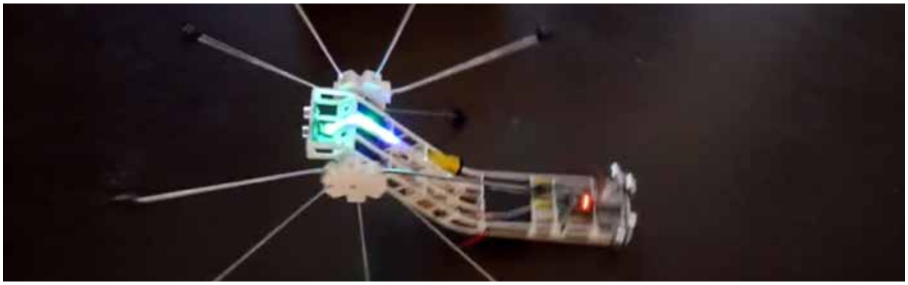
HyperCell 6 HyperCell Freehand User Interface: https://vimeo.com/68836252.


HyperCell 7 HyperCell Virtual Reality = Motion Tracking interaction: https://vimeo.com/78387283.

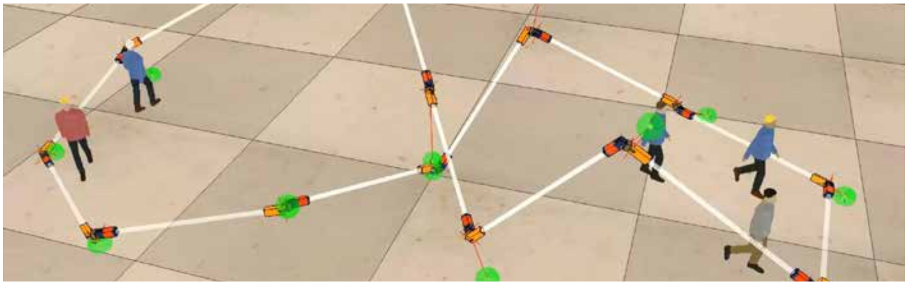
MetaBody Series:

MetaBody 1 Ambiguous Topology_Teaser: https://vimeo.com/105027652 & Technical Details: https://vimeo.com/105421757.

MetaBody 2 Reflect-Ego: https://vimeo.com/113264230, Master students' project tutored by the researcher.



MetaBody 3 roboZoo: https://vimeo.com/113264651, Master students' project tutored by the researcher.



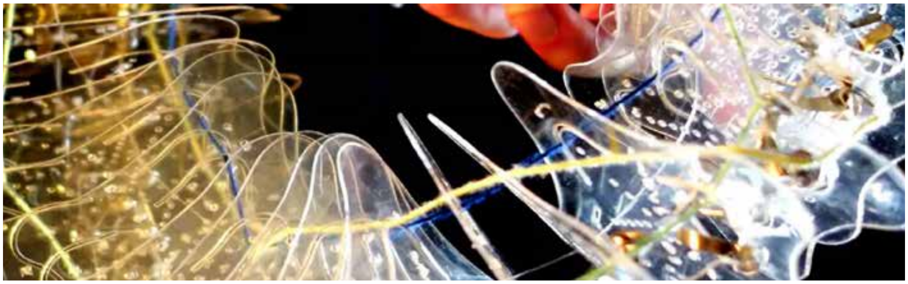
MetaBody 4 HyperLoop Vrep simulation: https://vimeo.com/117388146.

Studio & Workshop Series:

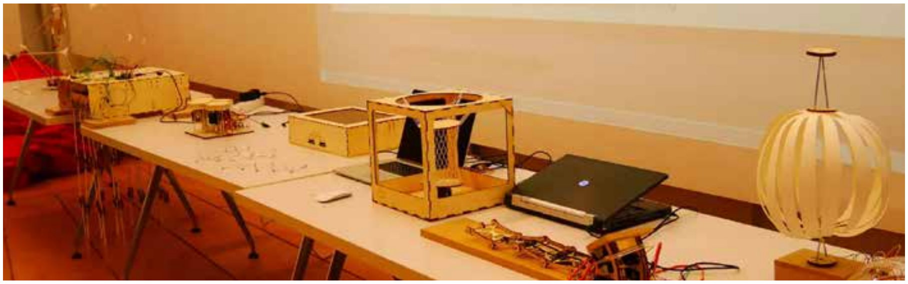
Studio 1 Interactive-Performance Environment Master Studio: https://vimeo.com/99547203.

Studio 2 Interactive-Activating Environment Master Studio: https://vimeo.com/132665634.

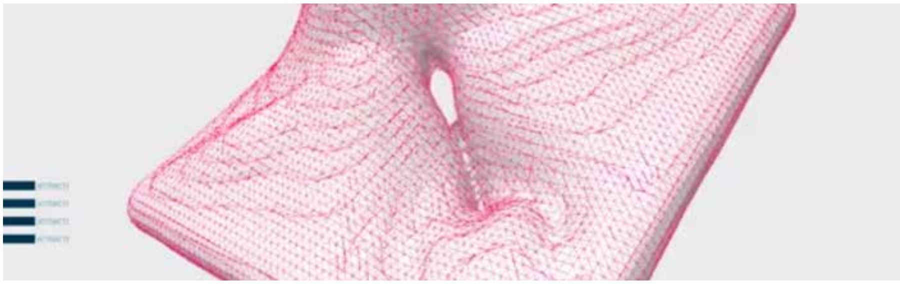
Workshop 1: InteractiveBody Workshop 1.0: https://vimeo.com/61092607.



Workshop 2 InteractiveBody Workshop 4.0: https://vimeo.com/123616248.

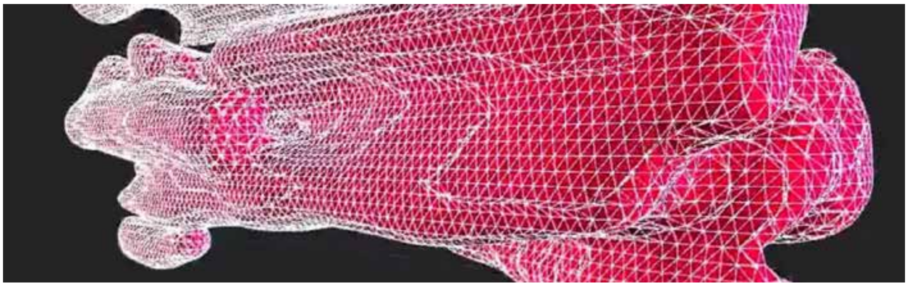


Workshop 3 InteractiveBody Workshop 5.0: https://vimeo.com/145983370.



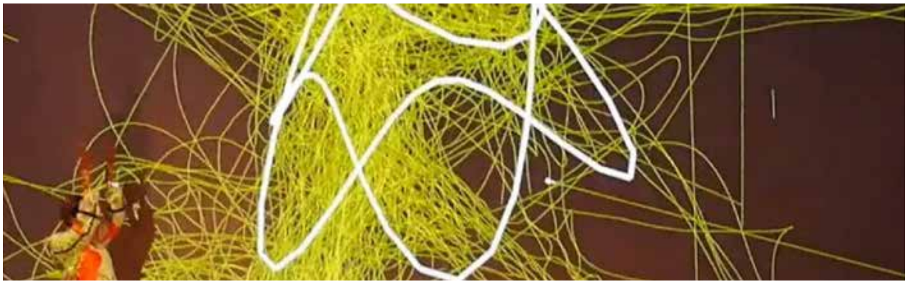
Workshop 4 Swarmmy Workshop: https://vimeo.com/39280102.

//OTHERS

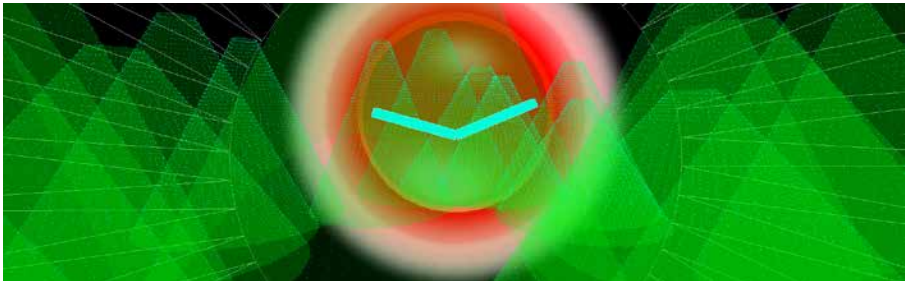


Others 1 A showreel of projects developed in “Processing” as a creative coding tool: https://vimeo.com/126749919.

Others 2 An animation illustrating the main visual effects of a CD Cover Design: https://vimeo.com/104761795.



Others 3 Visual Design for “Immaterialicious”, the First Ever Interactive Fashion Show in the Netherlands: https://vimeo.com/174651503.



Others 4 The Deep Sound of Maramure, a real-time interactive performance cooperating with Romania composer who blending the traditional Romania music with contemporary electric music: https://vimeo.com/217832317.

Curriculum Vitae

Jia-Rey(Gary) Chang was born in Taiwan. After completing his M.Arch degree in Architecture and Urban Design Department, UCLA, under the direction of Neil Denari in 2009, he came back to his Alma mater, the Architecture Department in TamKang University, Taiwan, researching on interactive and parametric architecture. In 2010, he established "P&A LAB" (Programming and Architecture LAB: http://pandalabccc.blogspot.com, and lately integrated into archgary.com: http://www.archgary.com to continue) exploring the new possible relationship between the programming and architecture. Meanwhile, he also worked in the Architecture Department of the National Taipei University of Technology as an adjunct lecturer.

In 2011, he joined the Hyperbody LAB (http://www.hyperbody.nl/) to further develop his preliminary research on the "HyperCell", a bio-inspired architectural component with intelligence, kinetic energy, self-assemble and self-adaptive capacities based on evolutionary development biology and swarm behavior principles. Cooperating with choreographers, visual artists, composers, and programmers, he has been involved in an EU project, MetaBody (http://metabody.eu/), during 2011-2014 to explore the pro-activeness and intra-action between the human body, its movement and spatial quality. Meanwhile, he is also extremely interested in the transdisciplinary topics of fashion design, creative coding, visualization, 2D/3D simulation, interactive design and motion tracking technology, and conduct numerous workshops over the years.

| Cell Phone: +31(0)648615006 | E-mail: archgary@gmail.com
| Website: www.archgary.com, http://pandalabccc.blogspot.com/

Publications

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.

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.

Biloria, Nimish & Chang, Jia-Rey. (2016). Swarmscape: A Synergistic Approach Combining Swarm Simulations, Body Movement and Volumetric Projections to Generate Immersive Interactive Environments. *Advances in Swarm Intelligence: 7th International Conference, ICSI 2016* (pp. 142-153). Bali: Springer International Publishing.

Chang, J.-R. (2015). From Interactive to Intra-Active Body: New Organic Digital Architecture. *New Architecture, 162*, 40-45.

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.