Sentient Matter:
Towards Affective Human-Architecture Interaction

by
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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Architecture
in
Engineering

Waterloo, Ontario, Canada, 2015

Author's Declaration

“I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public

ABSTRACT

Interactive design has been embedded into every aspect of our lives. Ranging from handy devices to architecturally scaled environments, these designs have not only shifted the way we facilitate interaction with other people, but they also actively reconfigure themselves in response to human stimuli. Following in the wake of interactive experimentation, sentient matter, the idea that matter embodies the capacity to perceive and respond to stimuli, attempts to engage in a challenging arena that few architects and architectural researchers have ventured into. In particular, the creation and simulation of emotive types of interaction between the architectural environment and its inhabitants.

This ambition is made possible by the collaboration of multiple disciplines. Cybernetics, specifically the legacy of Pask's conversation theory, inspires this thesis with the question of why emotion is needed in facilitating human–architecture communication; why emotion appraisal theory (P. Desmet) within psychology supports the feasibility of an architectural environment to elicit emotional changes on its participant as well as the possibility of generating a next-step response by having the participant's emotive behaviors observed; and why movement notation systems, especially Laban Movement Analysis (a movement rating scale system), helps us to understand how emotions can be identified by motion elements that signify emotive behavior. Through the process of decomposing movement into several qualitative and quantitative factors such as velocity, openness, and smoothness, emotions embodied in motion can be detected and even manipulated by altering those movement factors. Moreover, with the employment of a Kinect sensor, live performance can be analyzed in real time.

Based on the above research and inspired by the Kinetic sculptures of Margolin, the final product of this thesis is the development of a prototype that translates human movements that are expressive of emotion into continuous surface transformations, thus making evident how such emotive states might be transcoded into an architectural form. In this process, four typical emotive architectural expressions—joy, anger, excited, and sadness—are researched. This thesis also documents three virtual scenarios in order to examine the effect of this interactive system. Different contexts, kinetic types, and behavioral strategies are presented so that we may explore their potential applications.

Sentient matter outlines a framework of syntheses, which is built upon the convergence of embedded computation (intelligence) and physical counterpart (kinetics). In the entire process, it considers people's participation as materials that fuel the generation of legible emotional behaviors within an architectural environment. Consequently, there is potential for an architectural learning capacity coupled with an evolving data library of human behavioral knowledge. This opens doors for futuristic designs where the paradigm shifts from "What is that building?" to "What is that building doing?"

Acknowledgements

To my parents: Thank you for your endless love and support in making me who I am.

To my supervisor, Philip Beesley: Thank you for your meticulous guidance during my thesis pursuit. I will always remember your encouragement to be rigorously innovative and ambitious.

To my committee members, Ila Berman and Rick Andrighetti: Thank you for challenging me in my intellectual endeavor with the most relevant insights.

To my friends, Joy Zhang, Tim Wat, Maryam Elnaggar, Edwina Chen Thank you for all the patience and encouragement you gave me at the hardest movement. I love you guys.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

"I go up", said the elevator, "or down."
"Good," said Zaphod, "We're going up."
"Or down," the elevator reminded him.
"Yeah, OK, up please."
There was a moment of silence.
"Down's very nice," suggested the elevator hopefully.
"Oh yeah?"
"Super."
"Good," said Zaphod, "Now will you take us up?"
"May I ask you," inquired the elevator in its sweetest, most reasonable voice, "if you've considered all the possibilities that down might offer you?"

Conversation with an elevator designed by the Sirius Cybernetics Corporation
in The Restaurant at the End of the Universe by Douglas Adams

There is a growing trend in today's architecture: new emerging innovations in software and robotics are substantially influencing the architectural design process that allows architecture to manifest definitions such as responsiveness, autonomy, cognition, and even emotion. Compared with the conventional status quo of architecture, which is pervasive and unmoving, this new trend encourages architecture to meet the changing needs with respect to evolving individual, environmental, and social demands. Within the scope of interactive architecture, this interdisciplinary field is specialized in emphasizing the communication between architectural environments and its inhabitants. Instead of explaining why the interactive system is necessary, meaningful, or useful to architecture development, sentient matter invests to clarify what is interactive design and whether things are presented to us as interactive.

This interesting dialog between Zaphod and the elevator by Douglas Adams[1] illustrates the dilemma of man creating with artificial intelligence; however, the elevator has its own consciousness, which always makes improper suggestions, in spite of Zaphod's requests. Allowing artifacts to think like a human has been a timeless fantasy. Within the last century, the emergence of cybernetics has led us to seriously considered making this fantasy a reality. The definition of cybernetics as a modern field of research is credited to Norbert Weiner, from his influential book Cybernetics, or Control and Communication in the Animal and the Machine.[2] Evident in the title, Weiner introduces the concept that all self-regulating living and nonliving systems can be explained through the same principles. Based on this, Katherine N. Hayles led a movement, also known as the second-order cybernetics, which takes the notion of feedback one step further by creating artificial cognition from the continuous interaction with people.[3]

Furthermore, the Zaphod and elevator dialog also speaks out on the very nature of "interactive design" in which interaction concerning the transactions of information between two systems (for example, between two people, between two machines, or between a person and a machine). The key to a successful transaction should be in some sense circular, which means the causality should be in both directions; otherwise, it can only be referred to as "reactive." From a historical point of view, this concept of "interactive design" was derived from the legacy of Gordon Pask's conversation theory.[4] In the 1960s, British cybernetic scientist Gorden Pask introduced cybernetics theory into architectural applications, and his conversation theory has been regarded as the essential paradigm of second-order cybernetics. As noted in Pask's

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1.Adams, Douglas. 1995. In "The Hitchhiker's Guide to the Galaxy." Pg 181-182.

2.See section 1.2; Wiener, N.; Cybernetics: Or Control and Communication in the Animal and the Machine.Cambridge, MA,MIT Press, 1965

3.See section 1.2; Hayles, N.K.; Boundary Disputes: Homeostasis, Reflexivity, and the Foundation of Cybernetics, 1996

4.See section 1.2; Maria Femandez; Gorden Pask: Cybernetic Polymath; Leonardo, Volume 41 #2 ; The MIT press, 2008 conversation theory, a fundamental requirement for a conversation is dependent on mutual comprehension to agree or disagree, which enables both parties to understand the creation of meaning. During the interaction, two participants represent a cognitive structure of knowledge, and each of the parts has a different perspective or a different role to play. This insight can be observed from the many works on interactive design: for example, the Musicolour Machine,[5] Ada,[6] and Dune.[7] Therefore, this idea suggests a conceptual framework that the built environment needs in order to facilitate a prosthetic extension of our physical or mental state and, at the same time, contribute stimuli that can affect and have an effect on us.

This integration requires the recognition and expression of human connotative behaviors. Therefore, it is necessary to define a common language used by both parties to bridge the communication gap in order to decipher another's behavior and allow this interpretation to influence his or its response. Emotion appraisal theory[8] can provide brief guidance for understanding this "common language." The theory states that almost any action is the reflection of one's emotional state. Therefore, emotions actually are perceptual assessments of external stimuli based on our "experience filter."[9] If we overlap the emotion appraisal theory to Pask's conversation theory, then, we may find intriguing similarities between the human perception process and the cybernetic control system; thus, a "common language" is perceived, in this certain sense, as a stimulus to each part.

From that perspective, affective movement would be a good solution to reflect the qualities that infer how one feels and communicates. In other words, we can understand one's emotion by observing his or her behavior. However, body movement contains a high degree of flexibility, which makes it challenging to unveil the underlying clues between movement and its legible emotional meanings. This has been resolved previously through the movement notation system, especially Laban Movement Analysis (a movement scale rating system developed by choreographer Rudolf Laban)[10] is employed to provide a systematic approach. "Shape" and "effort" are two main components of Laban Movement Analysis, which describe the physical features and expressiveness of body movement, respectively. Petra Fagerberg, in his research on designing gestures for affective input,[11] tried to collaborate those two components with J. A. Russell's emotion circumplex[12] and found the connection between movement and emotion. Where he defines shape is related to the valence of emotion, while effort is related to the arousal of emotion.

However, expressing emotion through an architectural form is challenging, especially under the circumstance where human

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5.See section 1.2; John Hamilton Frazer, The Cybernetics of Architecture: A Tribute to the Contribution of Gordon Pask; Kybernetes 30, nos.5-6 (2001), 641-651

6.See section 1.2; Kynan Eng, Andreas Bäbler; Ada-Intelligent Space: An artificial creature for the Expo.02;To appear in : Proceeding s of the 2003 IEEE/RSJ International Conference on Robotics and Automation (ICRA 2003)

7.See section 1.2; Studio Roosegaade; DUNE 4.2: The interactive landscape of light alongside the Maas River in Rotterdam NL; https://www.studioroosegaarde.net/project/dune-4-2/

8.See section 1.3; Roseman I.J., Smith G.A; Appraisal theory: Overviews, Assumption, Varieties, Controversies; New York: Oxford University Press; 2001

9.See section 1.3; Bartley S. Howard;Principles of Perception; Harper & Row Publishers; 1958

10. Ann Hutchinson Guest; Dance notation: the process of recording movement on paper;Dance Books, 1984

11. Petra Fagerberg, Anna Stahl, Kristian Hook; Designing Gesture for affective Input: An Analysis of Shape, Effort and Valence; Stockholm University; 2010

12. James A. Russell; A Circumplex Model of Affect; Journal of Personality and Social Psychology 1980, Vol.39, No.6, 1167-1178 communication is dynamic. Most theories of the experience about emotion and architectural form were derived from the nineteenth century; during that time, architects discussed the correlation among symbolic meanings, emotions, and static architectural space. These experiences, therefore, cannot serve the purpose of interactive architecture. With the quantum leap in technology, however, advancing innovations in other fields have been adopted in architectural design. Computing affect, a major subject of developing humanoid robots, thus, is adopted in this thesis, which resulted in the translation of motion–emotion, which is used in order to allow architecture to recognize and even learn from human behaviors as well as internalized emotional intents. Surveys about the computing affect indicates a method that translates LMA descriptors to low-level quantitative parameters in terms of velocity, openness, and smoothness.[13] This helps us to identify salient movement characteristics necessary to express particular emotional intentions and eventually result in a data set for a target emotive expression. This task is accomplished with the application of a Kinect sensor[14]; human movement, therefore, has the capacity to be detected and represented in the digital dimension in real time as a Kinect skeleton model that traces all the main joints of the human body.

This effort also implies a new way of architecture kinetics syntheses where human movement is directly involved in that process. Inspired by Reuben Margloin's kinetic sculpture Connected, which is a torqued square wave sculpture connected with a dancer by multiple strings,[15] we may question whether the movement data collected from Kinect can replace those strings to manipulate a kinetic model. If so, will it be restricted to a certain prototype or have the capacity to adapt to variant kinetic types?

Organization

Sentient matter presents a process-oriented guide to create this interactive system by taking human emotions and emotive behaviors into account. Three fundamental questions are considered throughout this thesis: Why is emotion significant to the establishment of interactive architecture? How do we achieve the emotion-motion-digital parameter translation? How do we collaborate architecture with this transcode process?

Thus, this thesis is organized as follows. The first chapter begins with a background survey of the contemporary development of interactive architecture ranging from different scales, which is in order to point out the definition of interactivity that the causality is double direction. Cybernetics and conversation theory are introduced right after that to claim how critical the mutual comprehension and agreement are in

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[13] *See section 2.3; Emotional Interaction Through Physical Movement; Jong-Hoon Lee, Jin-Yung Park, Tek-Jin Nam; J. Jacko (Ed.): Human-Computer Interaction, Part III, HCII 2007, LNCS 4552, pp. 401–410, 2007.*

[14] *See section 2.4; Andy Payne; Kinect+Firefly; http://www.grasshopper3d.com/profiles/blogs/firefly-1-0066-andkinect-0-0003-now-available*

[15] *See section 3.1.2; Reuben Margolin and Chunky Movement; Waves; http://www.reubenmargolin.com/waves/index.html*

creating interactivity. With the review of other theories (Valera,[14]Noe,[15] Thompson[16]) and architecture work (Ada, Dune), it is more convincing that a common language with a shared cognitive structure needs to be manifested in order to make the behaviors of each part in the conversation believable; thus, the solution resides in understanding the human perceptual experience. Emotion appraisal theory is, thus, adopted. By cross referencing both the cybernetic control model and the emotion elicit model, an affect loop emerges that illustrates the brief mechanics of possibilities of interactions. Meanwhile, it indicates the requirement of a particular method to interpret emotional behaviors.

The next chapter presents the key issue of this thesis, which emphasizes the underlying cue between motion and emotion. Movement notation system, especially LMA (Laban Movement Analysis) and Russell's emotion circumplex are employed here. Through the collaboration of both parts, LMA descriptors (which decompose movement to qualitative movement characteristics) are labeled and referred to as certain emotion clusters. Furthermore, literature reviews about the computing affect (emotive palpus) provide the approach to define LMA descriptors in digital parameters (quantitative). Therefore, the emotions entailed in movement are translated to corresponding data sets. More importantly, this study also indicates that the connotative meaning of movement also can change with the altering parameters. Based on all the previous research, the second chapter results in an automatic recognition algorithm and manipulation of the Kinect sensor. Live performance of the human actor will be detected and assessed by three terms of qualities: velocity, openness, and smoothness, respectively.

In the last chapter, architecture kinetics are investigated in terms of ways and means. An important concept, indeterminacy variables, is taken into consideration, which suggests different strategies of interactive behaviors necessary to manipulate architecture expression. Meanwhile, inspired by Margolin's kinetic sculpture Connected, this thesis focuses on integrating human movement with architecture kinetics. By keeping development of the Kinect sensor application, human movement as well as the expressiveness would be condensed to a dynamic trajectory and then manipulated into a wavy surface prototype, which is originally emerged from a sine wave. Nevertheless, this mathematics-based method can serve for more than one certain kinetic type, no matter if it is rotated, folded, or stretched. Therefore, this thesis considers this syntheses process as a control system to test its performance in three virtual scenarios. Different contexts, objectives, and interfaces are aimed to present its unlimited potential.

14. See section 1.2;Francisco J. Varela, Humberto R. Maturana; Autopoiesis and Cognition: The Realization of the Living; 1980

15. See section 1.2;Alva Noe; Action in Perception; The MIT press, 2005

16. See section 1.2;Evan Thompson; Mind in life; 2007

INTERACTIVE ARCHITECTURE
& EMBODIED EMOTION

Fig.1.01 Monde Arabe Institude, Paris,Photo By Metthew Pillsbury,2008

1.1 EMERGENCE OF INTERACTIVE ARCHITECTURE

“Interactive design” has become an emerging subject these days. It can be found everywhere—ranging from the body scale or personal space to large installations and architecture scales. It is, therefore, worthy to discuss the meaning of the word interactive. Rather than a fixed definition, pioneer designer Usman Haque used an interesting metaphor to sketch the boundaries of this word. He said we can barely recognize that stone is interacting with the environment; even after tens of years, the stone is decayed by time because the stone has no effect on the environment affecting it. The causality is completely one direction, so it is merely a reaction.[1]

Reverting back to the architectural context, we may consider whether things are presented as interactive actually. For example, the seminal project for kinetic architecture is the institute of Monde Arabe. While the facade is conceived as the modern interpretation of traditional Arabic symbol, the intent of the kinetic design was to control the light, and a dedicated mechanism was developed to achieve this. Given a hybrid role as a semiotic reference and light manipulator, this project is important and has received much acclaim but minimal discussion about its potential for kinetics. Even the designer, Jean Nouvel, appears to have no interest in the 25,000 pieces of kinetic shutters and conceded the failure of the system by saying the movement is minimal due to purposeful slow mechanical response.[2] Indeed, the kinetic is typically considered in terms of a sun-tracing motion, and with an on/off approach, where the motion defaults to the operational speed of the mechanical system. It is merely responding to certain input conditions; thus, it should not be described as interactive.

Contrastingly, interaction focuses on the exchange of information between two systems. It could be two people, two machines, or a person and a machine. In one interaction loop, A provokes B, but B affects A.

1.Usman Haque; Architecture, Interaction, Systems; Responsive Textile Environments; Tuns Press, 2007

2.B. Jean Nouvel: Architecture and Design 1976-1995, Milan: Skira Editore, 1997

Fig.1.02 Whisper(Schiphorst, Kozel,Andersen et al.,2002-2003) evolved out of five movement workshops

During this loop, unexpected information would be discovered and, subsequently, encourage further interaction. But if B failed to affect A, or the reaction of B is too unexpected to understand, then the interaction would break down. Therefore, the loop depends on the openness and continuation of cycles of response. This insight is particularly manifested in designing interactive clothing such as Whisper,[3] which is a network installation consisting of electronically enhanced garments with breath- and heart-rate readers and LED displays. The garments are used to share real-time body data. The data is translated to sound and light projections on the floor. When participants gradually become aware of the light and sound, they can snap together in various playful ways. More than just whisper, the goal for those interactive designs is to promote the communication between the inner self and the outside environment.

A design may begin with the participants' first-person interaction with his or her own body-states and then extend through the network to allow numerous participants to share state data. In Lisbon, Portugal, a similar kind of interactive installation has been acting as social media and benefiting society. The project, named Dancing Traffic Light,[4]

3.Danielle Wilde, Thecla Schiphorst, Sietske Klooster; Move to Design/ Design to Move: A Conversation About Design for the Body; ACM, 2011
4.SMART's Dancing Traffic Light; Urdesign; Lisbon; 2014

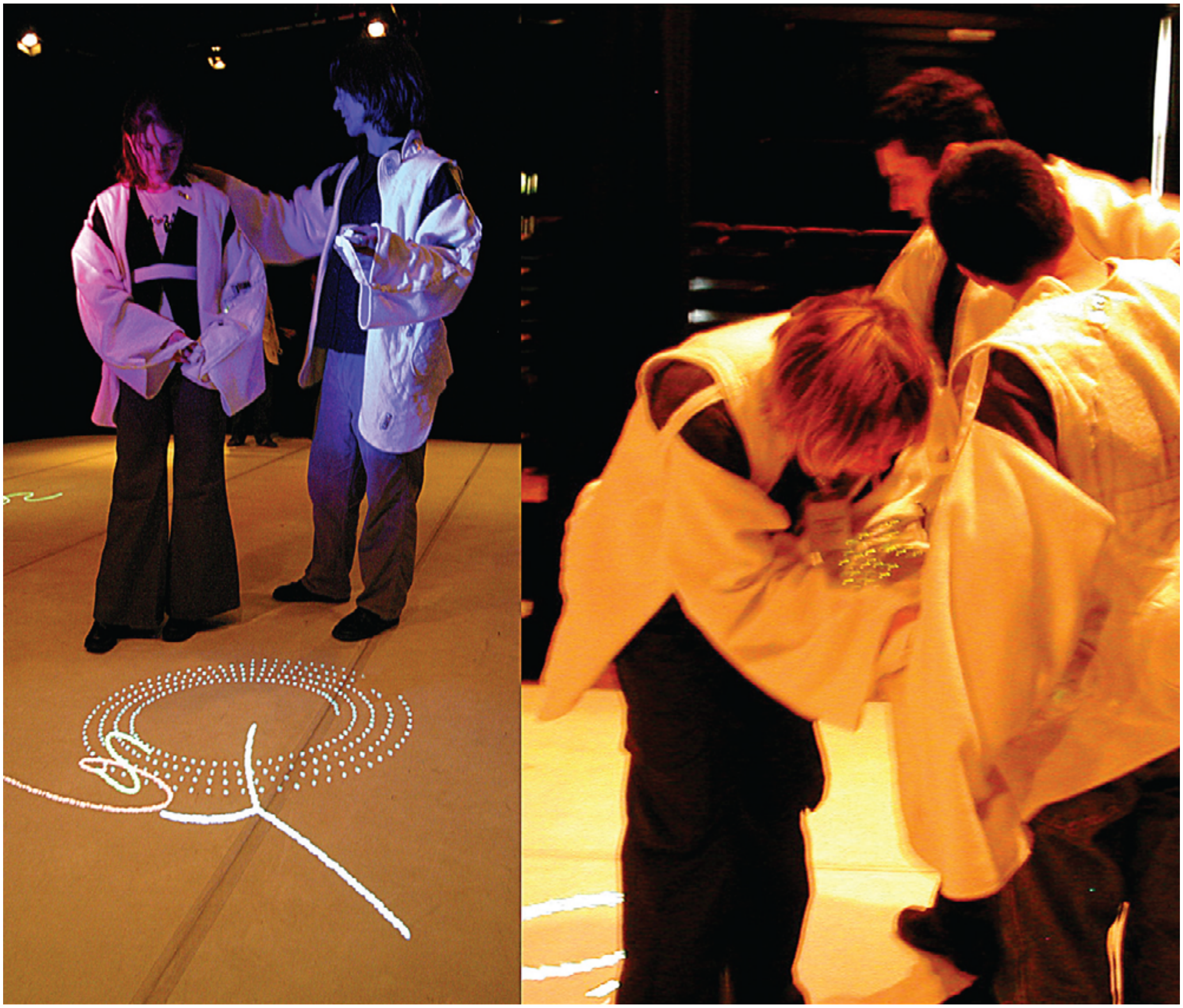


Fig.1.03 Whisper(Schiphorst, Kozel, Andersen et al.,2002-2003) installation interaction and garment design

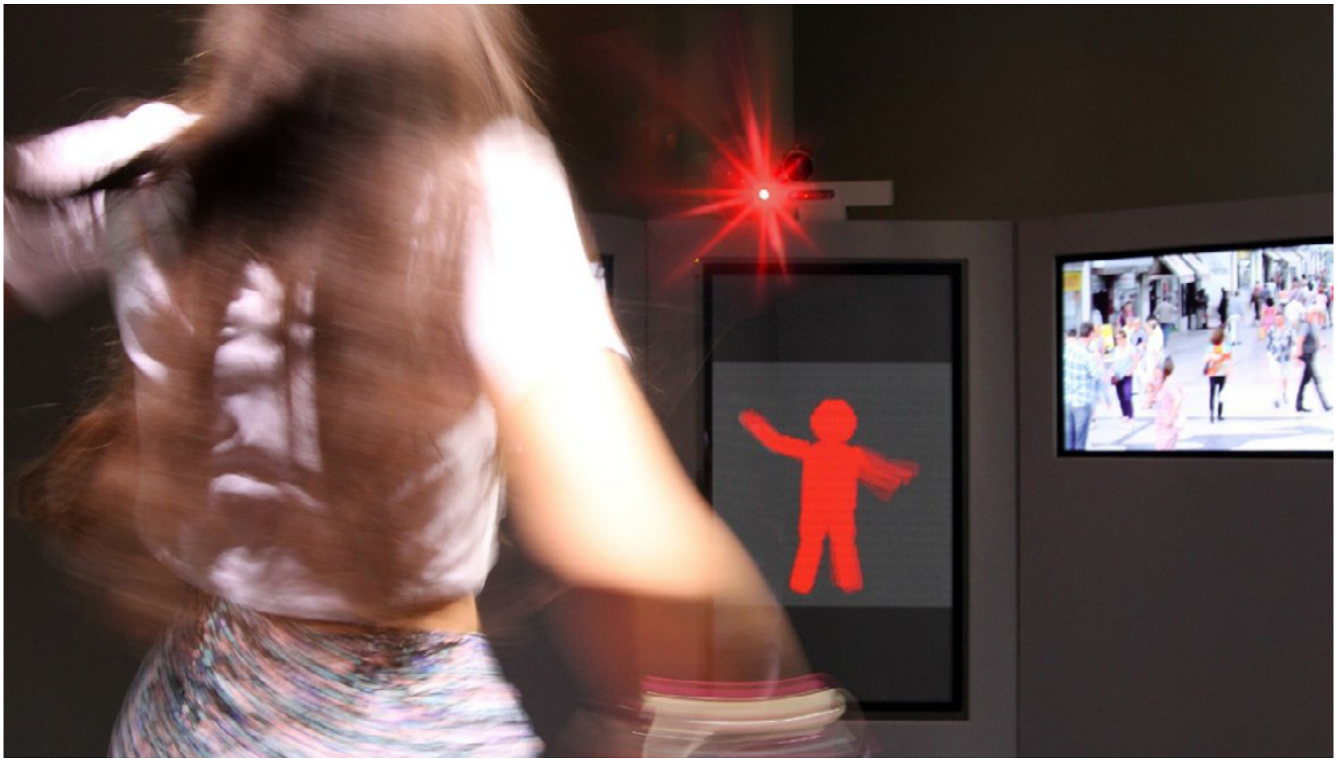


Fig.1.04 Inside of The Installation, girl is dancing while watching the street

Fig.1.05 Outside of The Installation, people is dance with the traffic light

designed by SMART and Urdesign, is providing a lot of fun while preventing people from venturing too early into the street. This creative design contains two parts: a dancing room on a square invites random participants to walk in, where they can dance with their favorite music; then motion detectors will collect their movements and display them on the traffic light in real time. Monitors, which show the situation around the intersection, encourages participants to perform responsively to people who are waiting at the red light and, in turn, might be even more interested in the dancing traffic light than recklessly crossing the street. As a result, 81 percent more people are waiting at the red light. No matter, it is designed for spectacle, entertaining diversion, and simply unadulterated fun; thus, we cannot deny its remarkable ability to transform our experience and perception of what is around us.

Considering the precedents above, let us revisit Usman's metaphor. If A is people, B is the artifact, how B responds to A in an affective and recognizable way seems extremely significant. An answer resides in understanding ourselves. Humans are perennially inquisitive creatures, always seeking novelty in their environments. This novelty engenders uncertainty with respect to one's present state of experience.[5] The interaction of human–architecture, human–robot, or human–computer, according to Luciana Parisi in her book Contagious Architecture, is aimed to activate our motivation to search for novelty, which triggers a series of emotive responses and results in the change of our behavioral expressions. However, in that process, it is necessary to display rich emotions in order to be believable.[6] This insight also proves that learning from behavior or response that humans show in connecting with surrounding circumstance is necessary to contribute engagement or empathy in the design process of interactive architecture or artifacts. A survey of the integration of human factors in designs of various scales is shown as follows.

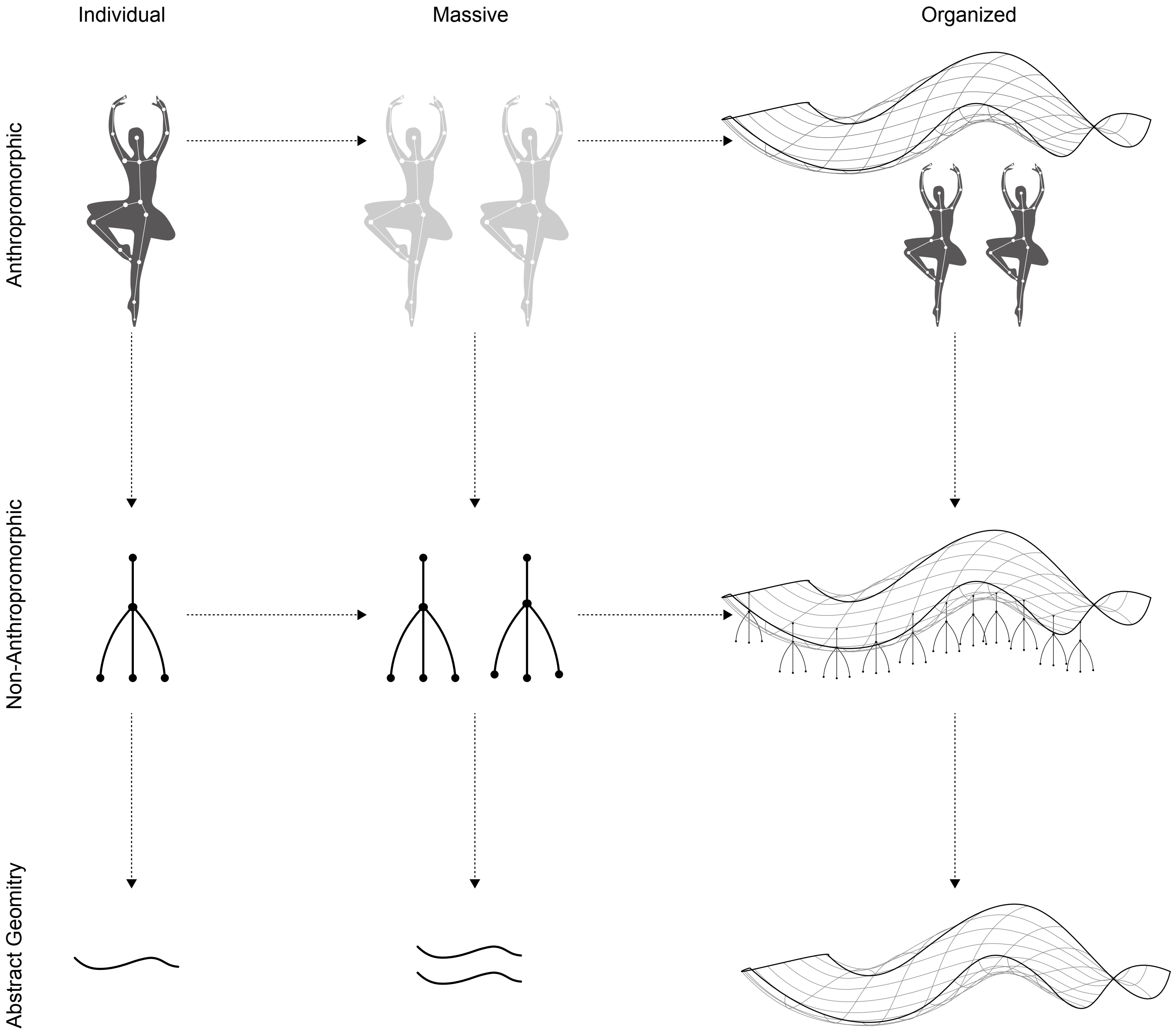
5.Ruxton "Responsive architecture subtle technologies.", Cambridge, ON: Riverside Architectural Press. 206.p.3

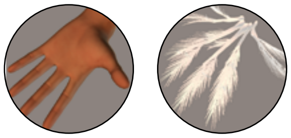
6.Luciana Parisi; Contagious Architecture: Computation, Aesthetics, and Space; The MIT press, 2013

As the diagrams shows, this matrix is organized by two axes, respectively, the organize level and abstract level. In the vertical, the anthropomorphic form is placed at the beginning. In Ali Samandani's research of a humanoid robot, hand movement is addressed in manipulating feather-like-shaped robotic membranes to express a target emotion. The significance of this research is that the relation of movement and its connotation are traceable. With grasping this relation, we can synthesize emotive behaviors without relying on human forms. In the second line, these principles have been adopted in synthesizing a nonanthropomorphic kinetic form. Instead of complex human body movement, movement elements are separately manipulated and articulated with psychology meanings. With this sense, a desired emotion is literally manifested. Along with this, the tectonics of kinetic forms reach the maximum abstract level; thus, all superficial features are excluded but for the movement characteristics in terms of speed, velocity, etc.

Horizontally, kinetic prototypes are arranged with different organized levels. One extreme is that each component is controlled individually. As shown in the second column, multiple kinetic samples are duplicated and massively distributed to the field in order to manifest a higher indeterminacy degree. Another extreme is that all components are under a centralized order, as the third column shows. It is not equal to a single movement control, which makes the overall look the same but keeps the whole arrangement in the balance of homeostasis and indeterminacy.

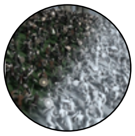
As previously noted, the correlation indicates the potential of the architectural form to learn from human behavior in order to facilitate a believable performance, though no direct reference says that an abstract kinetic surface can perform the same as an individual human-like robot. However, this is only a partial information exchange. How to let an architectural system understand us is missing in this discussion. Therefore, the following sections will look deeper into this critical issue, which involves the study of cybernetics.


Individual
Massive
Organized
Anthropromorphic
Non-Anthropromorphic
Abstract Geomitry



Emotive Robot

Feather shaped humanoid robot that can mimic hand movement to display affective movements.
a) anthropomorphic (human-like) hand model
b) non-anthropomorphic frond-like hand model.

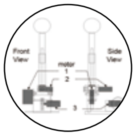


Massive/ Golaem Crowd

Mainly used in film production for generating crowd movement. Each individual is controlled by a few number of movement sample and distribute individuals in the whole scene randomly. The crowd movement therefore looks variable but stay consistency

Connected

The sculpture was decided upon has similarities to a torqued square wave, but rather than adding two sine waves, one axis is tied to the dancer's arms, and the other axis is tied to the legs. These twin movements allow for a wide range of expression in the sculpture, and the strings can also be distributed between multiple dancers.



Emotive Palpus

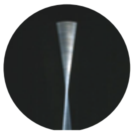
A robot prototype embeded with synthesized movement which is manipulated by three movement facotors, realtively speed, openness, smoothness. Through altering those three factors, the movement of this prototype can express at least four different emotions.

Dune

Large scale nteractive landscape, consisted by huge amount of fiber shaped components. Twinkling and making sound when visitors approaching. In the design of its interactivity strategy, a few of people's performance are estimated as stimulus that initiate Dune's responvie behavior.

Hylozoic Ground

Choreographed airflow pushes particulate matter through the Hylozoic environment, where it is Swallowing actuator,whiskers, hygroscopic islands and stry burr filters. The responsiveness relies on both the occupancy of visitors and the actions between each parts.

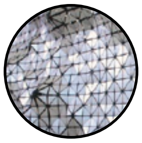


Standing Wave

Kinetic sculpture from 1919. This piece of art work is simply made by a metal sheet and an acuator. But, when it is vibrating, the kinetic rhythm may contribute empathy the its audiences.

Nervous Structure

This is an interactive, audiovisual installation that consists of twin curved sculptures covered with sound-absorbent foam, illuminated by a video projection of computer-generated lines that reacts to your movements. The outputs are calibrated to both mirror and complement the interactive video projection.



Aegis Hyposurface

The surface will be capable of registering any pattern or sequence which is generated mathematically, and launched by an embedded network of half a dozen Scenix microchips. It deforms physically according to stimuli captured from the environment, which may be selectively deployed as active or passive sensors.

1.2 CYBERNETICS AND CONVERSATION THEORY

"Responsive is used throughout this book to speak of how natural and artificial systems can interact and adapt. Speaking of evolution, we might think of how environments act via natural selection on diverse populations. While that traditional definition is included here, we also want to include conscious action."

---Beesley, p., Hirosue, S. and Ruxton, J., Towards responsive architecture, in Beesley, Hirosue and Ruxton "Responsive architecture subtle technologies.", Cambridge, ON: Riverside Architectural Press. 206.p.3

From the perspective of cybernetics, conscious action is a form of response to input, which entails the thinking of doing something, and the actual doing of it can be summed up or synthesized. The approach to a conscious action requires an input system: thus, a processing system that analyzes this input and an output system that reacts to the analysis of the input. This allows architecture to articulate with diverse types of interactions, all of which produce differing levels of indeterminacy; thus, at one level of indeterminacy, human interaction is added on to produce highly modulated indeterminacy. The diversity does not depend on architecture itself but rather on the inputs and the processing criteria. This inspiration has emerged from the legacy of cybernetics.

Cybernetics has its origins in self-regulating systems, which typically require a control system to set motion in a process to provide corrective feedback. The definition of cybernetics as a modern field of research is credited to Norbert Weiner, as developed in his influential book Cybernetics, or Control and Communication in the Animal and the Machine; explicit in the title is the idea of homeostasis, which is “defined as the ability of an organism to maintain itself in a steady state”; in other words, all self-regulation systems, including biological or mechanical, can be conceived through the same principle. This is known as first-order cybernetics.[7]

7.Wiener, N.; Cybernetics: Or Control and Communication in the Animal and the Machine. Cambridge, MA,MIT Press, 1965

"The high point of functionalism is the concept of a house as a "machine for living in." But the bias is towards a machinethat acts as a tool serving the inhabitant. This notion will, I believe, be refined into the concept of an environmnet with which the inhabitant cooperates and in which he can externalize his metal processes."
---Gorden Pask, The Achitectural Relevance of Cybernectivs, 1969A, 496

Cybernetics had a crucial influence on the birth of various modern sciences: computer science, control theory, artificial intelligence, cognitive science, and artificial life. After some of the sciences became independent, the remaining cybernetists thought it necessary to distinguish themselves from the more mechanistic approaches by emphasizing autonomy, self-organization, cognition, and the role of the observer in modeling a system. In this context, Katherine N. Hayles led the movement, which has become known as second-order cybernetics and which took the notion of feedback one step further. It is defined by the belief that knowledge is not passively received either through the senses or by way of communication. Therefore, cognition is defined by its continuous interaction with perceptual activities of the inhabitant of an environment. She then compared these two approaches to cybernetics with contemporary research on self-organizing systems, through embedding with the principal of reflexivity. The rules that maintain the steady state are recursive, thus enabling more complex behavior.[8]

Gordon Pask, a cybernetic scientist, architect, and digital artist, is regarded as the champion of second-order cybernetics. He is also known for his conversation theory, a particularly coherent and potentially the most productive theory of interaction encompassing human-to-human, human-to-machine, and machine-to-machine configurations in a common framework. In the last century, he proposed the idea of a computational architecture of thought, which explored the role of architecture in defining a new form of cognitive structure that can learn and adapt to the external.[9] For Pask, architecture is a cybernetic system that can learn like the brain adapts and changes through creative conversation between the

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8.Hayles, N.K.; Boundary Disputes: Homeostasis, Reflexivity, and the Foundation of Cybernetics, 1996
9.Maria Femandez; Gorden Pask: Cybernetic Polymath; Leonardo, Volume 41 #2 ; The MIT press, 2008

Fig.1.06 British Scientist Gordon Pask Co-inventor of An Electronic Brain Used As A Teaching Aid Called Eucrates I,1956

building and its users. At the time, Pask conducted several experiments with mechanical and electrochemical devices that possessed a conceptual framework for building a responsive architecture, thus allowing human and artifacts to coexist in a mutually constructive relationship.

In the best-known practice, the Musicolour Machine[10] is a light show that responds to sound. Its algorithmic program contains a primitive cybernetic cognition, which enables the machine to become bored of making a response to the surrounding acoustic environment. The sequence of light outputs is dependent on the frequencies and rhythms that it can hear, but if the input becomes too continuous, the Musicolour Machine would become bored and start to listen for other frequency ranges or rhythms unless the musician makes a change in the music composition. In this interaction loop, the participants actually provoke and produce the data (the light output).[11] There would be nothing if no one comes to the designed conversation, in which information is reconstructed by constant interaction among entities. Compared with first-order cybernetics, there is an identification of a control and output; in conversation theory, the element that is recognized as either the controller or controlled is essentially arbitrary.

This tendency to embody thought or to embed it within the environment was popular in the 1960s. Some critics believe that the 1960s was the decade of interactive art and interactive or adaptive architecture. In Britain, the Archigram group of architects built almost nothing, but the designs featured in Archigram magazine were iconic of this movement. Ron Herron's fanciful Walking City in 1964 caught the mood, adaptive in the sense that if the city found itself somehow misfit to its current environment, it could walk off to find someplace more congenial.

Associated with this enthusiasm for adoptive architecture, Cedric Price, mentioned as a fellow undergraduate student of Pask's at Cambridge and his only link to architecture, was appointed as the architect of the project

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10.John Hamilton Frazer, The Cybernetics of Architecture: A Tribute to the Contribution of Gordon Pask; Kybernetes 30, nos.5-6 (2001), 641-651

11.Usman Haque; The Architectural Relevance of Gordon Pask; Article first published online: 9 JUL 2007, DOI: 10.1002/ad.487

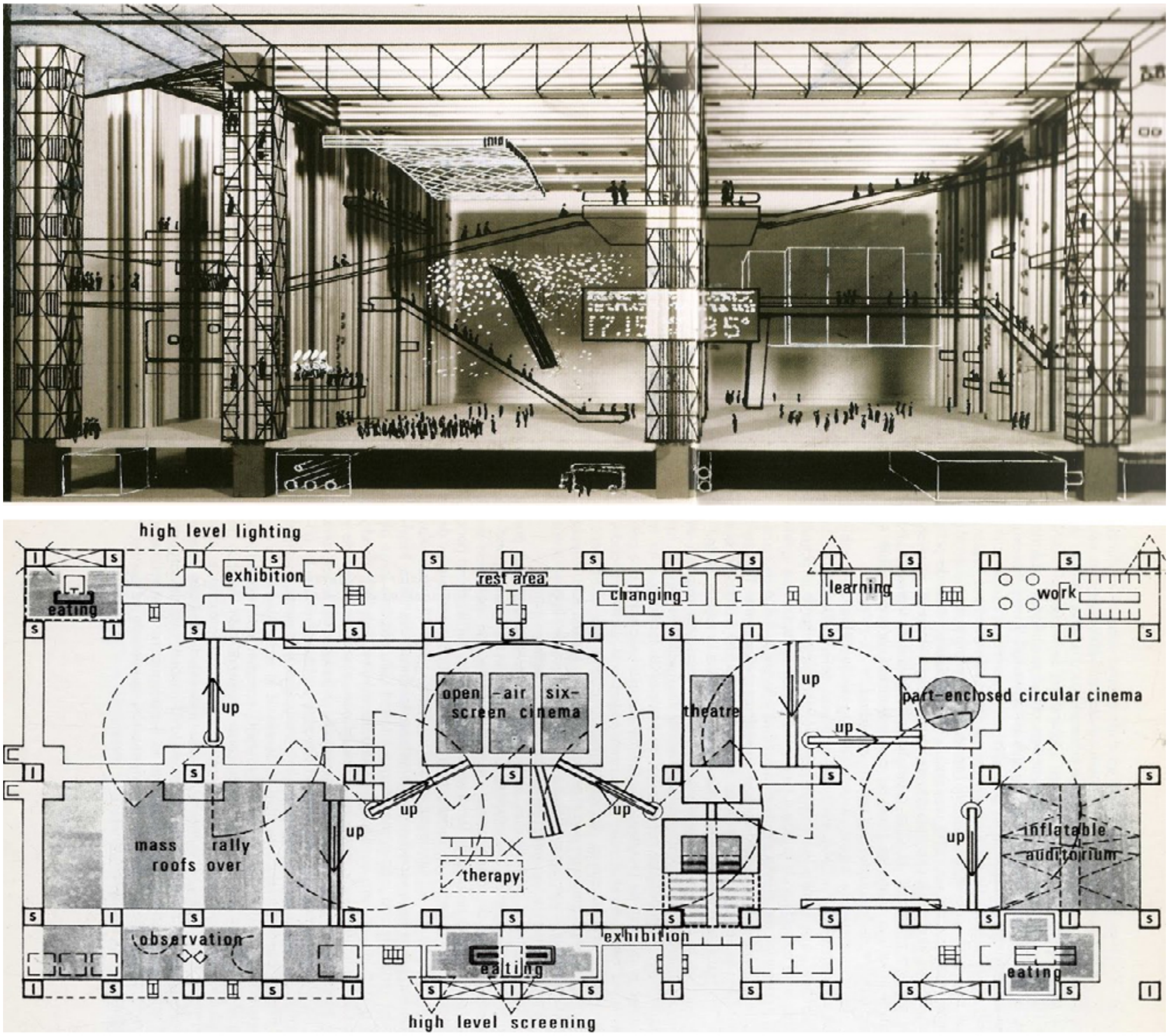

Fig.1.08 Drawings of Fun Palace, Joan Littlewood and Cedric Price, 1961

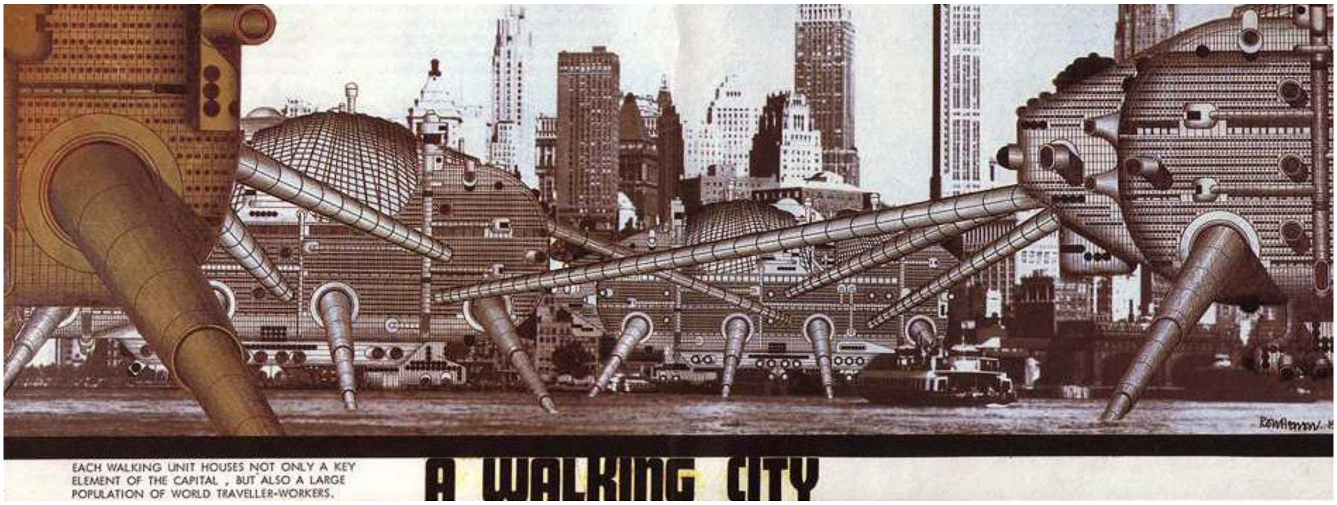

Fig.1.07 Ron Herron's Fanciful Walking City, London, 1964

Fun Palace,[12] 1which was known as one of the major unbuilt landmarks of postwar British architecture. The concept was from Joan Littlewood 1960's "turned … to a childhood dream of a people's palace … with music, lectures, plays under an all weather dome," Pask agreed to join the Fun Palace team and organized the cybernetics subcommittee with Littlewood and Price.

The Fun Palace was intended as a reconfigurable adoptive space that could support an enormous variety of activities that could be changed and updated over time. This program called for architecture that was informal, flexible, unclosed, and impermanent; the architecture did not need to be simply a response to the program but also a means of encouraging its ideas to grow and to further develop. This cybernetic architecture includes the possibility of constructing a digitally controllable structure, which can transform its uses according to changing circumstance. Pask argued that the interaction requires goals and actions that displayed the interactive qualities of agreement, understanding, and consciousness and are emergent qualities for the establishment of a true

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12.See Pickering, A.; Cybernetic Brain: Sketches of Another Future, Chap 7,Page 364; University of Chicago Press, 2010

12.See Pickering, A.; Cybernetic Brain: Sketches of Another Future, Chap 7, Page 365-370; University of Chicago Press, 2010 dynamic conversation.[13] In that conversation, human and artifacts could work together to form a self-organized system that enacts cognition and ultimately leads the building to adapt and transform. Now, at the beginning of the twenty-first century, Pask's conversation theory seems particularly important because it suggests how, in the growing field of ubiquitous computing, humans, devices, and their shared environments might coexist in a mutually constructive relationship. A more recent precedent, Ada-Ada intelligence space is an entertainment exhibit that seems to directly incarnate the cybernetic oriented toward a notion of a cognition triggered by its sensorimotor knowledge, using the language of light and sound. She received 553,700 visitors over five months during the Swiss Expo in 2002. Coinciding with Pask's theory, Ada has been enabled to augment its cognitive knowledge by learning from different gestures, sounds, and movement of people. For that reason, Ada's experience is not exclusively determined by the algorithmic computation but rather from empirical knowledge and, in turn, enriching the algorithm by learning this knowledge.[15]

Moreover, Ada's behavior is designed to have a certain level of coherence and to convey an impression of a basic unitary sentience to her visitors. As a communicative agent, Ada tries to maximize its own goal functions just like the Musicolour Machine, in which her designers interpret her happiness. Thus, the system can assess its level of happiness; that assessment could be used to determine whether a certain action contributes to this goal. The degree of success with which visitors can be convinced that Ada is an artificial organism depends on the nature of their interaction. The operation of the space needs to be coherent, real-time, and reliable enough to work during extended periods of time. It also must be understandable to visitors and sufficiently rich in the depth of interactions so that visitors feel the presence of basic unitary intelligence. To approach a natural progression in interacting with visitors, Ada incorporates at least four basic behavioral functions to provide. First, she can track the location of groups of visitors and give them a sign that they

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13 Jeffrey I. Krichmar and Gerald M. Edelman; Machine Psychology: Autonomous Behavior, Perceptual Categorization and Conditioning in a Brain-based Device; Cereb. Cortex 2002 Volume 12, Issue 8

14.Kynan Eng, Andreas Bäbler; Ada-Intelligent Space: An artificial creature for the Expo.02; To appear in : Proceeding s of the 2003 IEEE/RSJ International Conference on Robotics and Automation (ICRA 2003)


Fig.1.09 Ada, Intelligence Space, Swiss Expo, 2002

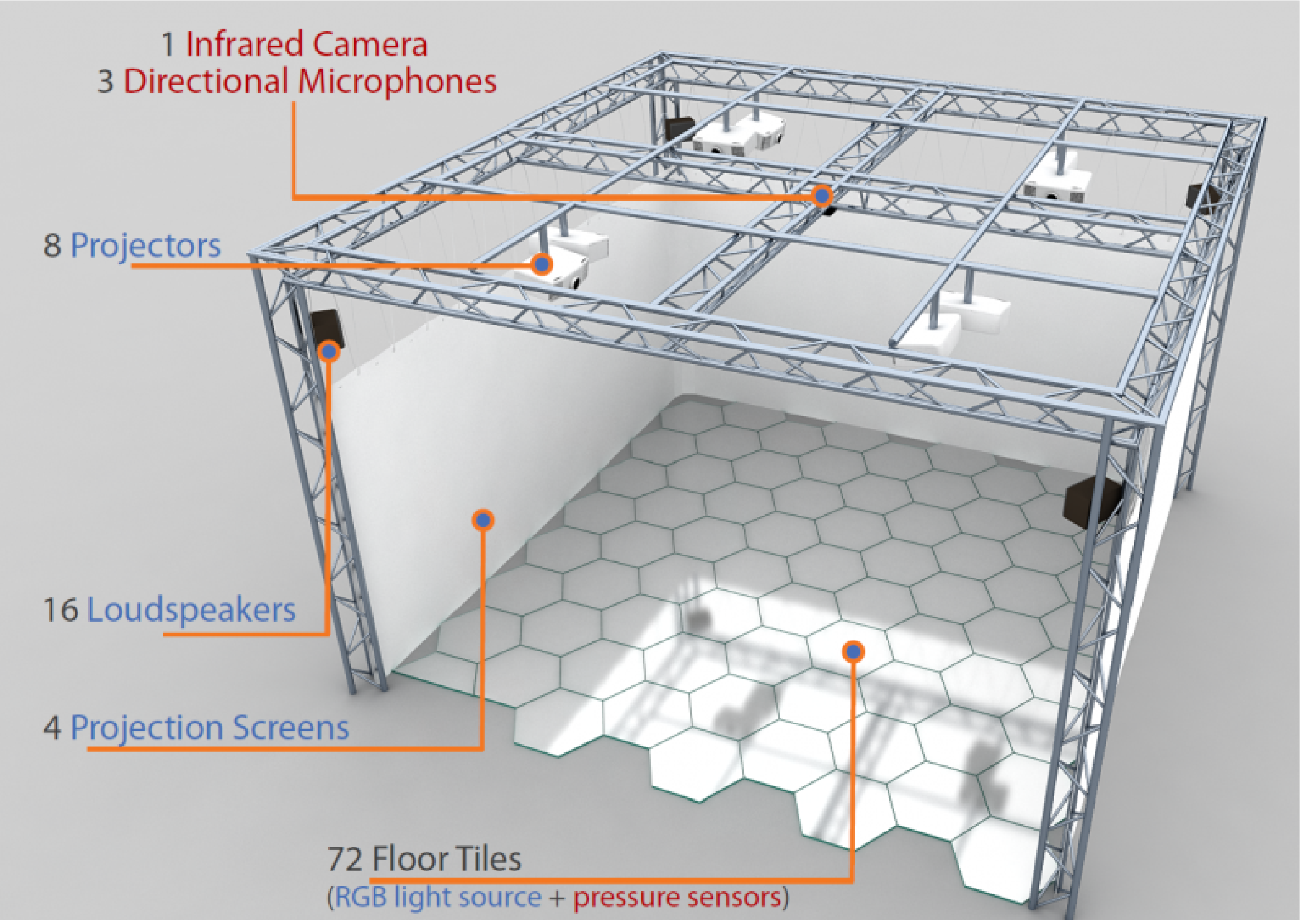

Fig.1.10 XIM Composition Diagram

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15. M. P. Inderbitzin, Wierenga, S., Väljamäe, A., Bernardet, U., and Verschure, P. F. M. J., "Social Cooperation and Competition in the Mixed Reality Space eXperience Induction Machine", Virtual Reality, vol. 13, no. 3, pp. 153-158, 2009 are being tracked. At the same time, Ada identifies visitor responsiveness as cues to arrange the next step in behavior. When the conditions are appropriate, she will interact with participants by playing a number of games and continuously evaluating the result of her actions, expressing emotional states accordingly, and attempting to regulate the distribution and flow of visitors. The key infrastructure of Ada is the eXperience Induction Machine (XIM), which is equipped with a number of sensors and effectors (as follows).

- One infrared camera at the top of the rig provides a bird's-eye view.
- Three directional microphones in the center provide the system with auditory input to localize visitors and to recognize specific sound events.
- Sixteen speakers with the corresponding sound equipment.
- The space is surrounded by four projection screens (2.25m x 5m); eight video projectors are used to display content.[15]

To account for an explicit human contribution that allows architecture and its inhabitants to converge on a mutually agreeable nature of feedback, computer scientists Valera[16] and Thompson[17] believe that architecture, for that point, can approach anthropomorphic qualities. "Cognitive processes and structures emerge from the activities of being which are performed within the world," said Thompson in the book Mind in Life. Rather than be exhausted by preprogrammed algorithms, the study of "agreement, understanding, or an universal discourse" is embodied in the structure of human experience itself: specifically, the experiential evidence of space, shape, material, temperature, color, sound, or movement. Based on this learning, the cognitive structure could be enriched to a high level of complexity and lead the conversation between architecture and people to a further step. Extending the theory, Noe[19] argues that all that experience should be synthesized with the exercise of sensorimotor actions as the embodiment of perceptual knowledge because perceptual knowledge should not be separated but intrinsic to the movement, gestures, and

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16.Francisco J. Varela, Humberto R. Maturana; Autopoiesis and Cognition: The Realization of the Living; 1980

17.Evan Thompson; Mind in life; 2007

18. Alva Noe; Action in Perception; The MIT press, 2005

Fig.1.11 Dune 4.2

practices of a body. In other words, thought is always an embodied gesture or other form of expression, which is not necessarily enlivened by a human or animal body but by any body, including artificial.

A practice of embedding experiential knowledge is that the innovative landscape installation Dune,[19] designed by architect and artist Dann Roosegaarde, entails the perceptual experience within the primitive forms of nonanthropomorphic gestures. This installation consists of swaying reed-like fibers fitted with microspeakers and LEDs and performs several behaviors. “When no body is there, it will fall asleep—glooming softly; but, when you enter into it, the light appears when you walk, as an extension of your activities; when you make a lot of noises, the landscape goes crazy—lighting crashes.” Dune predefined the behavioral experience of the human in advance and hence walking in, touching, and any engagement now is giving Dune a new catalyst that changes the conventional way people interface with artwork, instead of being asked to stand back and view from a distance. Its designer also argues for its cognitive features as the mimicry of a pet or wild animal. He stated in the interview that one day he found an old lady barking at Dune. She told him she was trying to see whether it could behave like her dog did at home. As in the above, we can see the Dune’s expression contains an ambiguity of natural embodiment rather than complete naturalness that allows an open-end interpretation by users instead of the simplistic, one to one expression pairs.[20]

To summarize, the conversation between two systems relies on mutual comprehension and agreement and agreement to disagree to enable the creation of meanings. During the interaction, two participants represent a cognitive structure of knowledge, and each part has a different perspective or a different role to play. Participants do not profit from the variety they bring as an individual but from the variety that evolves from the exchanges. As for an interactive architecture environment, architecture learns from the inhabitant just as the inhabitant learns from the architecture.

19.Studio Roosegaade; DUNE 4.2: The interactive landscape of light alongside the Maas River in Rotterdam NL; https://www.studioroosegaarde.net/project/dune-4-2/

20.Helen Castle; Alice in Technoland; AD, 4dspace: interactive architecture, V75-01; 2007

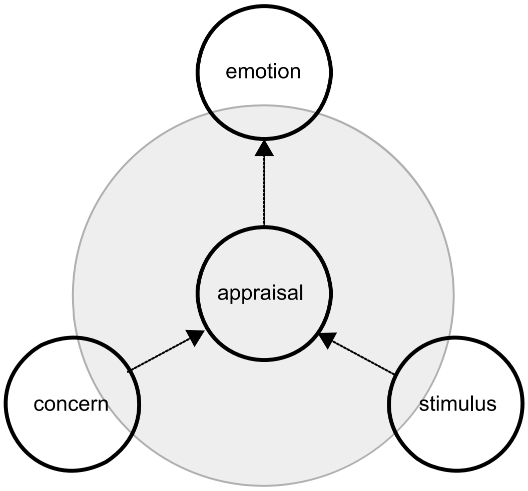

Fig.1.12 Emotion Appraisal Model

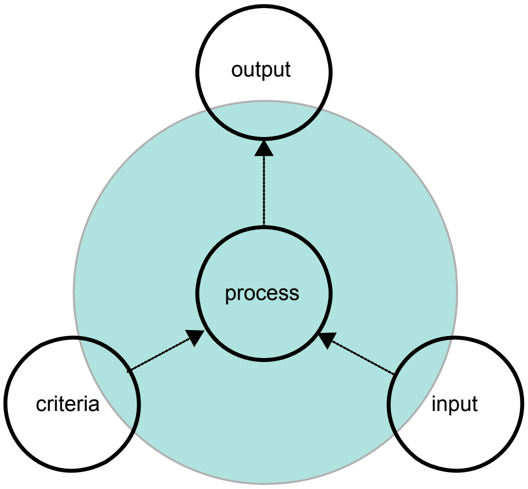

Fig.1.13 Cybernetic Control Model

1.3 PSYCHOLOGICAL BASIS OF INTERACTIVE DESIGN

From Musicolour machine to Ada and Dune, many projects have demonstrated the huge potential of an architecture environment that can affect us by offering human–computer or human–architecture interaction. Along with this, we can assume a system, the expression of which could explicitly articulate with human feeling or emotion and, hence, can achieve a life-like or human-like conversation. To that end, the first task is to understand the functions of how human perception is processed and how emotion is elicited.

Pieter Desmet,[21] the pioneering psychologist of the cognitive view of emotions, argued that emotion always involves an assessment of how an object may harm or benefit a person. The process of emotions is explained by the process of appraisal. An appraisal, the direct immediate sense judgment of weal or woe, is at the heart of every emotion. Without appraisal, there can be no emotion, for all emotions are initiated by an individual's appraisal of his or her circumstances. Based on this, Desmet developed the conceptual model of the emotion appraisal process[22] (Fig. 1.12). Two elements, stimulus and concern, are defined in which the input process is used to influence =one's emotional state. Compared with the input-process-output system (Fig. 1.13), it is feasible to address the human perception process on the design of a cybernetic system, though human perception is a far more complicated system.

1.3.1 INTERCHANGEABLE STIMULI

Stimulus, according to Frijda[23] (The Emotion, 1986), could be any perceived effect that has the potential to elicit an emotion. This can be an object, an agent, or an event. In the case of an intelligent visual agent, an affective expression could be observed from the agent, which would be perceived as the stimulus by its viewers. Subsequently, it can affect a viewer's emotional state and eventually change his or her behavior. More than that, when viewers engage in that scenario or narrative, their

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21 P.M.A Desmet, P.Hekkert; The Basis of Product Emotions; Delft University of Technology, Department of Industrial Design; 2002

22.Roseman I.J., Smith G.A; Appraisal theory: Overviews, Assumption, Varieties, Controversies; New York: Oxford University Press; 2001

23.Frjida N.H;The emotions; Cambridge University Press; 1986

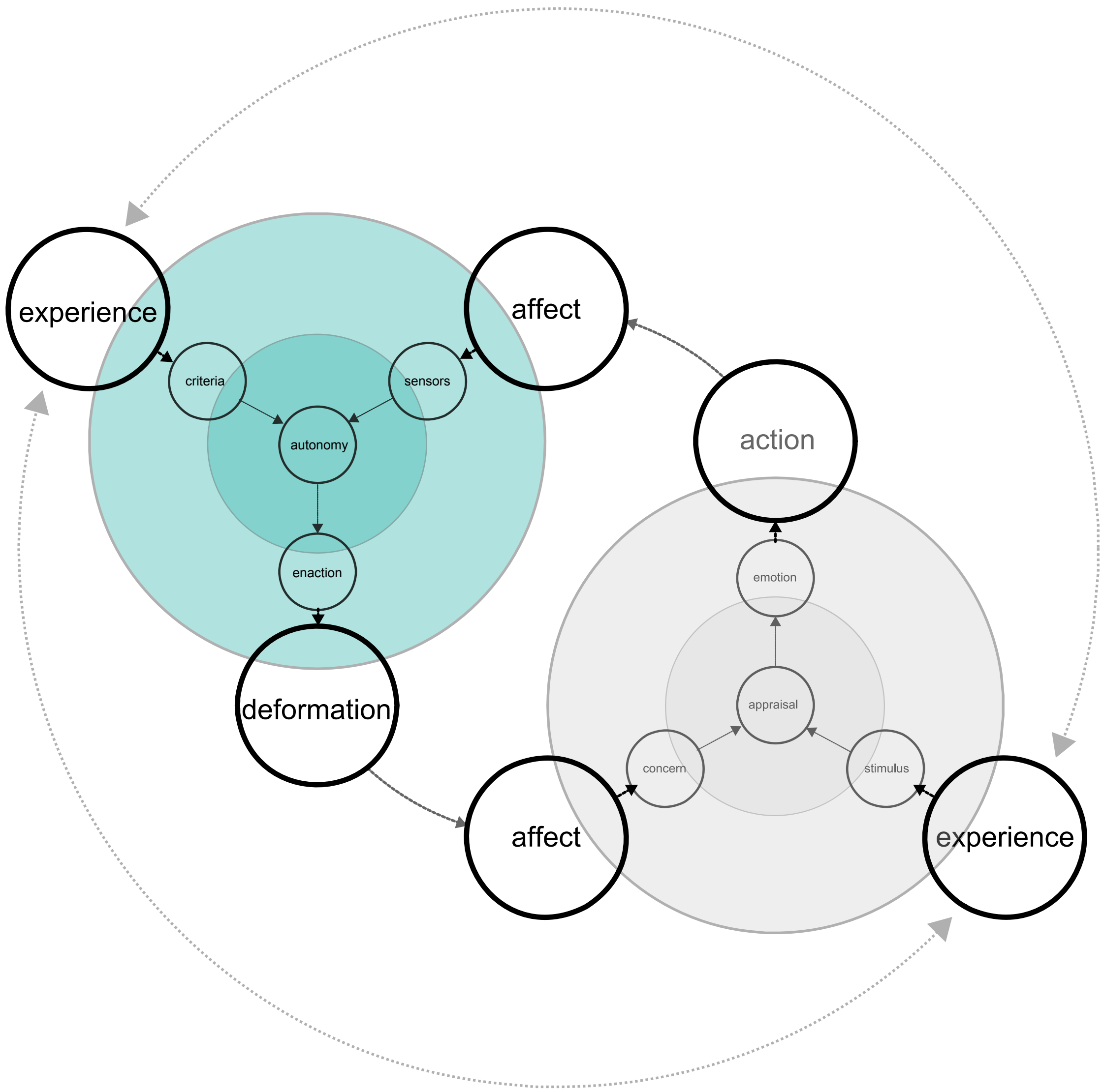

Fig.1.14 The Interchargeable Affect

The collaboration of two system (cybernetic control and emotion appraisal) implies a framework of how the interaction between two parts can possibly run. In this loop, one's behavior will be considered as stimulus by the other to generate next step response.

emotions are also identified by the agent through having their affective behavior observed.

Furthermore, the insight of psychology indicates many similarities between cybernetic control and emotion appraisal, which might be applied to contribute a reflexive behavior according the occupancy. The input of a cybernetic system is equal to a stimulus to emotion appraisal, which may come from everything in this physical world. But, for an interface design, it is impossible to fully simulate human perceptions that can process infinite numbers of stimuli. Thus, in the design process, a certain modality has to be selected. Moreover, as opposed to emotion appraisal, is that, if an artifact wants to communicate with people, its expression must be recognizable. Therefore the system has to take people's reaction to that modality as input. Thus, the stimuli in fact can be understood as a common language that is interchangeable between people and the artifact .

Predator 2001,[24] an art installation designed by architect Greg Lynn and painter Fabian Marcaccio, is an example for adopting the perceptual knowledge of movement. This project started with a digital model, which is embedded with a kinetic ability. The model is connected to pressure sensors combined with a canvas surface. When Marcaccio, the painter, brushed pigment onto the canvas, the intensity of pressure embodied in each brush stroke instigated shrinking and wrinkling in a digital dimension, and, in turn, the paint responded to the affects generated in a previous transformation.16 From that standpoint, we can image that architecture can dynamically reorganize its appearance as the adaptation of the affect in the interaction with its users; this includes the possibilities of constructing a digitally controllable structure that can transform according to the changing occupancy.[25]

24.Gregg Lynn Form; Predator; 2001; http://glform.com/environments/predator/

25.Ali Rahim; Catalytic Formations: Architecture and Digital Design; Taylor & Francis Press; 2007

Fig.1.15 Predator Installation, Greg Lynn at MKK,
Museum Fur Moderne Kunst, Frankfurt, 2011

1.3.2 EXPERIENCE FILTER AND SELF-PROJECTION

A common language is not enough to build up the interaction. Look back at previous precedents, in Musicolor or Ada, a latent intention was manifested in their expression. Musicolor was capable of expressing boredom, and Ada was looking for happiness in its environment. Behind this latent interaction, there is the capacity to recognize people's behavior, just like humans perceive incoming stimuli. To approach this, we still need to learn from our psychology lectures.

In the emotion-elicit process, the component of concern involves the concept of experience filter,[26] which is an accumulation of unconscious memory that stores the data about all past experience. Incoming stimuli are classified and sorted according to one's characteristics and associated with other prior analogous situations or objects that have already been filed in the experience filter. That can account for why emotions are subjectively experienced states, to which we all react differently. Depending on our background, previous experience, mental and physical states, and other individual factors, the concern component attributes meaning to the incoming stimuli, which, in turn, has an impact on emotion appraisal.[27] To the context of human–architecture interaction, Hermann Lotze and Rob Vischer,[28] who discussed the importance of experience in interpreting art and architecture, were evidently thinking about the processes that take place in experience association. Vischer noted that, "We have the wonderful ability to project and incorporate our own physical form into another objective form," which means one's impression of mood conveyed by architecture or other forms of agent would involuntarily associate with an analogous scenario in his prior experience.

Moreover, "To understand the theory of music expression, it is necessary to observe our own production of sounds, the meaning and use of our own voice." In Empathy, Form, and Space, Problems in German

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26.Bartley S. Howard;Principles of Perception; Harper & Row Publishers; 1958

27.Dezheng Feng, Kay L. O'Halloran; Representing emotive meaning in visual images: A social semiotic approach; Journal of Pragmatics 44, 2012

28.Vischer Robert; Empathy , form and space: problems in German aesthetics, 1873-1893; Chicago Press c1994

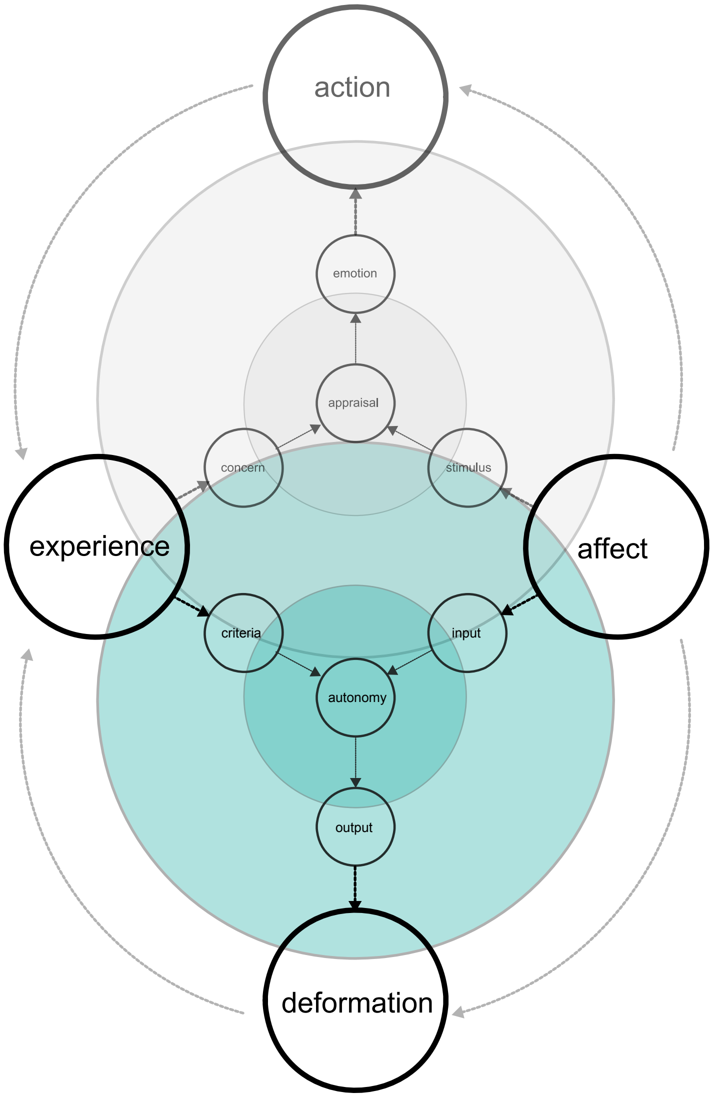

Fig.1.16 Experience Filter for Artifact
Through the continuous interaction with human, the interactive system may learn from participants' behaviors to evlove its experience filter.

Aesthetics (1873–1893), Heinrich Wolfflin said, "We perceive the physical forms as meaningful because we expect to process everything with the categories of our experience that we shared with it."[29]

Wofflin's note indicates great inspiration for architecture to recognize and learn from its user. With the shared "experience filter," it could be the experience from just about any stimulus; architecture is enabled to interpret its user's actions and let this interpretation influence its response. In that sense, the experience to certain stimulus is considered as the cognitive structure, and the modality of those stimuli is actually a common language for both parts in the communication

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29.See Empathy , form and space: problems in German aesthetics, 1873-1893; Chapter of Heinrich Wolfflin, Section I: Pschological Basis; Chicago Press c1994

BODY MOVEMENT AND AFFECTIVE EXPRESSION

As discussed in the previous chapter, interactive system design requires the specific research of a “common language.” It is necessary to include systematic theory of how to express and how to interpret. This thesis emphasizes body movement and its connotative meanings. Thus, movement is most commonly used in our daily lives to express our inner thoughts and emotions. The current state of affect-expressive movements research is mainly focused on variant body movement, including full-body movement, certain part movement, and gait. Through particular movement analysis, affect state, or even, namely, emotion could be conducted, and that method is quite coherent with the objective of creating interactive environment. Thus, at the beginning of this chapter, I introduce a review of various movement study as the following categories.[1]

Communicative Movements cover a broad range of movement, which are performed in daily life and may convey affective states. A communicative movement can select from a library of movement types to express an affective state and may be accompanied by a modulation level.

Functional Movement is to perform a task unrelated to the expression of affect (e.g., walking or knocking). In contrast with the former category, an affective state can only be expressed through modulation of a functional movement, and expressiveness is secondary to function

Abstract Movement is used neither to explicitly accomplish a task nor communicate a meaning. Expressiveness of a movement can be analyzed independently of a possible symbolic meaning of the movement itself, and movement types can be selected that do not necessarily occur during daily life.

Artistic Movement, such as choreographed and nonchoreographed dancing, can display exaggerated expressions and consist of movement types. Artistic movement varies in terms of movement types in which

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1.Michelle Karg, Ali A. Samadani, Rob Gorbet, Kolja Kuhnlenz, Jesse Hoey, and Dana Kulic; Body Movements for Affective Expression: A Survey of Automatic Recognition and Generation; IEEE transactions on affective computing, Vol 4, No.4; 2013 to express an affective state and may be accompanied by a modulation level. For choreographed artistic movements, different affective states are expressed only by modulations because the movement type is specified by the choreography. The thesis is focused on artistic movement to infer the underlying correlation between movement and emotion.

2.1 ARTISTIC AFFECTIVE MOVEMENT

"One of the very first times I did it (the show), was in Brooklyn. A lady came back to me afterwards and looked at me with a very white face. And she had obviously been crying and she said "you will never know what you have done to me. Thank you" and left. I asked about her later, (it) seemed that she had seen her child, her nine year old son, killed in front of her by a truck. They had made every effort to make her cry and she was not able to cry. But when she saw (the dance) "Lamintation". She said that the grief was honorable and that it was universal and she should not be ashamed of crying.When she saw Lamentation, she said she felt the grief was honorable and it was universal and she need not to be shamed of crying, for her son."---Voice form Martha Graham

In theater and dance, the human body has been used as the narrative instrument in which to convey or enhance the emotional content of the character or story. The postures and movements are not simply decorative but rather sophisticatedly selected and encoded to let the audiences determine whether to like or hate the character or if the story is a tragedy or comedy—the theory of which has been fully developed in ballet and mime systems. But the drawback is that movement in either ballet or mime is propositional, such as a raised hand meaning to stop, which is in order to fit the dramatic purpose. Therefore, it is not directly linked to human emotions.[2] In contrast, modern dance emerged from ballet and mime but, in most cases, contains no narrative and, rather, expresses highly convincing emotions, which suggest to us the cue about how emotion embodies in movement.

Martha Graham (1894–1991) was a foremost pioneer of modern dance and choreographers around world. She developed her very own language of dance, which consisted of jagged and constrained but powerful

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[2] Akinleye A.; Watching Dance: Kinesthetic Empathy; Geography of the body, DanceUK News, Issue 70; 2008

Fig.2.01 Lamentation, Richard Move as Martha Graham,Photoed by Josef Astor

movements that are quite distinctive to the long fluid movements in a classic ballet system. She focused on exposing the innermost secrets of depression, rage, grief, and ecstasy. Her solo dance, Lamentation, in 1930 is the best representation of her notion of dance. In this dance, she sat on a low bench, wearing a tube-like shroud. She writhed, twisting as if trying to break out of that skin; thus, a figure of unbearable sorrow. However, she once stated that no emotions were put into the performance. But the gaits, gestures, and motion phrases showed the flickering aspects of repression, denial, private longing, heartbreak, personal conflict, and hypocrisy.

With the instance of modern dance, artistically affective movement displays exaggerated expressions that may barely occur in daily life, but it stores infinite numbers of feelings and emotions and then projects those recognizable emotions to the audience. Coinciding with self-projection theory, the task of recognizing affective movement needs the understanding of the linkage between movement and emotion, which requires an efficient tool for analyzing and correlating physical characteristics and expressive qualities of the movements.[3]

2.2 MOVEMENT NOTATION SYSTEM

As noted by *Ann Hutchinson Guest* in her book Dance Notation, Recording Movement on Paper, a good notation system make senses in the following aspects: universality (capability of coding all forms of movement), comprehensiveness, movement analysis (anatomically and physiologically movement coding), versatility in movement description (truthful representation of intention and expressivity in addition to structure), visuality (a visual presentation), legibility (distinctive and discrete coding symbols or categories), and practicability (capable to integrate with modern technologies).[4]

Based on Guest's notation system criteria, *Judee K. Burgoon* categorized a notation system into functional and structural approaches. The

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3. Diana F. Green; Quality of Movement-Emotions; Choreographing From Within: Developing the Habit of Inquiry as an Artist; 2010

4.Ann Hutchinson Guest; Dance notation: the process of recording movement on paper;Dance Books, 1984

5.J. Burgoon, L.Guerrero and K. Floyd; Nonverbal Communication; Allyn and Bacon, 2010 functional approach is to describe the communicative and linguistic function of a displayed movement, which is nonrelated to the expression of affect.[5] For instance, knocking the head means agreement. The structural approach investigates how bodily movement is present and the notation of posture and movement. Comparing these two approaches, expressing emotion apparently is the secondary task of a functional approach, while a structural approach contains kinetics and expressive details, which are more appropriate for affective movement analysis.

2.2.1 LABAN MOVEMENT ANALYSIS

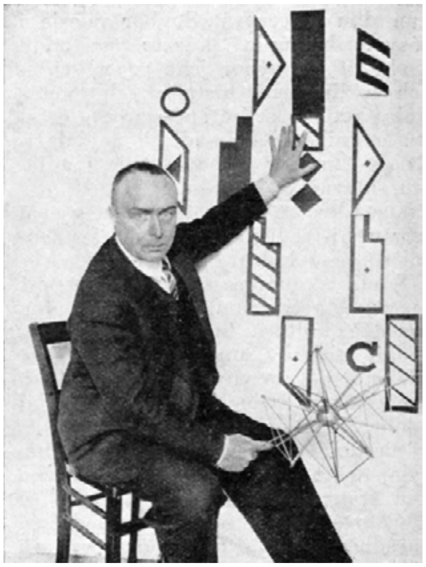

Fig.2.02 Rudolf Laban and His Notation Code

Laban Movement Analysis (LMA),[6] as a prominent example of a structural movement notation system, provides a universal language for observing, describing, notating, and interpreting movement, which defines the kinematic as well as its expressive features. Originated in Germany at the beginning of the twentieth century by *Rudolf Laban* (1879–1958), pioneer of European modern dance and proponent and theories of movement education, LMA now has been developed as a movement rating scale system for the purpose of understanding how emotions could be identified by motion elements. This method of movement study focuses on the interdependence of thinking, feeling, and action, which is valuable for exploring the relationships between motion and thought, motion and emotional state. With this perspective, the characteristics of LMA perfectly exist with the needs in extracting emotional cues from motion and decoding movement to qualitative and quantitative factors.

LMA is comprised with five fundamental factors: body, space, effort, shape, and relationship.[7] Body deals with which body parts move, where the movement initiates, and how the movement spreads through the body. Space describes the size of the mover's kinesphere and what crystalline form is being revealed by the spatial pathways of the movement. Shape describes the changing form the body makes in space,

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[6] *Ann Hutchinson Guest; Dance notation: the process of recording movement on paper;Dance Books, 1984*

[7] *Maletic Vera; Body, Space, Expression: the development of Rudolf Laban's movement and dance concepts; Berlin; 1987*

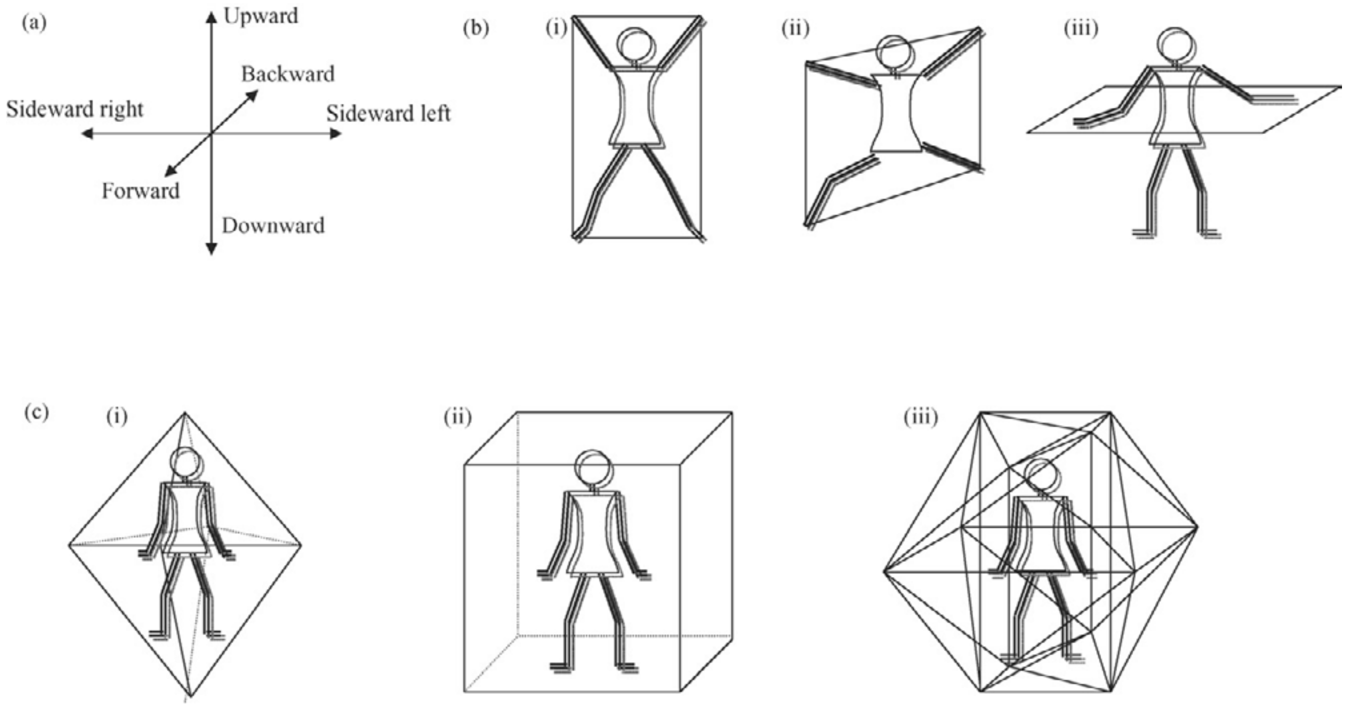

Fig.2.03 Diagrams of Some of The Organizational Definitions of LMA Space.
(a) The Axis Scale constructed from the length, width, and depth of the body representing the six pure vertical, horizontal, and longitudinal directions that the body can move through Space. (b) The three Planes of spatial movement derived from the Axis Scale whereby each direction in the Plane is a combination of two Pure Directions: (i) the Vertical Plane (Upwards + Sidewards right or left, Downwards + Sidewards right or left); (ii) the Sagittal Plane; (iii) the Horizontal Plane (Forwards + Sidewards right or left, Backwards + Sidewards right or left). (c) Three examples of the many geometric shapes that the body can move through Space: (i) the Tetrahedron; (ii) the Cube; (iii) the Icosahedron.

while effort involves the dynamic qualities of the movement and the inner attitude toward using energy. Relationship describes modes of interaction with oneself, others, and the environment. Each individual has his/her own unique repertoire of and preferences for combinations of these basic elements, which can be sequenced, phrased, patterned, and organized together in a particular personal artistic or cultural way. While individuals do show habitual predilections for certain effort configurations, human beings also possess the capacity to comprehend the nature of effort qualities and their patterning in dynamic sequences. Therefore, this thesis focuses on the shape and effort component because these two are the major direct specifications or indications of expressive human movements.

2.2.2 SHAPE

In LMA, the shape component describes the physical dimensions of motion, which is the formal content of movement. When the body interacts with the spatial environment, the environment is conceptualized as a geometric space. These physical dimensions of body present as qualitative features. According to Laban's notion, there are six specific shape qualities: rising and sinking (vertical plane); spreading and enclosing (horizontal plane); advancing and retreating (sagittal plane) (Fig. 2.03). [8]

The polarities of opposing shape factors are as specific as rising verse sinking, spreading verse enclosing, and advancing verse retreating; in the simplest form, opening and closing manifests the active or negative intuitive attitudes to either internal or external stimuli. In other words, those shape features are derived from the emotions of hate or love. This point in many ways concurs with the valence theory of J. A. Russell,[9]which distributes emotions in a system of coordinates, where the y axis is the arousal (intensity of emotion) and the x axis is the valence (pleasure to displeasure). Two valence groups (pleasure and displeasure)

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8 Maletic Vera; Body, Space, Expression: the development of Rudolf Laban's movement and dance concepts; Berlin; 1987

9.James A. Russell; A Circumplex Model of Affect; Journal of Personality and Social Psychology 1980, Vol.39, No.6, 1167-1178

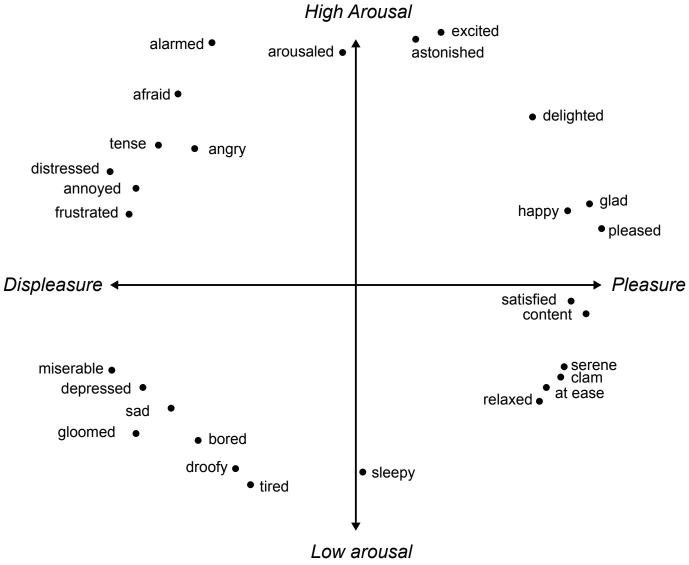

Fig.2.04 Circumplex Diagram, J.A. Russell

define different arousal levels. Therefore, we can hypothesize that the shape qualities set up the basic valence tone in expressing emotion. In Petra Fagerberg's research on designing gestures for affective input,[10] an actor was asked to dance with eight different emotions in order to label shape characteristics in a discrete emotion set. The actions were concentrated on presenting the general expression of emotions rather than a choreographed dance posture, which is to avoid the misreading caused by experiential, personal, or cultural variation. Movement is measured by LMA shape qualities and classified according to different emotion categories as follows:

- Excitement: extreme spreading, rising, and advancing
- Anger: somewhat spreading, rising, and advancing
- Joy: somewhat spreading, somewhat rising and advancing
- Satisfaction: neutral in all planes of movement
- Sulkiness: enclosing rising and retiring
- Fear: enclosing descending and retiring
- Sadness: enclosing descending and retiring
- Disappointment: somewhat enclosing descending and retiring

As the diagrams in Fig. 2.05 shows, emotion types selected in Fagerberg's research are identified in this coordinate system. Furthermore, the shape characters of expressive movement can be generally separated into two groups: spreading and closing. From this collaboration, we may assume that the valence of emotion is, to some extent, associated with shape factors.

10.Petra Fagerberg, Anna Stahl, Kristian Hook; Designing Gesture for affective Input: An Analysis of Shape, Effort and Valence; Stockholm University; 2010

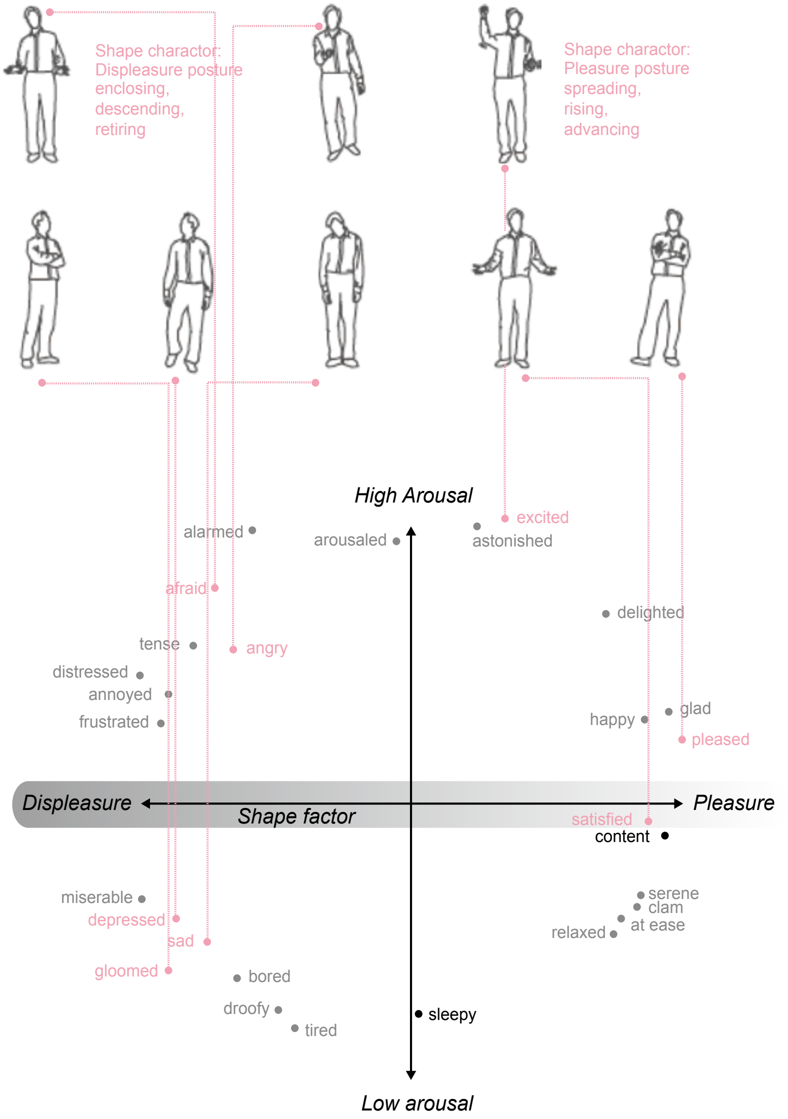

Fig.2.05 Diagram of Shapes in Fregburg's Experiment. The result implies Shape factors are related with valence value.

2.2.3 EFFORT

Effort factor refers to the movement's expressiveness, which describes the change in the intensity of emotion entailed throughout the movement, which involve four factors: weight, time, flow, and space. As previously discussed, shape qualities define movement patterns as well as the primary emotion valence, while effort factors diversify the opposing polarities of shape factors with variant expressive nuances. For instance, stretching out our limbs, we choose the shape quality sample, with a different degree of strength, continuity, and velocity; thus, the same movement pattern disparately expresses emotions. In general, light/smooth/long duration movement may present pleasure and enjoyment; by contrast, the strong/jagged/short duration movement shows suddenness or even aggressiveness. From that standpoint, the effort component is about how emotions or feelings govern the patterning of movement. In LMA, the four effort components are defined as follows.[11]

Weight Effort mainly describes the forces (pressure or tension) throughout movement. The strong weight effort is manifested in the increase of forces. Smashing something using our fists would be the paradigm of strong weight effort. On the opposite end, light-weight effort is about the release of forces. For instance, wiping tears from a child's face.

Time Effort presents velocity of movement. Quick time effort is the acceleration of movement: for example, being startled by something unexpected. Conversely, sustained time effort, such as embracing an old friend, an example of deceleration of movement. At the same time, it is also interesting to note that the duration of movement or gesture is rendered by individual emotion. Referring to Laban's notion "Our perception of time is completely relative. Torturing tension feels endless, of long duration, and joyous tension, however, quickly vanishes' (Gymnastik und tanz, p.72).

11.Rudolf Laban, F.C Lawrence; Effort: Economy of Human Movement; London; 1974

"When we observe human movement we can notice first of all its regular change...the manifestation of force between tension and release, subjects all movement to a kind of pulsation, to breathing----"
Foreword by Rudolf Laban,"Labanotation,by Ann Hutchinson(New York: A Theater Art Book,1954),p.XVg

Flow Effort presents the continuity of movement. Rigid flow effort is manifested in constrained and bounded movement, as if the mover has a strong will to control every segment of movement. Opposite to that, free flow effort leads to smooth and relaxed movement without obtrusive pause. For example, swinging limbs just like a feather floating in the breeze.

Space Effort is the tendency of orientation, which is implicated. With the increase or decrease of extension in space, space effort of movement gives the quantitative sense of the focus of movement. The central space effort is narrower to point out the focus; comparatively, the peripheral space effort is a wider movement for multifocus.

In Fregerberg's experiment, eight test emotive body languages were classified and divided into three effort levels—from minimal effort to maximal effort level: sadness, being in love; sulkiness, surprised-interested, pride, satisfaction; excitement, anger, surprised-afraid. As the results illustrate, despite the difference in shape factors, the effort graphs of the emotional body language expressed in each effort group shows the same pattern. Minimal effort level involves sustained, light, fluent, and direct effort; neutral effort level involves sustained, light, bound, and direct effort; maximal effort level involves quick, strong, bound, and flexible effort. Ally with Russell's valence and arousal model, the hierarchical effort group manifested in the various arousal level.

From the review of Fregerburg's experiment, a general method to identify emotive movement is indicated as a shape component, which corresponds

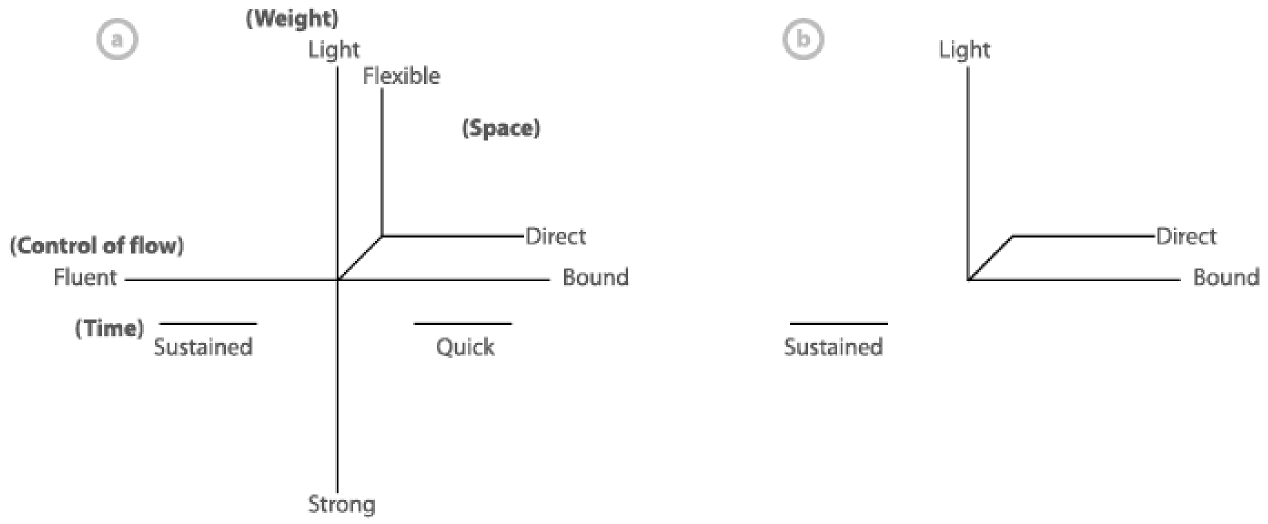

Fig.2.06 An Example Effort Graph of Inserting A Light Vulb. [Laban and Lawrence]

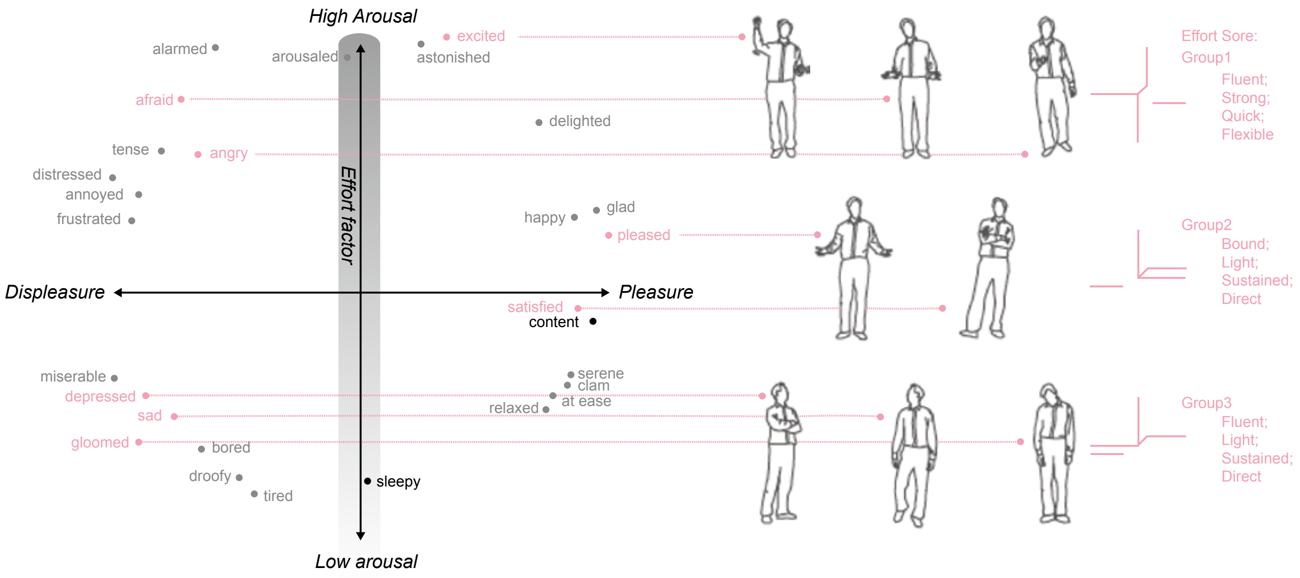

Fig.2.07 Diagram of Efforts in Fregburg's experiment. The result implies Shape factors are related with arousal value

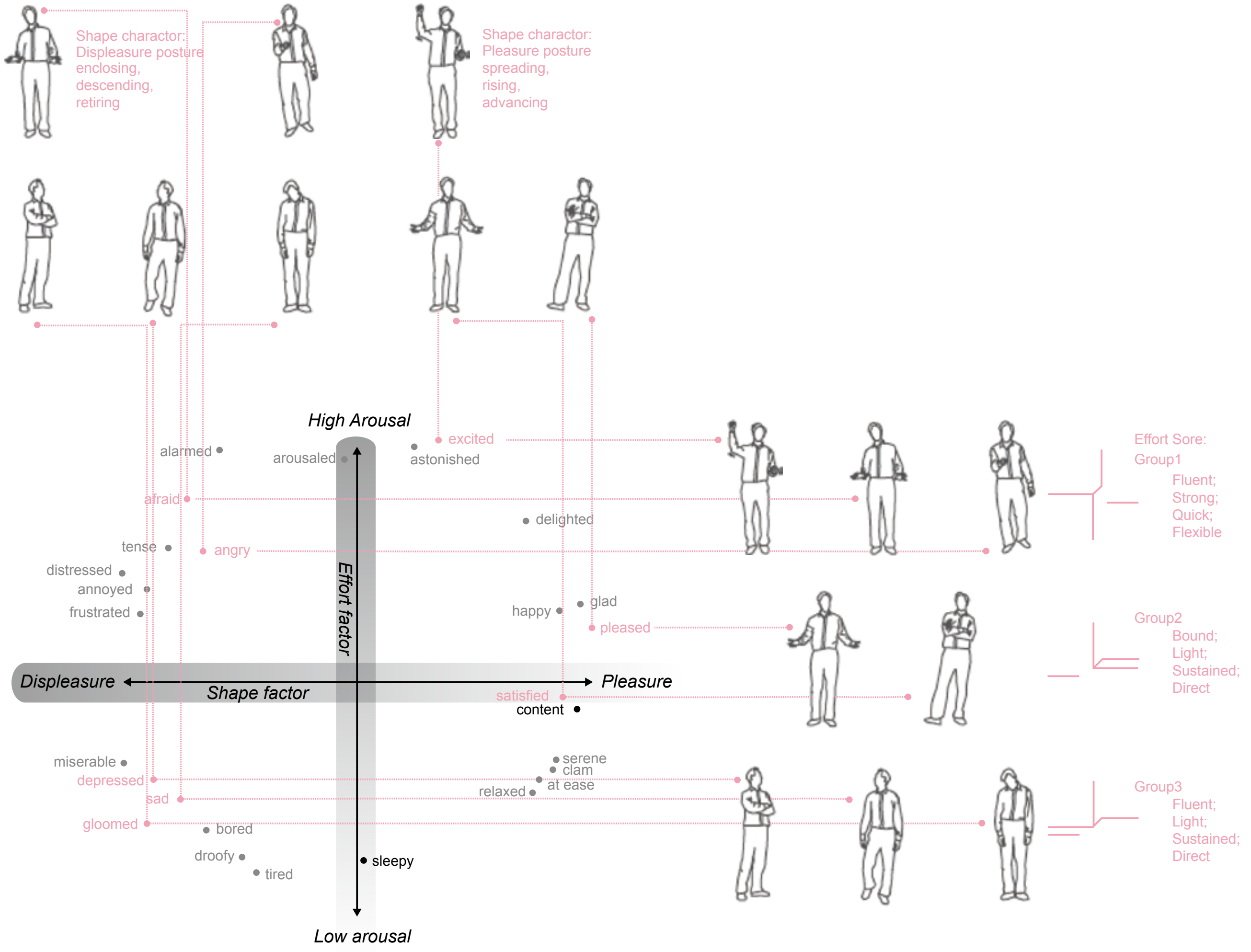

Fig.2.08 LMA Decripters in Circumplex Digram.

with the valence of emotion, while the effort component corresponds with the arousal level. Meanwhile, shape describes the physical features of movement, and effort indicates the expressiveness as well as the energy use in movement. Therefore, the correlation between LMA descriptors and Russell's valence and arousal assessment system allows us to reveal the underlying cues that connect movement and emotion. However, this translation is still too vague and lacks the quantitative factors for automatic recognition usage. Thus, the concern here is to figure out a second-level translation from qualitative descriptors to quantitative data.

2.3 THE RECOGNITION OF AFFECTIVE MOVEMENT

Because the LMA component needs to be translated to low-level quantitative parameters; thus, the first task is to find out the directly related characteristics of movement. *Delsarte T. Shawn's*, *Every Little Movement: A Book About Francois Delsarte (Dance Horizons, 1968)* identified nine laws that contribute to the meaning of a movement: altitude, force, motion (expansion or contraction), sequence, direction, form, velocity, reaction and extension.[12] The Delsarte system has been applied by automatic recognition and generation of affect-expressive full body and hand and arm movements. This understanding corresponds with Laban's notion of laws of sequencing, the alternating rhythms of stability and mobility and exertion and recuperation—all of which provide a governing pattern and order that prevents movement from being chaotic. With grasping the sequencing of movement, it can offer a better insight of human perception of affect-expressive movement.

More specifically, *Boone and Cunningham*'s research on *children's decoding of emotion in expressive body movement*[13] reported salient features that indicate affective states in motion. In this research, participants can interpret affective states from dance movement by utilizing six cues: changes in tempo (anger), directional changes in face and torso (anger), frequency of arms up (happiness), duration of arms away from torso (sadness), muscle tension (fear), and the duration of time leaning forward (sadness).

More than named kinetic characteristics, the quantified data is also important. To that end, a perceptual user study can help to offer better insight into how kinetic features affect expressing a desired emotion. An example-based research, *Expression of Emotions in Dance: Relation Between Arm Movement Characteristics and Emotion*, proposed by *Misako Sawada, Kazuhiro Suda, Motonobu Ishi*, reported an experiment to examine how dancers alter movement characteristics to express emotions. Because certain movement characteristic seem necessary

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12.T. Shawn, Every Little Movement: A Book About Franc¸ois Delsarte. Dance Horizons, 1968.

13.R. Thomas Boone and Joseph G. Cunningham; Children's Decoding of Emotion in Expressive Body Movement: The Development of Cue Attunement; Brandeis University, Developmental Psychology 1998, Vol. 34, No. 5, 1007-1016 for relevant perception of a certain emotion, a set of movement control parameters in terms of force, speed, and directness were selected in the experiment to measure a test movement. In order to exclude the unexpected influence on a viewer's perception of emotion, which might be caused by factors other than movement characteristics, the authors chose to use a certain body part and body action to concentrate on the movement characteristics only.[14]

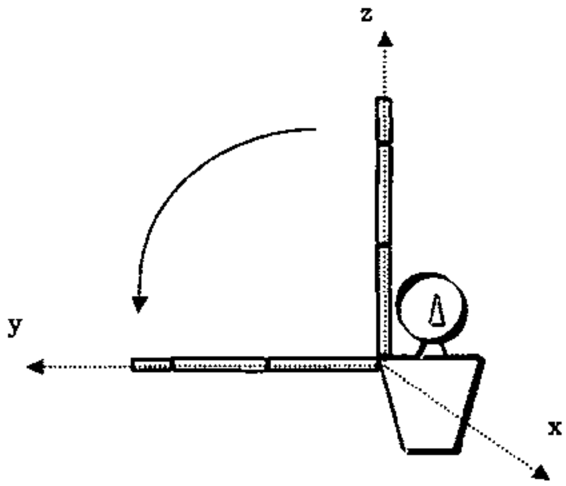

Fig.2.09 Neutral Movement Used To Express Three Emotions

In this first part of the experiment, the female modern dancers were asked to express three emotions: joy, sadness, and anger. The dancers had to use the right arm, use a neutral movement, and then alter the movement characteristics for emotional expression. Each expressive movement was videotaped for kinetic data analysis. The resultant maximum velocity was noted as speed, the resultant maximum acceleration as force, and the total finger travel distance as directness. The results show that, in anger expression, dancers altered the movement features in speed and force via performing faster and stronger movements, which are more obvious

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14.Misako Sawada, Kazuhiro Suda, Motonobu Ishii; Perceptual and Motor Skills; Expression of Emotions in Dance: Relation Between Arm Movement Characteristics and Emotion; 2003, 97, 697-708 compared with other emotional expressions. Joy and sad expressions were associated with slower and weaker characteristics, but the difference is that, in expressing joy, a longer distance and a variable trajectory were illustrated. On the other hand, sad expressive movement tended to be slower and lost energy.

In the second part, twenty-two students volunteered to exam whether audiences can precisely perceive the emotion from the modification of arm movement. As a consequence, the participants indeed could accurately perceive the actual emotion. Those results indicate a discriminate function of affective movement perception that, for joy perception, depends on indirect character, and sad perception depends on weak and direct movement. Anger depends on strong and fast movement. Meanwhile, these emotions contribute to a framework for extracting a minimum representation of affective states through dynamic arm movement. The same approach is also reported in Berthouze's research. Berthouze proposed a system that compared distances between body joints to infer affective states. Low-level motion features are discriminated upon by groups of observers from different cultures to fit a certain emotion category.

Furthermore, to exclude the perceptual bias of the anthropomorphic form, research of synthesized expressive movement is taken as reference, such as that from B. Hartmann, M. Mancini, and C. Pelachaud in Implementing Expressive Gesture Synthesis for *Embodied Conversational Agents*[15] and *Perception of Human Motion with Different Geometric Models*[16]. Jessica K. Hodgins reported that viewers, who were shown a series of paired motion sequences, can successfully recognize the affect states through the embodiment of abstract geometric models, stick figures, and polygonal models. The result also indicated that a viewer's perception of an affective state is not influenced by the model appearance but rather by the movement characteristics.

15.Bjorn Harmann, Mazurizio Mancini; Implementing Expressive gesture synthesis for embodied conversational agents; GW'05 Proceedings of the 6th international conference on Gesture in Human-computer interaction and simulation, Pg 188-199, 2006

16.Jessica K. Hodgins, James F.Orien; Perception of Human Motion with Different Geometric Models; IEEE transaction on visualization and computer graphics, Vol.4, No.4, 1998

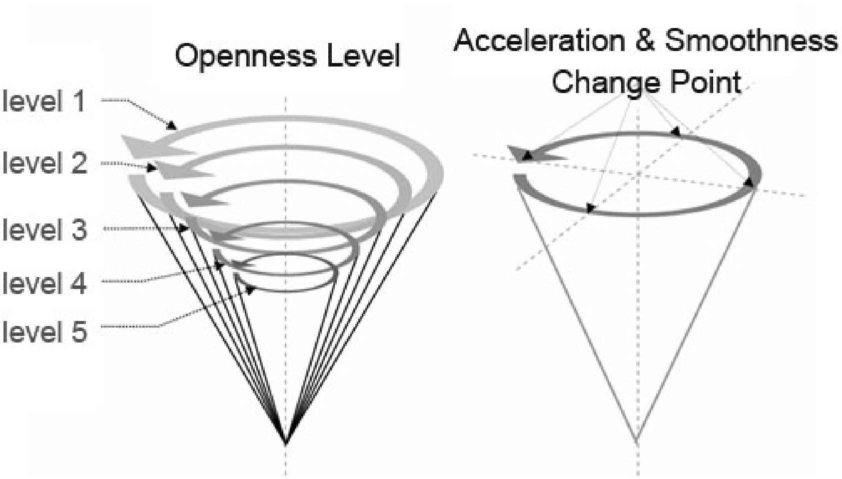

Fig.2.10 The Levels of 'Openness' And The Change Point of 'Acceleration and Smoothness'

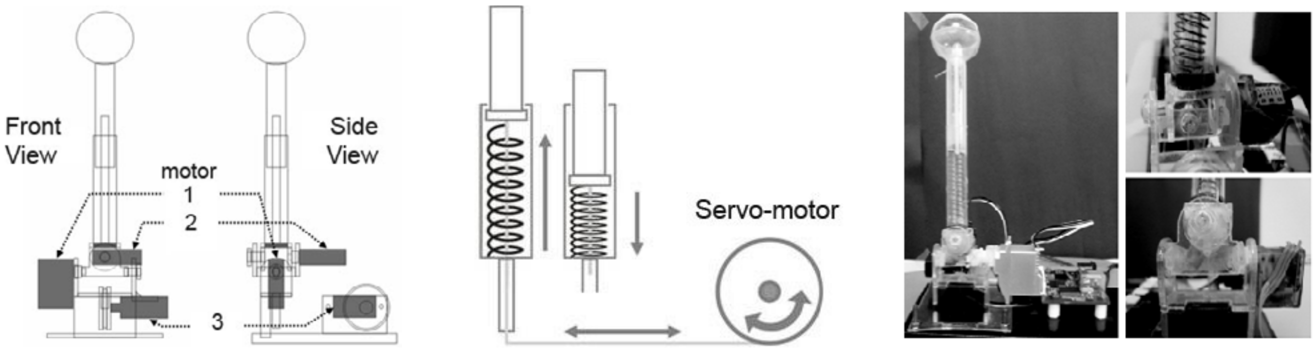

Fig.2.11 Emotive Palpus Hardwares and Drawings

In Joon-Hoon Lee's research, Emotional Interaction Through Physical Movement,[14] a kinetic prototype palpus (a metaphor of palpus of creature [like an insect or snail]) is manipulated by a set of motion modification rules that can adjust the velocity and the range of motion for a desired style. Its movement was manipulated by three movement characteristics in a specific velocity, smoothness, and openness. Each characteristic has five levels to differentiate each time of a circular movement.

- Velocity: five levels to differentiate each time of a circular movement basis
- Openness: five levels to differentiate width and height of a circular movement basis
- Smoothness: five levels of circular movement without acceleration to movement with four accelerations

The purpose of this experiment was to discover the relation among two elements of emotion and three elements of movement. The emotional effect from the movement elements—velocity, openness, and smoothness—was examined and analyzed. Five levels per each movement were provided and repeatedly presented three times. After watching one movement representing a level, participants selected the most appropriate emotion from the list in a questionnaire.

The result in the document showed that velocity was first noticed by the viewers as correlating with activation/arousal axis of emotion. Along with openness, it affects the perception of activation/arousal during a change in direction, either from shrink to open or open to shrink. For smoothness, it is correlated with pleasantness/valence.

Combined with our previous investigation, this study is an additional step of the motion-to-emotion translation. In Section 2.2, it has been proved that arousal is associated with the shape characteristics and valence is associated with effort values. In this step, shape and effort are transcoded to specified and quantified parameters. A more important contribution is that movement can be synthesized to connote a target emotion meaning no matter if it is acted out by the human or artifact body.

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14 Emotional Interaction Through Physical Movement; Jong-Hoon Lee, Jin-Yung Park, Tek-Jin Nam; J. Jacko (Ed.): Human-Computer Interaction, Part III, HCII 2007, LNCS 4552, pp. 401–410, 2007.

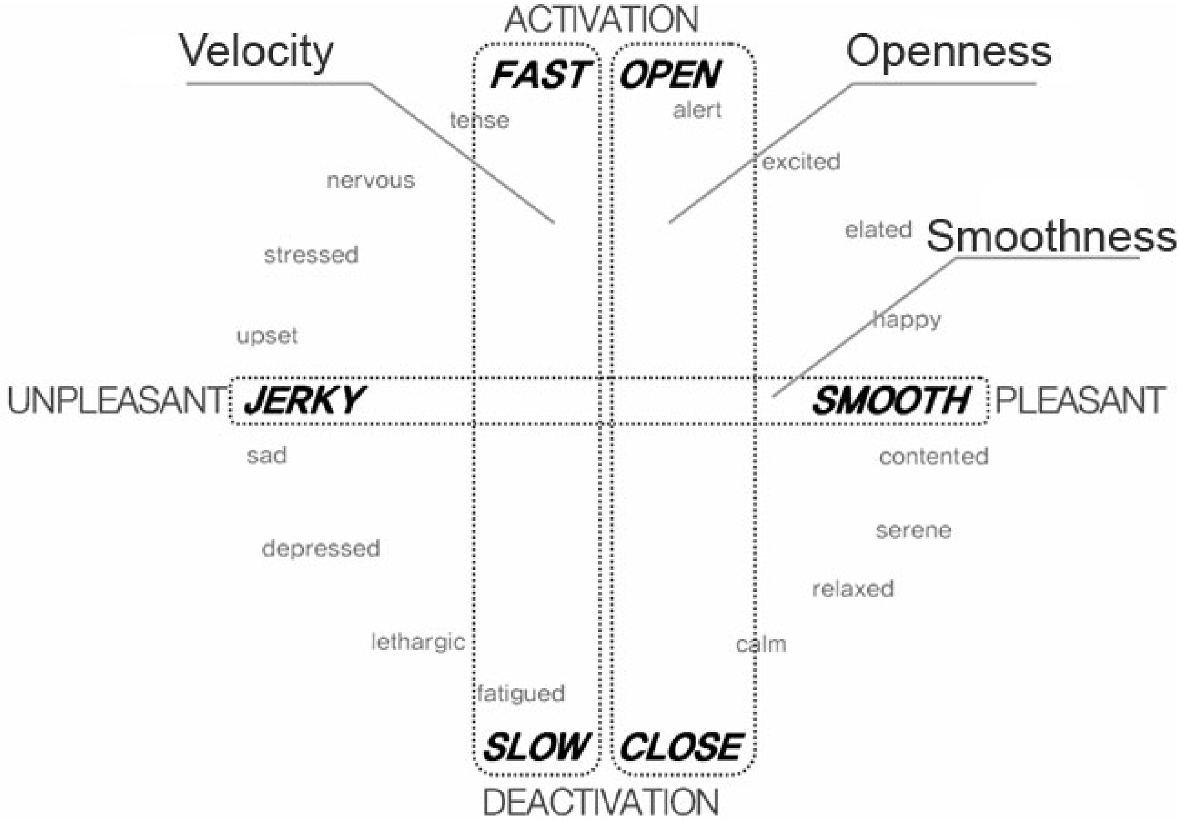


Fig.2.12 The Emotion-movement Relation Framework of Emotive Palpus

2.4 AUTOMATIC RECOGNITION OF AFFECTIVE MOVEMENT

From the previous literature review, I have stated that, in the automated affect recognition process, LMA descriptors need to be translated to low-level quantitative parameters. However, due to the high flexibility of the human body, creating a real-time computational model of a live performance is challenging. A survey of automatic affect recognition and generation (Michelle Karg) documents approaches have been applied to record expressive motion: mainly, computer vision, motion capture, and pressure sensors. Most studies that approach real-world scenarios are based on computer vision and lack regions of the hand, head, upper body, or whole body. But how to capture and measure those movements are considerably significant to all of the researchers. The traditional method is to videotape the movement and then observe using the naked eye. This is inaccurate and has limited collaboration with other work platforms, especially interface design. A substitution is to use mathematical expression to mimic human movement. The drawback remains obvious, however. It demands high-level math talent and, at the same time, only works for certain agents. Most importantly, it is a mimic rather than a real performance.

Fig.2.13 XBOX360 Kinect

In this thesis, a Kinect sensor, which is a new kind of motion capture device, is introduced. Not only does it reconfigure the very nature of our interaction with technological environments, but, not long after its launch, Kinect became famous worldwide, and its impact has been truly

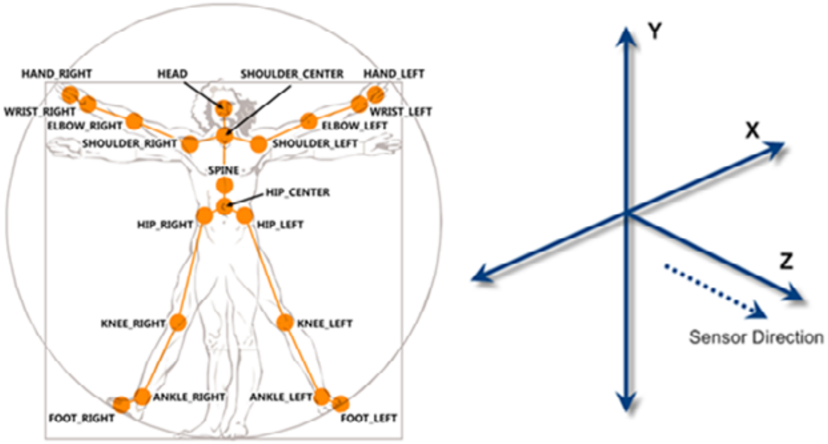


Fig.2.14 Joint Postion Tracked by The Kinect In The 3-dimensional Referential

remarkable. Technically speaking, not only does Kinect have an RGB camera, depth sensor, and multiarray microphone, it can also track body motion, sense hand/skeleton movement, and recognize gestures. It does so by using existing infrared-based camera technologies developed to scan three-dimensional objects in space. One of the functions of Kinect is skeleton tracking. The SkeletonStream produces SkeletonFrame objects and puts them together as an array to create a skeleton. It then defines a set of fields to identify the skeleton and describes the position of the skeleton and its joints. The skeleton-tracking engine follows and reports on 20 points or joints on each user (Webb & Ashley 2012:6). The position of each joint is defined by X, Y, and Z coordinates within a Cartesian grid. In fact, skeleton tracking employs a depth camera that uses an IR projector to record not the color of a surface but its distance of an object from the device. As Greg Borenstein notes, "Unlike conventional images where each pixel records the color of light that reached the camera from a particular part of the scene, each pixel of this depth image records the distance of the object in that particular part of the scene from the Kinect device" (Borenstein, 2012: 6).

Fig.2.15 Alloplastic Architecture: a performance artist dances with the structure that reacts to her presence

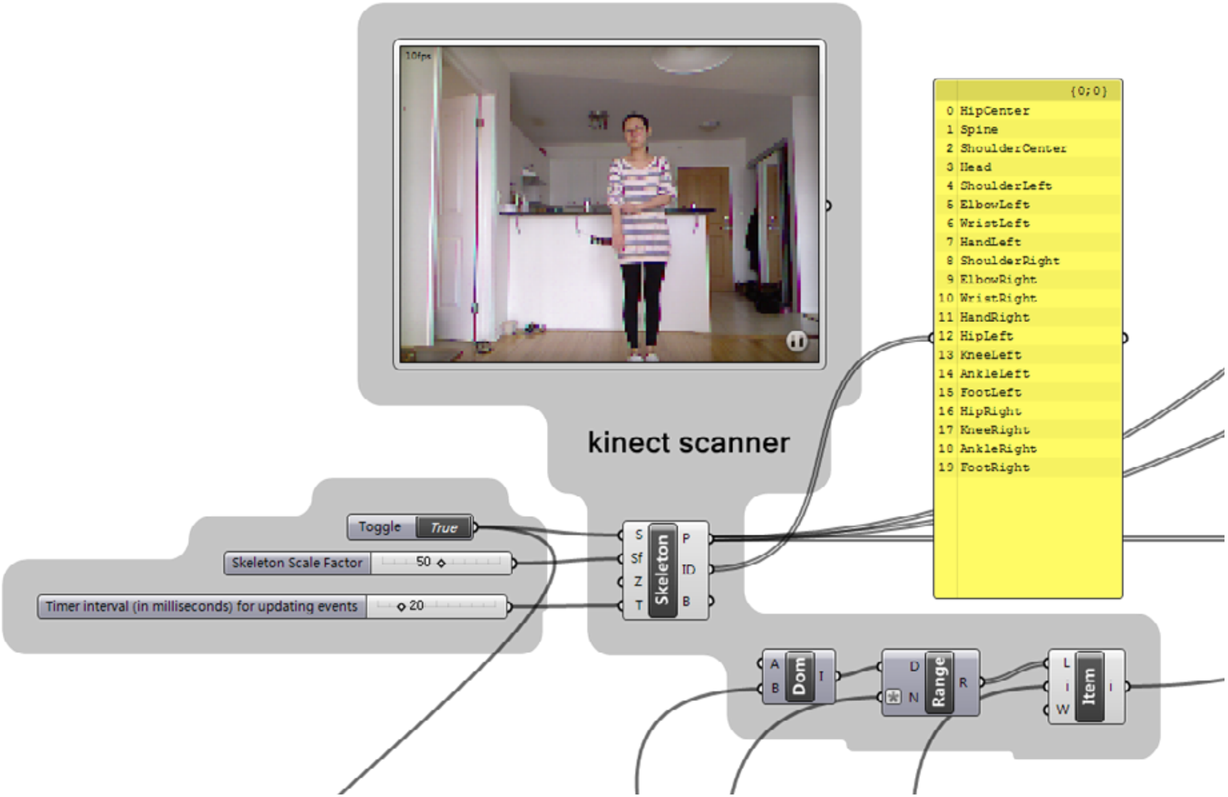
However, this new emerging device is rarely known in architecture design. In a handful of applications, Alloplastic Architecture: The design of an Interactive Tensegrity Structure (Behnaz, Neil, & Alvin, 2013) demonstrates an explosive innovation by manipulating Kinect. Based on a huge amount of effort on responsive tensile structure, Kinect was chosen as the control element of the tensegrity structure, which makes it more sophisticated. As mentioned in the last paragraph, Kinect captures the body of the user as a skeletal frame, detects its distance and position, and is therefore able to determine the exact position of the body in a Cartesian grid and send the information to a computer. Processing codes (through certain software such as C++, C# or Visual Basic) are sent through serial communication to the control panels in order actuate the muscle springs, though there is no particular statement in the paper that indicates how they write the algorithm to process the movement data. From the illustrations and video, each SMA wire, as far as I am concerned, is exactly linked with a certain Cartesian grid (skeleton frame). Therefore, the structure can reconfigure itself, precisely and sensitively, according to the presence of the user. In the final stage of that work, to test its performance, a dancer was invited to interact with the structure. As the dancer responds to the structure through her movements, the structure likewise reacts to the dance. [15]

As to my work, I adopt a particular tool to facilitate the utilization of Kinect. Firefly, a plug-in program of Grasshopper, enables the connection of Kinect to Rhino,[16] which is a widely used platform. With this sense, it can simulate various usages of human–architecture interaction in digital space. Compared with the method adapted in Alloplastic Architecture, Firefly can provide more accessible data, as shown in Fig 2.16, which identifies an entire data set of main joints of the human body, including the head, shoulders, elbows, wrists, knees, and angles. Designers are free to select one or multiple wanted joint points. With that, live performance is simultaneously recorded and analyzed with reliable data, and the task of motion capture becomes extremely easy and flexible.

After looking for a proper tool, the objective of automatic recognized affective movement is close to being achieved. By following the framework of motion-parameter-emotion translation, which is conducted from previous research, this section emphasizes a real-time movement analysis in which three qualities (velocity, openness, and smoothness) are collected from arm movement.

15.Behnaz Farahi Bouzanjani, Neil Leach, Alvin Huang; Alloplastic Architecture: The Design of An Interactive Tensegrity Structure; University of Southern California School of Architecture; ACADIA 2013

16.Andy Payne; Kinect+Firefly; http://www.grasshopper3d.com/profiles/blogs/firefly-1-0066-and-kinect-0-0003-now-available



Toggle True

Skeleton Scale Factor 50

Timer interval (in milliseconds) for updating events 20

```
{0;0}
 0 HipCenter
 1 Spine
 2 ShoulderCenter
 3 Head
 4 ShoulderLeft
 5 ElbowLeft
 6 WristLeft
 7 HandLeft
 8 ShoulderRight
 9 ElbowRight
10 WristRight
11 HandRight
12 HipLeft
13 KneeLeft
14 AnkleLeft
15 FootLeft
16 HipRight
17 KneeRight
18 AnkleRight
19 FootRight
```

Fig.2.16 Kinect Control Panel in Grasshopper

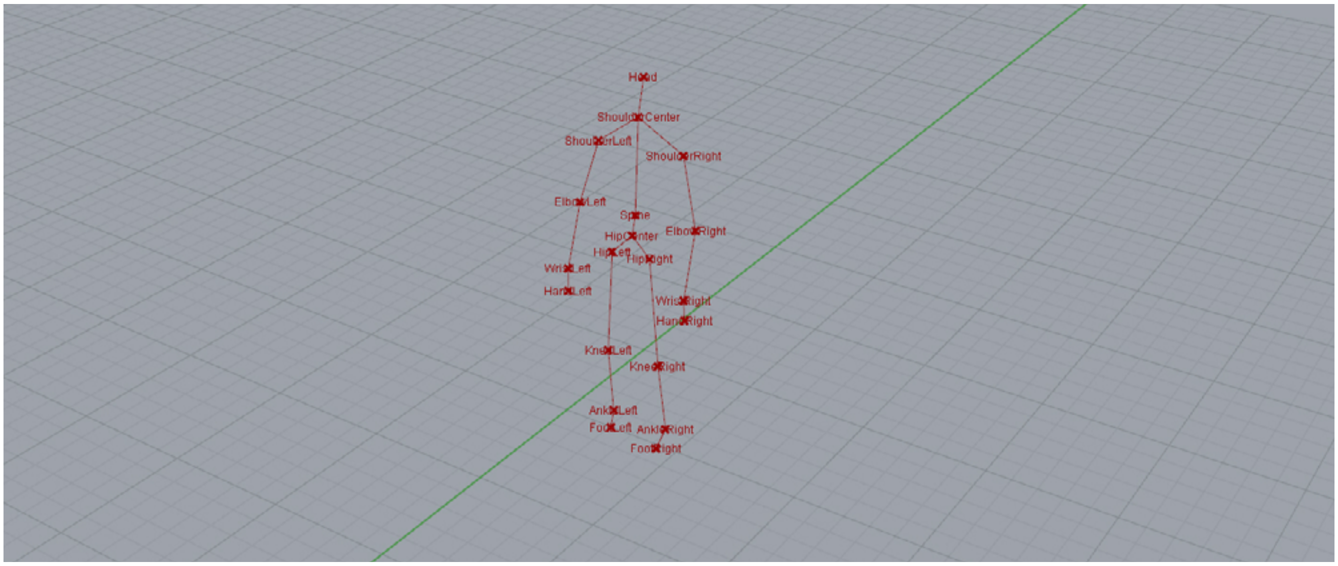
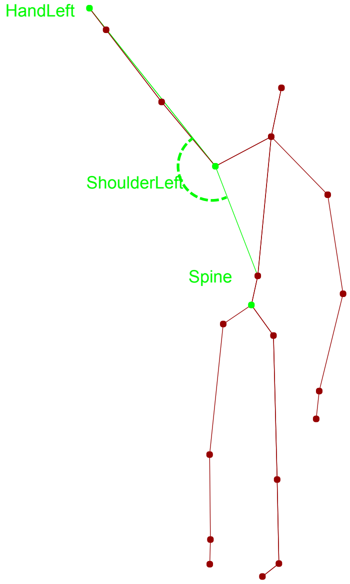


Fig.2.17 Kinect Skeleton in Rhino Space



Left hand, Left shoulder and Spine are selected. At the time, Actor stretches his arm as much as he could

2.4.1 OPENNESS DETECTION

Openness as one shape factor presents the movement tendency, whether engaging or retreating, and contains a positive or negative attitude. In this detection process, openness is manifested as the angle between the arm and torso. Three main joint points are selected: the hand, shoulder, and spine

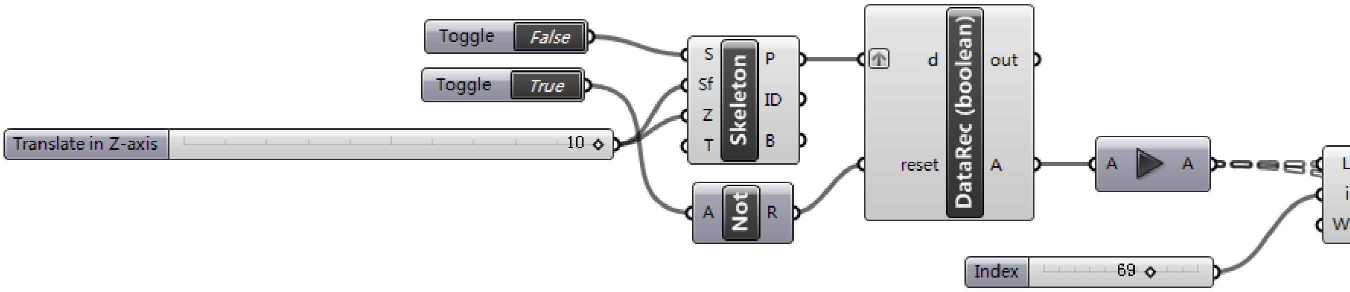
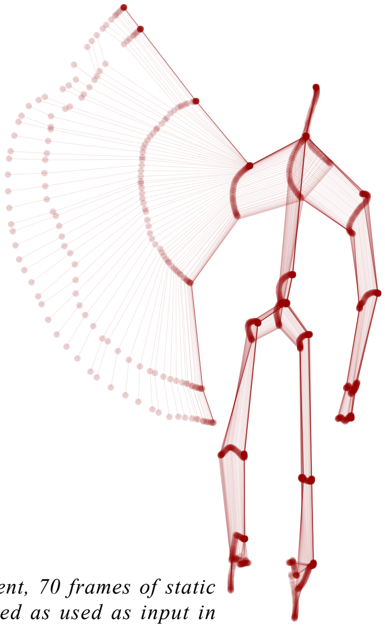


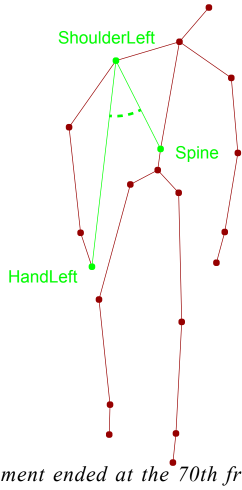
Fig.2.18 Openness Detection Script

However, only the angle is not enough to affect state recognition; thus, we also need to know the degree of openness of the current movement from a domain of angles. Thus, the construction of this domain starts from the maximum openness possible by the human body. An actor straightens up his left arm as much as possible then shrinks his arm to his body. During this process, 70 frames are recorded; the domain ranges from 0.670519 to 2.834528. Based on this, the current data in this domain refers to the arousal level of the actor.

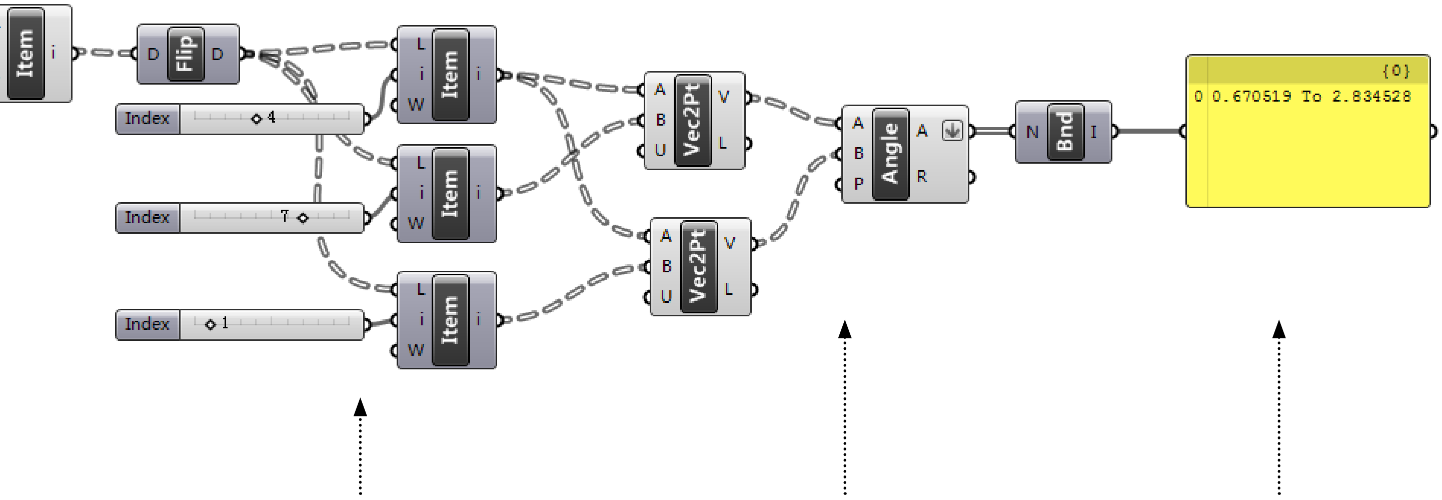
Movement Recorder



During the movement, 70 frames of static gesture are recorded as used as input in the algorithm to calculate the max and min angle.



Movement ended at the 70th frame with a very closed gesture



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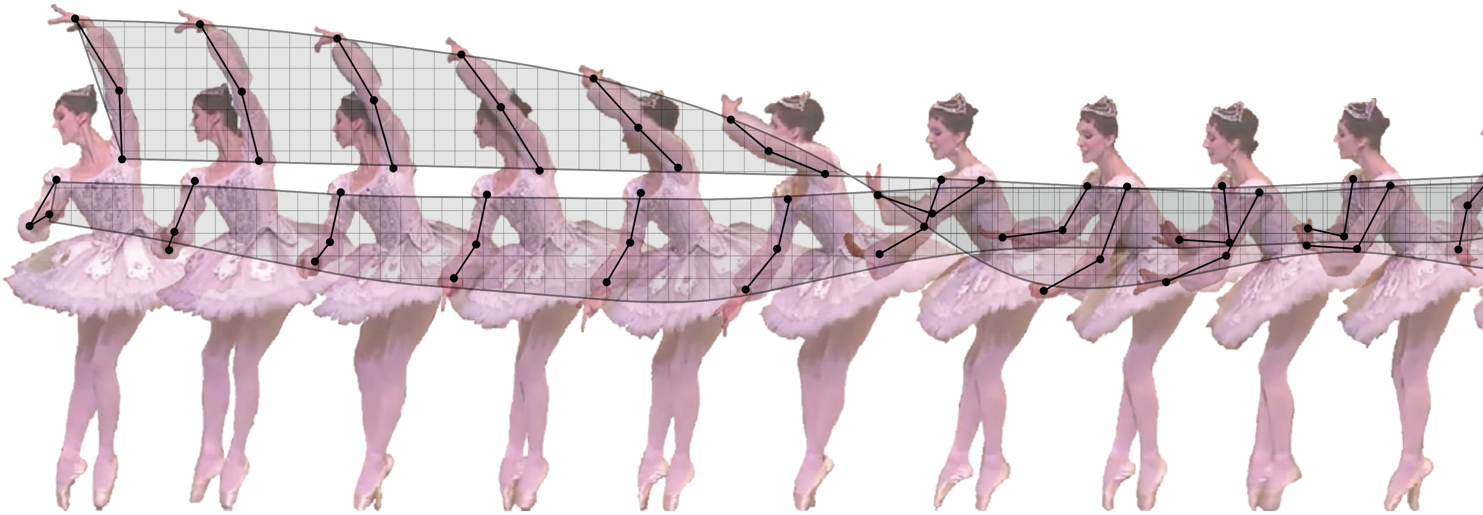
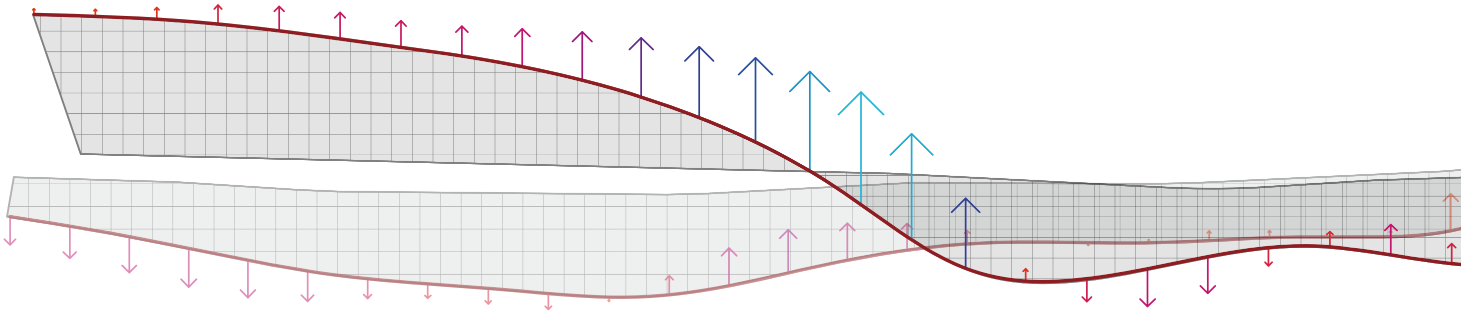
{0}
0 0.670519 To 2.834528
```

Joint Point Selection

Angel Calculation

Max and Min Domain





2.4.2 Velocity and Smoothness detection

Velocity implies the speed of the movement while smoothness describes the rhythm of changing the speed; this is the reason I put them together. However, as far as I know, neither of those values can be defined like openness by one salient parameter. To define speed, we need distance and time duration. In a certain time duration, longer travel distance means a higher speed and vice versa. Considering what have done to obtain the domain of openness, an episode of movement that contains multiple frames can offer a trajectory of a joint point. Therefore, limiting the time of that movement episode and extracting the length of trajectory are the preconditions necessary to obtain speed.

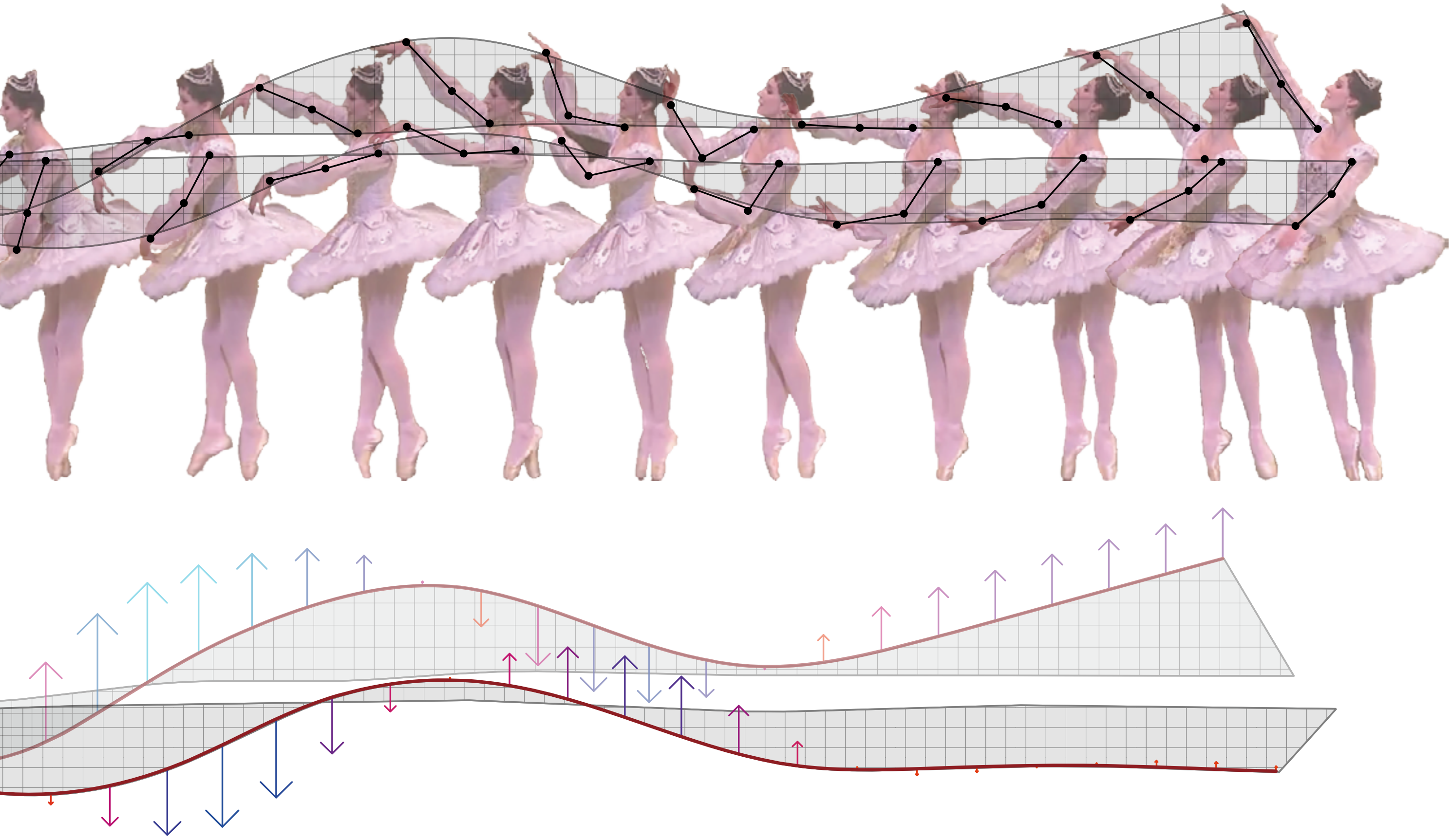
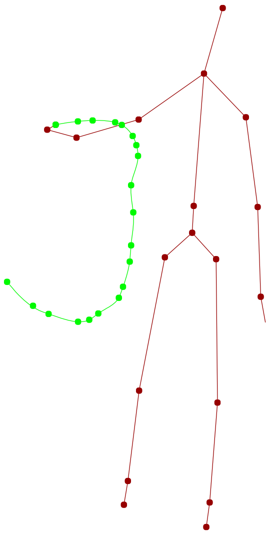
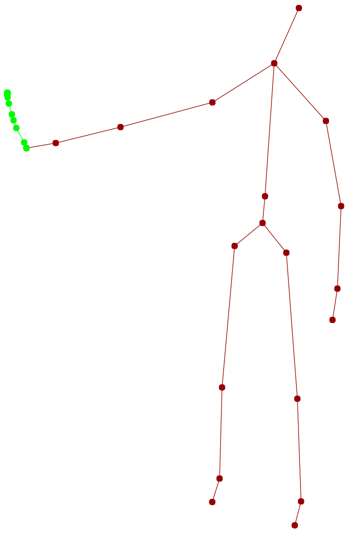


Fig.2.19 Diagram of Motion Trajectory

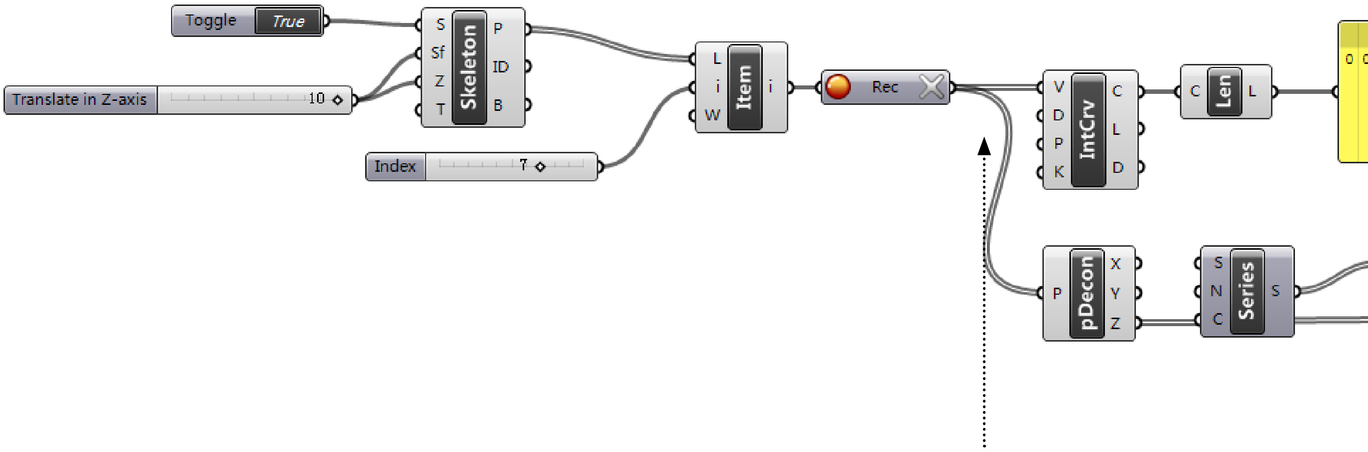
To read the tempo or rhythm from the trajectory is more complicated. Usually, a gentle movement's trajectory is smooth; conversely, a jerky movement's trajectory is steep and abrupt. From that point, the best description of that is the curvature on one point. As shown in the diagram, those arrows are the Z value of the decomposition of the tangent vector of points on the trajectory. The bigger arrow implies that, on that point, there is an obvious acceleration or deceleration. This number infers velocity and smoothness.



Left hand is selected. The recorder component can store 20 frames of positions in every one second duration. In this diagram, a larger amplitude arm swing

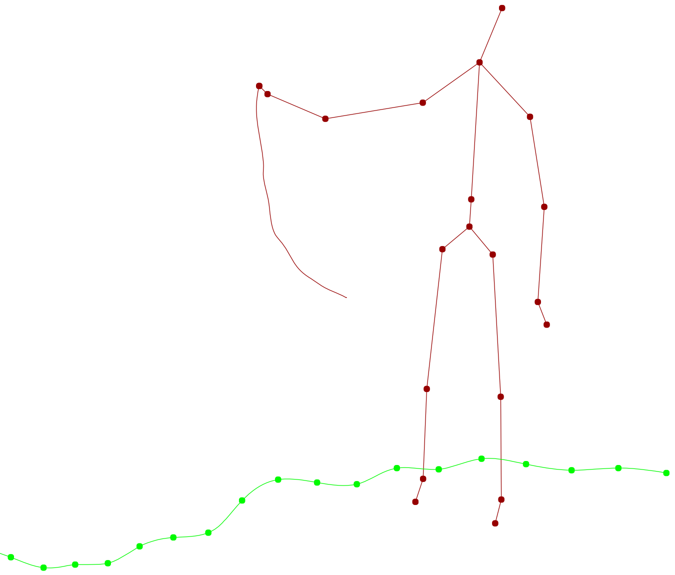


Comparatively, smaller amplitude arm swing left a much shorter trajectory. Depending on the length of trajectory, we can tell the speed or velocity of that movement

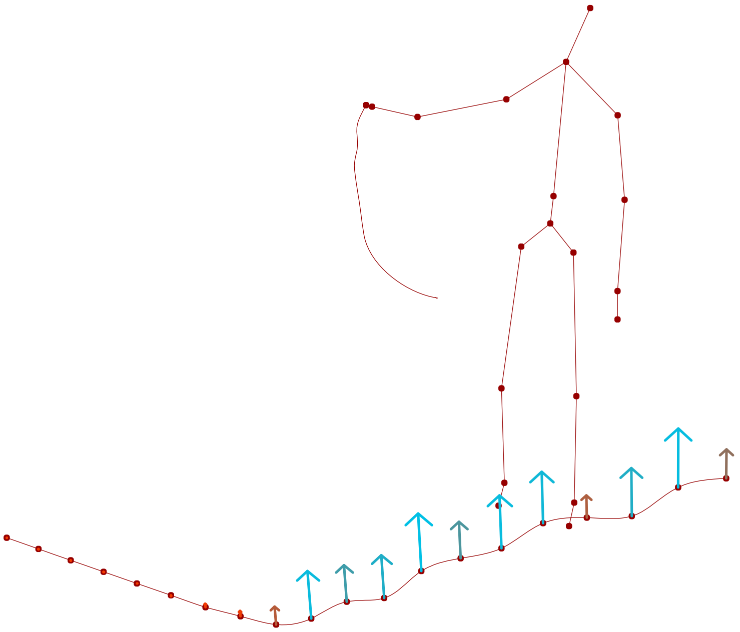


Arm swing trajectory

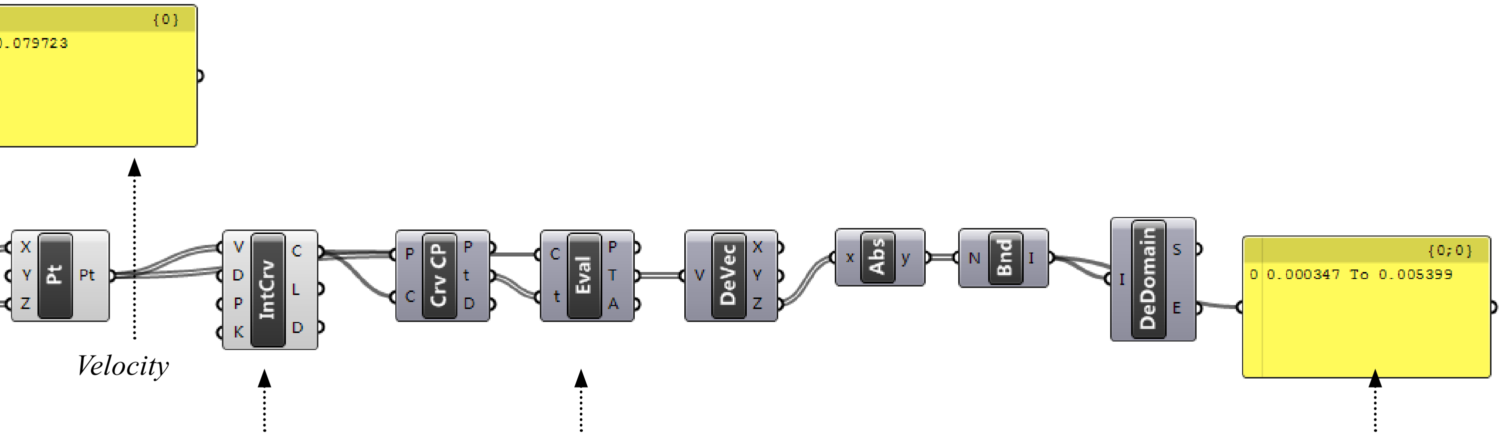
After the last step, translation between emotion and motion is accomplished. From Russell's circumplex diagram to the Kinect sensor, the vague emotion descriptors cooperate with the digital parameters. This translation not only contributes a reliable recognition of a participant's affect state but also provides variable inputs to the whole interaction system.



The Z values of arm swing trajectory trajectory is visible as the green points as shown in the diagram and connected to a planer curve.



The blue arrows represent the Z axis of the tangent vectors of that given points on the curve. The value represents the velocity in that second as well as the smoothness of the movement.



```
{0}
.079723
```

```
{0;0}
0 0.000347 To 0.005399
```

Velocity

Planar trajectory

Curvature analysis

Velocity & Smoothness

Fig.2.20 Velocity and Smoothness Detection Script

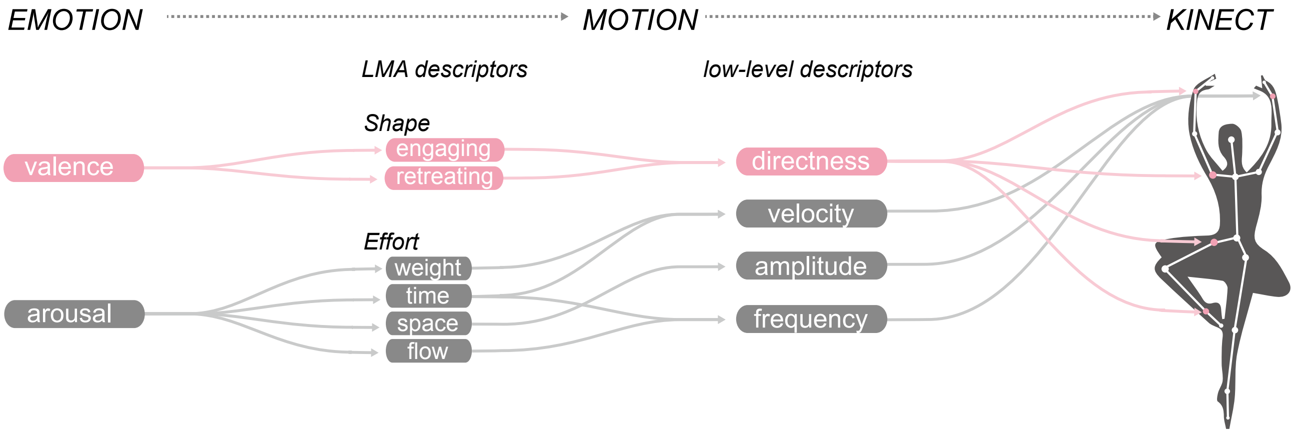


Fig.2.21 Diagram of Emotion-motion Translation

2.5 SUMMARY

In this chapter, we have indicated that an affective state can be discerned from the body as an instrument. The learning of a movement notation system, especially Laban movement analysis (LMA), provides a systematic translation approach to decode the formation of movement. Collaborating with Russell's circumplex model of emotion, which identifies the various emotion types in the coordinate of valence and arousal, LMA descriptors (shape/effort) are effectively associated with valence/arousal value, which results as the first stage translation of motion to emotion. Through having shape and effort in the movement observed, we can roughly infer one's emotional intent. The downside is LMA descriptors, which are highly abstract qualitative factors and are not specific enough to build up "experience filter." For that reason, a next step translation is needed.

The precedents of affect state recognition from either full body movement or individual part body movement demonstrate a further step translation, which rephrase LMA descriptors as quantitative movement characteristics such as speed, amplitude, velocity, etc. These low-level quantitative parameters are easier to measure and record than intangible qualitative descriptors. In the literature review of Emotive Palpus, those quantitative parameters are correlated again with Russell's circumplex model. Three movement characteristics are particularly mentioned: velocity, openness, and smoothness. As a result, the entire translation will process movement to those low-level parameters as the first step and then conduct the emotion intent according to the result. This study is critical in developing the human–architecture interaction. Because it provides architecture, the cognitive structure recognizes human movement. Meanwhile, the syntheses of affective architecture expression also can benefit from the dependency between quantitative movement features and certain affective states. Nevertheless, a Kinect sensor plays an important factor in developing this system. As it is added, automatic recognition and generation can simultaneously happen. The next chapter will focus on the generation part.

SYNTHESIZED AFFECTIVE MOVEMENT

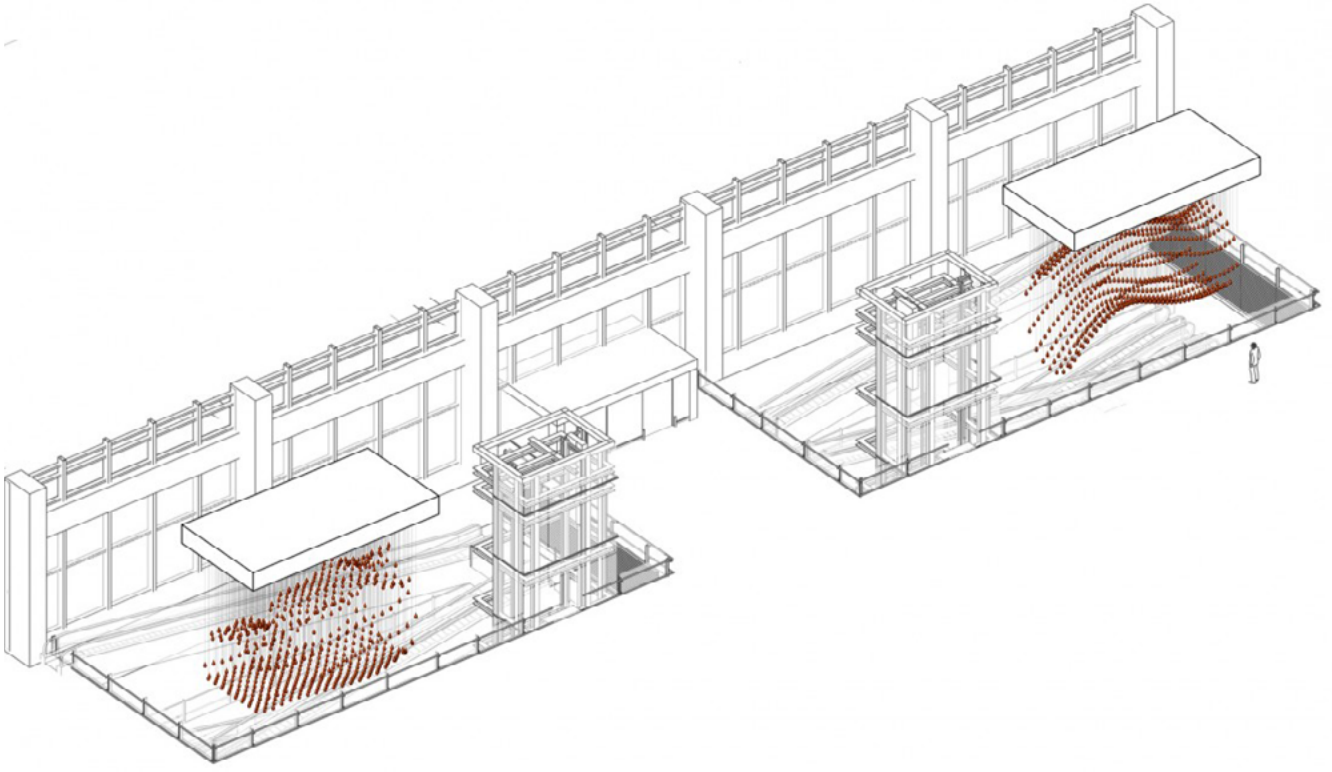


Fig.3.01 Kinecti Rain, Terminal 1 at Singapore's Changi Airport, 2012

3.1 SURVEY OF CONTEMPORARY ARCHITECTURE KINETICS: MEANS AND WAYS

In the previous chapter, the translation from emotion to motion is revealed. Rather than merely recognizing the affect state, this translation also can profit architecture expressions. As previously mentioned, movement as a common language should work for both parts in the interaction. Architecture kinetics, the manifestation of movement in architecture form, therefore, is an ideal platform in which to address this translation: it is mobile, operable, and directly interfaces with people. Thus, a survey of contemporary architecture kinetics application has been taken at the beginning, which focuses on means and ways of kinetics in order to exploit a feasible approach of architecture kinetic syntheses.

3.1.1 MEANS: INDETERMINACY VARIABLES

More generally, kinetic sculpture is exhibited in a public space, as with Kinetic Rain, which is designed by ART+COM studio and is located in Terminal 1 at Singapore's Changi Airport. The kinetic sculpture adds a contemplative element to the lively transit space of the departure hall. Kinetic Rain consists of two parts installed above the terminal's two central escalators. Each symmetrical element is composed of 608 copper-plated aluminium drops. Steel wires connect the drops to computer-controlled motors that raise and lower them with precision. The two elements move in dialogue through a 15-minute animated sequence, evolving from abstract to figurative three-dimensional forms. At times, the two parts move together in unison; at other times they mirror, complement, or follow each other.[1]

Architecture kinetics used to be attached with certain architecture elements such as a facade, ceiling, or wall. Aegis Hyposurface,[2] designed by dECOi architects led by Mark Goulthorpe, is presented as a kinetic wall. Various waves with different ranges, scales, and patterns are generated by electronic-controlled pistons to interact with a location.

Fig.3.02 Copper Rain Drop of Kinetic Rain

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[1] *ART+COM studios; Kinetic Rain; https://artcom.de/en/research_focus/kinetics/*

[2] *Mark Goulthorpe; Hyposurface: from Autoplastic to Alloplastic Space; DECOI Architect, Paris; http://www.generativeart.com/on/cic/99/2999.htm*

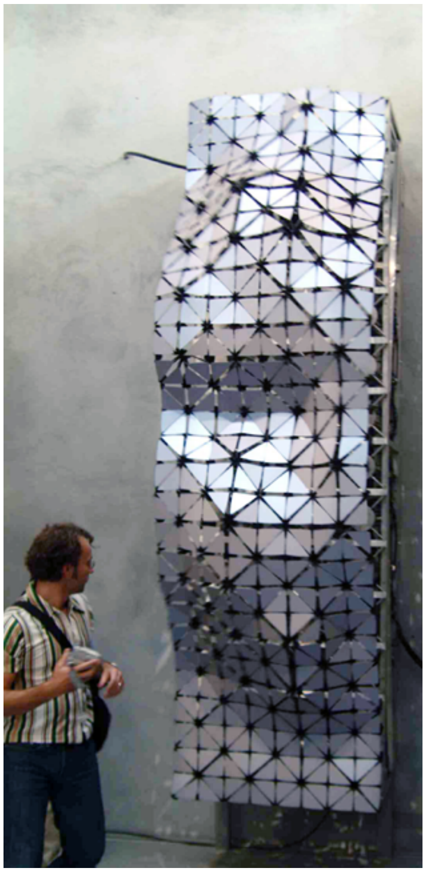

Fig.3.03 Component of Hyposurface

The original computer visualization presented the relief of a smoothly undulating surface as a natural analogy. The physical prototype was eventually a stretching skin operated by triangulated mechanism, which is capable of producing this abstract relief. The concept of this relief describes a relation to the concept of "trauma" in the positive sense of "an intense sampling of experience as the mind deploys its full cognitive capacity to account for unfamiliar pattern." From this standpoint, Mark Goulthorpe makes a case for indeterminacy over a prescribed composition.

In its creation, as in this reception, it suggests an alloplastic rather than autoplastic logic[3]*; the designer's role becoming that of an editor or sampler of a proliferation range of effect who retains the control of this interaction through the qualitative filtering of the input by the computer control system. Aegis is perhaps, therefore, not a form at all because it escapes design ideology; thus, conceived much rather as a matrix of the possibility of form, it is, in fact, the becoming/absenting of form in pattern.*

According to the statement above, the concept of indeterminacy is significantly enforced when designing kinetics. A gradient range exists between polarities of completely determinate to completely indeterminate. Kinetic Rain is a sample of the completely determinate. By contrast, Aegis was intended to be an indeterminate play between registered samples and through local occupancy of visitors. External forces, either environmental or by human intervention, do not produce a correspondingly direct reaction; rather, these inputs are processed according to the logic of the control system. This arrangement of kinetics coincides with the legacy of cybernetics. The registered sample is intended to maintain a steady state accordingly; the interaction with local occupancy is to create reflexivity, in which there is no predetermined performance criteria, with the control being emergent. From the above description, Aegis unveils the concept of control variables in extremes

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3. In Ferenczi's terms an autoplastic environment is one where the subject is challenged by a highly determining context and is forced to auto-adapt in the face of such resistance which can lead to neuroses of trauma. He contrasts this with an alloplastic environment in which there is the possibility of a reciprocal transformation in which both subject and environment negotiate interactively.

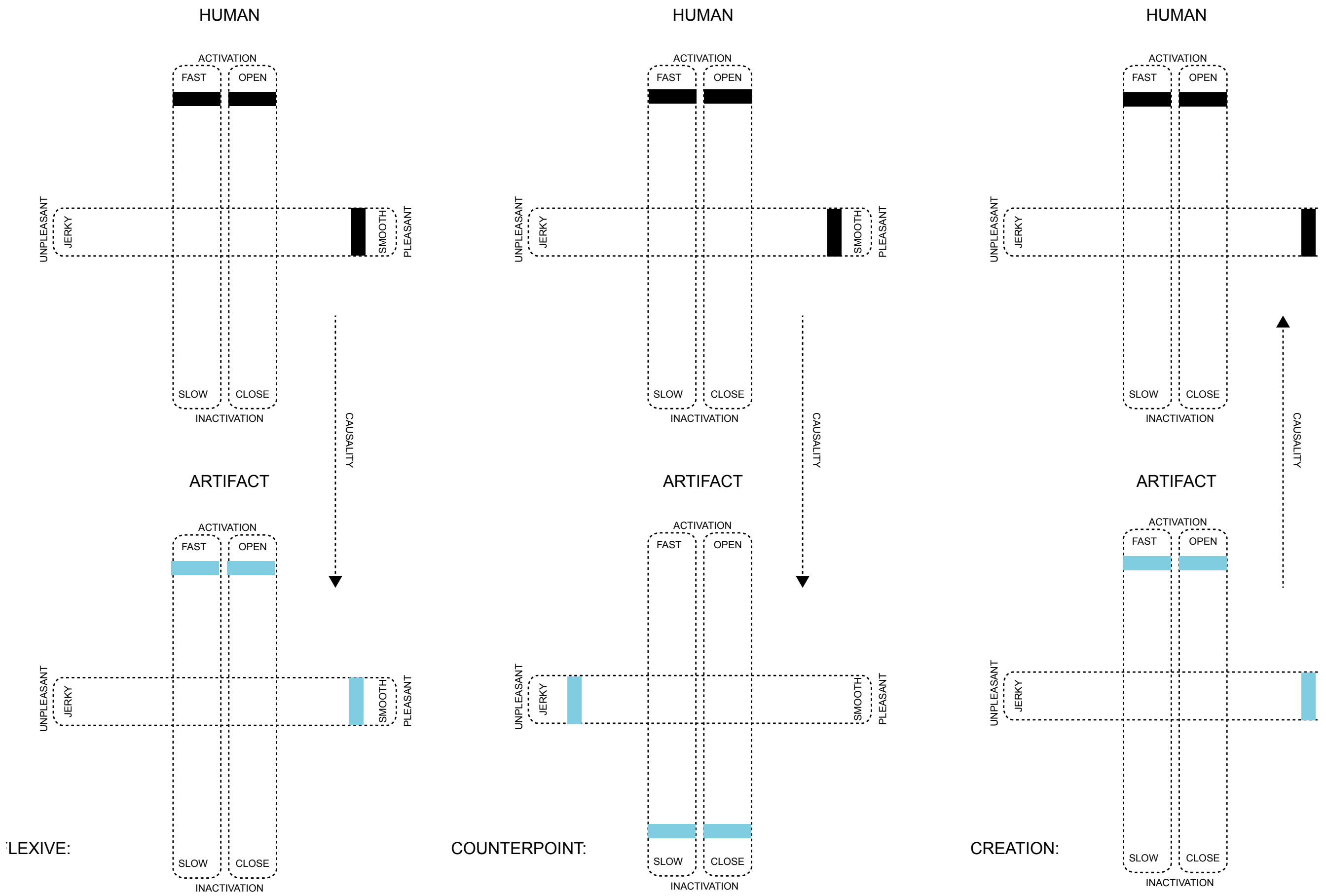
from total homeostasis to total reflexivity. In between these extremes would be degrees of predefined pattern formation and the facility of reconfiguration to produce reflexivity.

This concept is mentioned by Jules Moloney. As noted in his book, Designing Kinetics for Architectural Facades, indeterminacy variables are practiced as a sort of control system. A control system based on homeostasis would suggest that the pattern formation would be predetermined for a defined goal. On the opposite, a control system based on indeterminate would be highly reflexive. With an extreme position, the kinetic pattern can evolve through the autonomous interaction between each singular part.[4] For example, in Hylozoic Ground by Beesley, a hybrid control between homeostasis and emergence has many possibilities (for example, indeterminacy constrained within certain thresholds), or emergent outcomes can be studied and subsequently manipulated to produce some pattern consistency.

This insight indicates that an interactive system could be manipulated by several discrete strategies of interactive behaviors. Depending on the logic of how to process the occupancy information, architecture can react with people who are completely different. Thus, the system becomes more sophisticated, and its behaviors are even closer to conscious actions. To that end, three basic strategies are introduced here: reflexive, counterpoint, and creation.

Reflexive: This mode is the extreme end of generating indeterminacy in which human behavior in some way directly influences the generation of architecture responses; in another words, it could be considered as mimicry. People would feel as though their body movement or their actions are extended to another form. More importantly is that it is a significant procedure for an interactive system to build up the "experience filter." Through this continuous mimicry, the system can learn from human behaviors and gradually enrich its data library.

4.Jules Moloney; Designing Kinetics for Architectural Facades: State Change; Routledge (July 12 2011)



LEXIVE: COUNTERPOINT: CREATION:

Fig.3.14 Strategies of Interactive Behaviors

Creation: This mode is the other end of indeterminacy variables, which lets the artifact take the advance position in the interaction with a human. Just like kinetic rain, the behaviors of architecture are sophisticatedly choreographed and extremely expressive just like in film. To the context of affective interaction, this mode allows architecture to express a desired affect state or emotion, thus having an effect on human actions through certain methods. In particular situations, it could be applied as a control element to restrict peoples' behaviors.

Counterpoint: This mode is the medium between fully reflex and fully preset. To approach a counterpoint mode, the occupancy needs to be known first. Similar to the reflexive mode, peoples' behaviors are processed. The processing data, however, will compare with the preset criteria. Depending on the result of this comparison, the system could

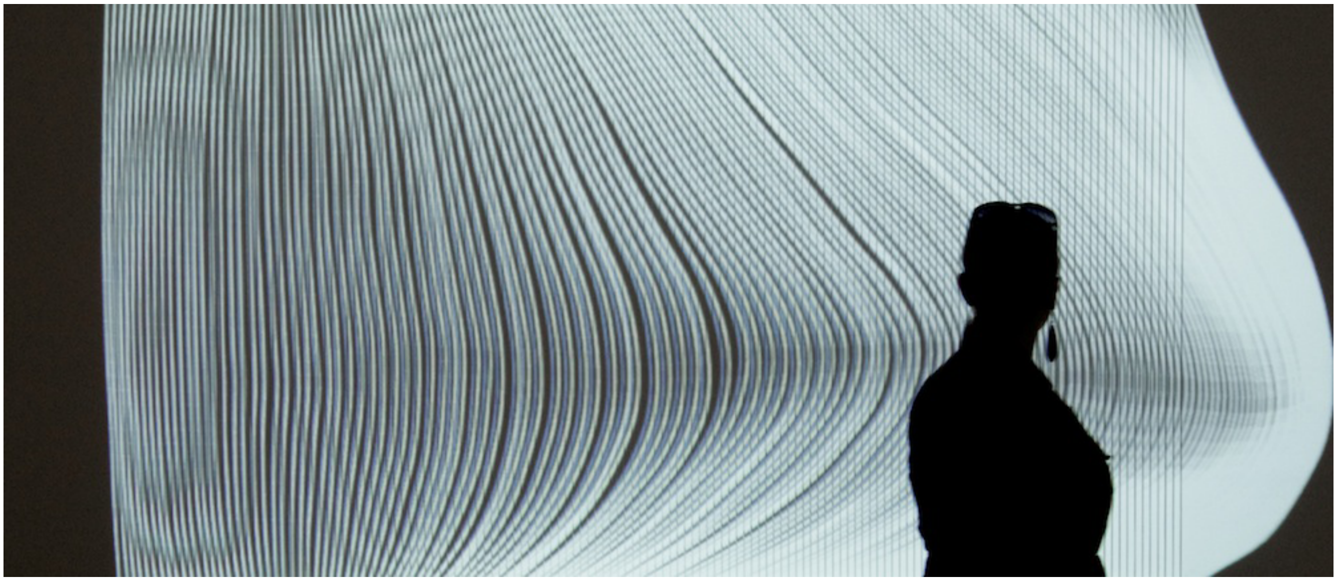


Fig.3.04 Nervous Sturcture (field), Santiago, Chile, 2012

react to particular gestures or movement.

3.1.2 WAYS: KINETICS AND BODY MOVEMENT

Different to many mechanical or algorithmic approaches, kinetics generated from the participation of human body movement seem more akin to the context of affective human–architecture interaction. Nervous Structure (field), 2012, is an interactive installation that consists of a wall-mounted sculpture containing hundreds of vertical and parallel lines made of elastic cord that are projected upon with a computer-generated interactive animation of a similar number of lines. The motion of these projected lines are ruled by a simulation, which makes them act like soft ropes, and said motion is influenced by a viewer's movements as interpreted by a computer, which surveys the scene through a video camera.[5] Thus, the physical gestures of the participant are translated into virtual forces that affect the computer-generated lines, while the physical strings of the sculpture remain motionless. The piece revolves around the

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5.Cuppetelli and Mendoza; Nerous Structure (2012); http://cuppetellimendoza.com/transposition/

Fig.3.05 Connected, Melbourne Australia,2011

idea of interface, which is interpreted as the point of contact between two different entities and is displayed in the work in several ways: between the viewer and the piece (a human/computer interface); between the real and the virtual (the physical structure and its relationship with the projected structure); between the foreground and the background (as the projection interferes with the sculpture).

Connected, the stage installation by Reuben Margolin and Chunky Movement linked human movement in its kinetic manipulation.[6] Margolin is famous for his insight and practice of kinetic sculpture. Most of his work is named after waves. Inspired by his mathematic background, a series of movement languages has been developed from sine waves, which could be described and modified by frequency and which determines the velocity of movement; peeks and valleys show the frequency and amplitude; and curvature, which describes the acceleration and direction. Square Wave, in which two sine waves are deployed to produce this torqued field kinetic pattern, is the best manifestation of using the language of waves. Through altering those wave parameters, the sculpture could perform a choreographed movement in space. Not narrowly in mathematics, just like he noted in his interview, this motion language is observed just about everywhere, including in human body movement. In the design of Connected, the concept of waves is blended with human factors. Rather than adding two sine waves, one axis is tied to the dancer's arms, and the other axis is tied to the legs. These twin movements allow for a wide range of expressions in the sculpture, and the strings also can be distributed between multiple dancers. With the scope of control variables, the sine wave is conceived as a homeostatic pattern; meanwhile, strings that bond the sculpture with dancers create indeterminacy.

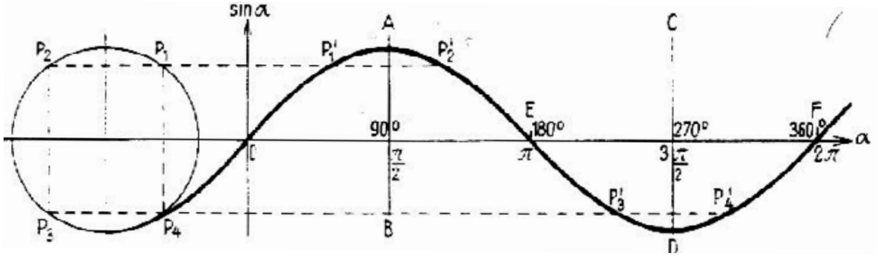
Considering the previous accomplishment, movement data from a Kinect sensor works equally with the strings and allows human movement to manipulate artifacts. Meanwhile, the affect embodied in those movements also is transmitted according to the notion of motion–emotion translation. This thesis, therefore, takes Reuben's square wave as a research sample to synthesize effective field kinetics.

6.Reuben Margolin; Waves; http://www.reubenmargolin.com/waves/index.html

3.2 THE MATH MODEL OF SQUARE WAVE

According to Reuben's work journal, the motion of the square wave comes from the sine wave. Here is the Sine expression.

$$y(t) = A\sin(2\pi ft + \varphi) = A\sin(\omega t + \varphi)$$



- A, the amplitude, is the peak deviation of the function from zero.
- ω = 2πf, the angular frequency, is the rate of change of the function argument in units of radians per second.
- φ, the phase, specifies (in radians) where in its cycle the oscillation is at t = 0.When φ is non-zero, the entire waveform appears to be shifted in time by the amount φ/ω seconds. A negative value represents a delay, and a positive value represents an advance.

3.2.1 A WAVY SURFACE

To explore a square wave, identifying a sine wave in three-dimensional space is the main issue. To help create the math model, first we could image a grid matrix. As we know, a sine wave describes a typical circular motion as a planer trajectory. An independent variable can only result in one dependent variable. We cannot manipulate a waving surface with only one certain number. Therefore, in step one, as shown in the diagram, a series of variables are input to the sine function to obtain a smooth section; then the surface would have a basic waving shape. However, since every section is the same, the overall shape of the wave lacks detail. The solution is to shift the sequence by adapting multiple continuous φ. The result is apparent that the surface is flowing and waving, which is similar to the square wave of Reuben's work.

3.2.2 THE SUPERPOSITION OF WAVES

Meanwhile, the principle of superposition[7] is applied in Reuben's square wave as well, which allows more than one wave to form a wavy surface. This principle describes two or more waves that travel through the same medium at the same time. The waves pass through each other without being disturbed. The net displacement of the medium at any point in space or time is simply the sum of the individual wave displacements. To form a more complex wave, I am going to explore what happen when two waves combine on a three-dimensional surface.

Case 1: Two Waves Travelling in Opposite Direction.
In this case, two waves (with the same amplitude, frequency, and wavelength) are travelling in opposite directions in the same medium, then, using superposition, the net displacement of the medium is the sum of the two waves. As the movie shows, when the two waves are 180° out of phase with each other, they cancel; when they are exactly in phase with each other, they add together. As the two waves pass through each other, the net result alternates between zero and some maximum amplitude. However, this pattern simply oscillates; it does not travel to the right or the left; thus, it is called a "standing wave."

Case 2: Two Waves Travelling in the Same Direction.
In this case, two waves (with the same amplitude, frequency, and wavelength) are traveling in the same direction. When the two waves are in phase ($\varphi=0$), they interfere constructively, and the result has twice the amplitude of the individual waves. When the two waves have opposite-phase ($\varphi=180$), they interfere destructively and cancel each other out. The phase difference between the two waves increases with time so that the effects of constructive and destructive interference may be seen. When the two individual waves are exactly in phase, the result is large amplitude. When the two gray waves become exactly out of phase, the sum wave is zero.

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[7] Superposition of waves, Daniel A. Russell, Acoustics and Vibration Animations ; http://www.acs.psu.edu/drussell/Demos/superposition/superposition.html

Wavy Surface

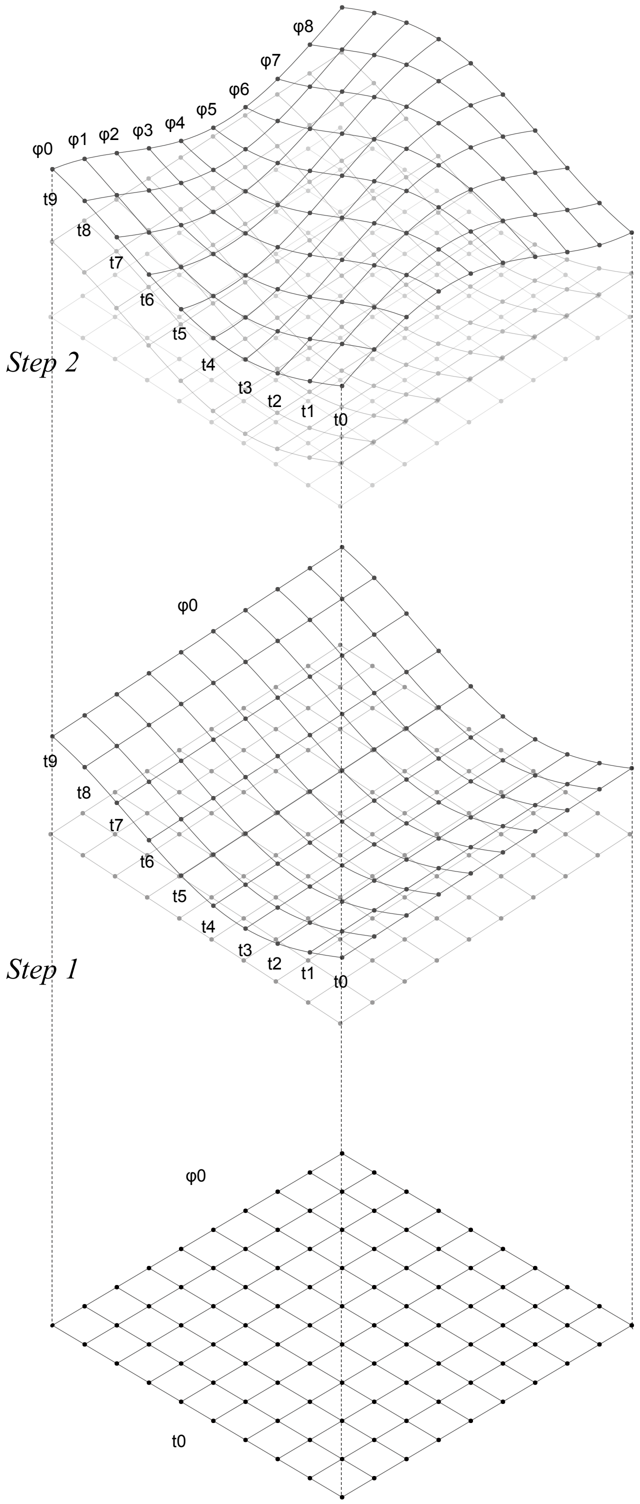


Fig.3.06 Wavy Surface Composition

Superposition Case:1
Two waves travelling in opposite direction

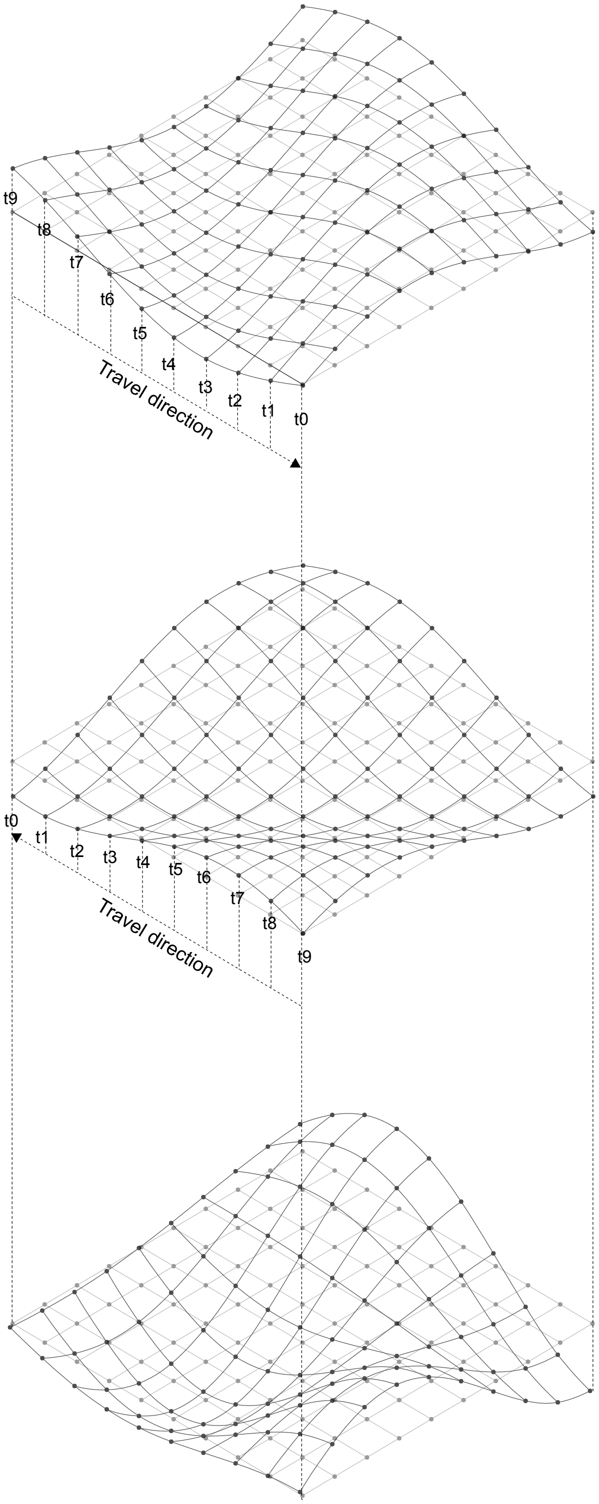


Fig.3.07 Standing Wave Composition

Superposition Case:2
Two waves travelling in same direction.

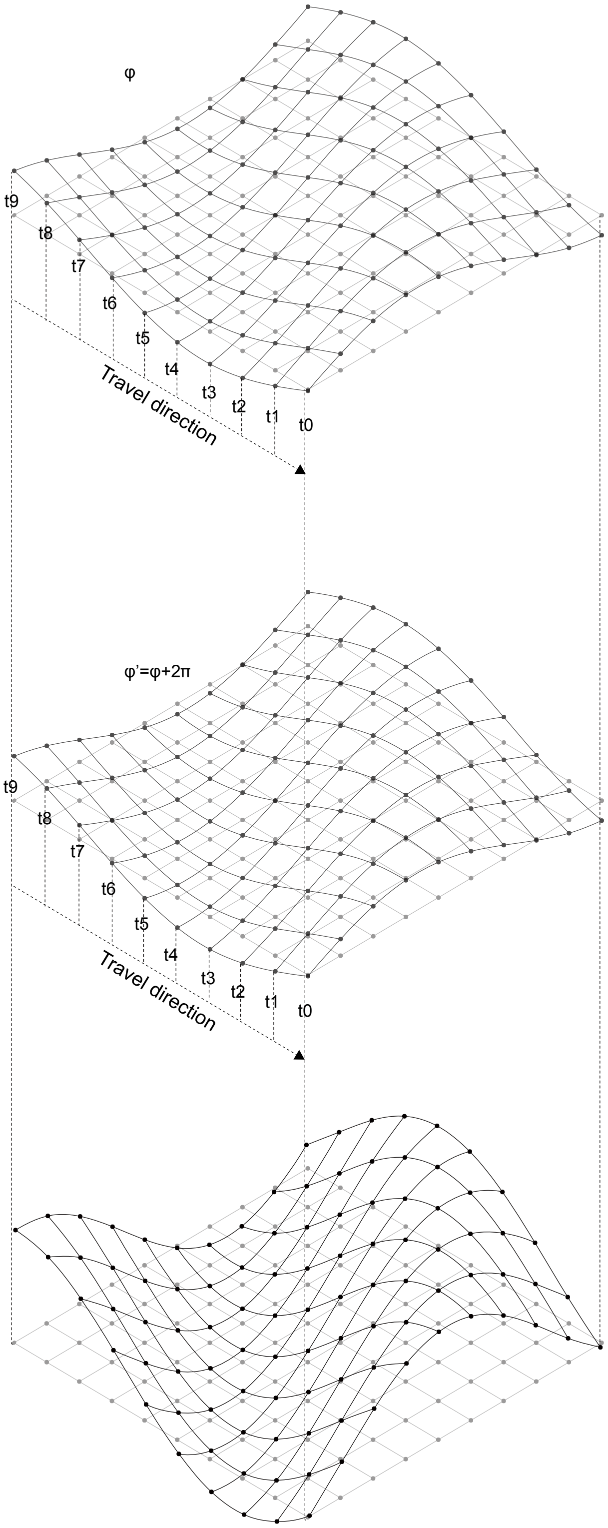


Fig.3.08 Constructive Interference

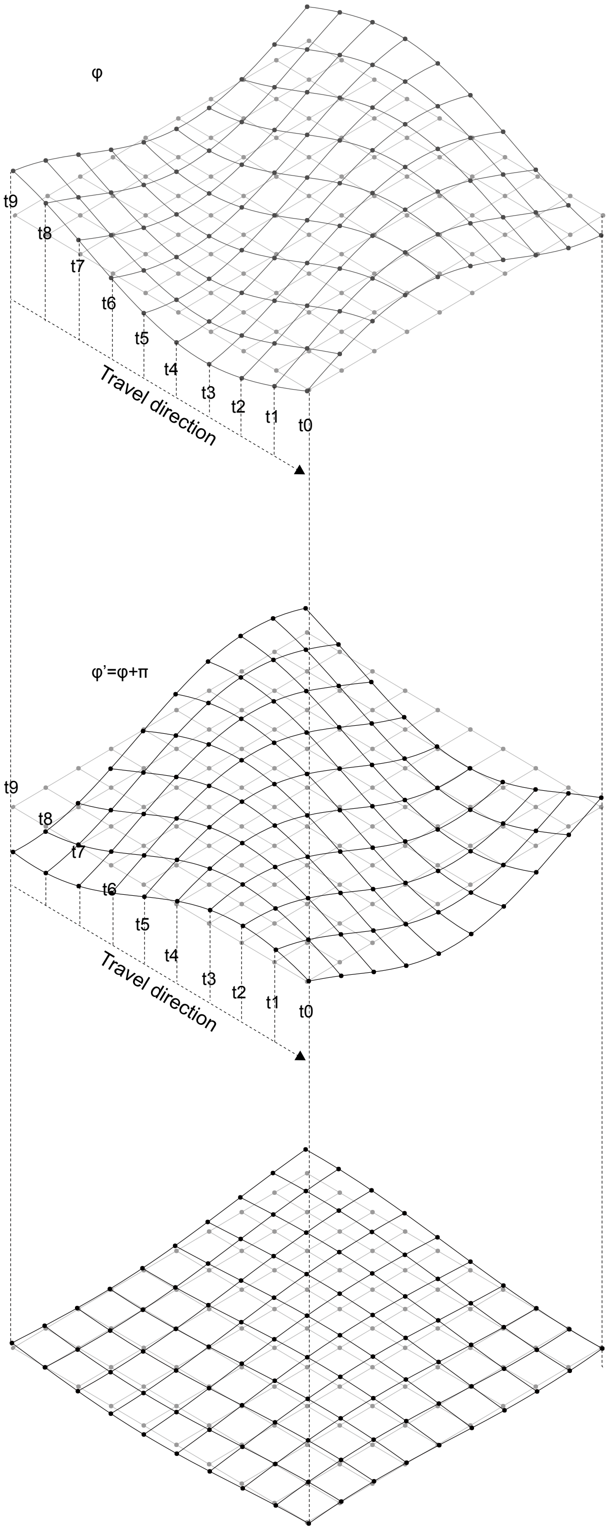


Fig.3.09 Deconstructive Interference

3.3 COLLABORATE WITH HUMAN MOVEMENT

Presently, we have gained the materials to exploit an interactive system, a math model of square wave (a basic kinetic model), and human movement data (from Kinect sensor). Thus, the question is how to connect them together. To demonstrate this process and validate the transfer of emotions from human movement to square wave, I have conducted the following experiment.

Experiment Design

This experiment attempts to let human movement take the place of a sine wave to generate movement. The precondition of this process is to obtain a motion sequence (earlier mentioned in Section 2.4.2) rather than individual joint positions. Thus, in this experiment, a Kinect sensor traces right and left wrists. When people swing their arms, 20 frames of wrist position are recorded. The Z value of wrist position in these 20 frames is collected as a data set and input to the square wave mesh. The principle of superposition is also applied in this experiment; two waves traveling from opposite directions are selected. In order to express emotions in the square wave, the actor is required to utilize typical emotive features in terms of four emotional categories (joy, excited, anger and sadness) in the arm swing movement according to movement notation system.

Procedure

Coinciding with affective movement recogniton, each movement contains the value of openness, velocity and smoothness. In expressing the for emotive features, each movement is performed separately and limited to 5 seconds, which is equal to 100 frames in total. Both the Kinect skeleton and the square wave are recorded.

Result:
As shown in the drawings, the square wave performed well when expressing joy, excited and anger. For joy, the movement presented a smooth wave with even rhythm. Compare to joy, movement to express excited is much more powerful, involve with higher velocity, larger amplitude but the rhythm is still even. For anger, the movement presented a lot of tension with brute strength. Meanwhile, the square wave movements were also capable of expressing negative emotions such as sadness—although the source movement, arm swing, is not the salient feature of expressing negative emotions. The energy contained in that movement is manifested in a motion sequence. For sadness, the movement is slow and lazy and seems as though it is losing power.

Movement Sequence 01
Emotion Type: Joy
Movement Features: Slow, Open, Smooth

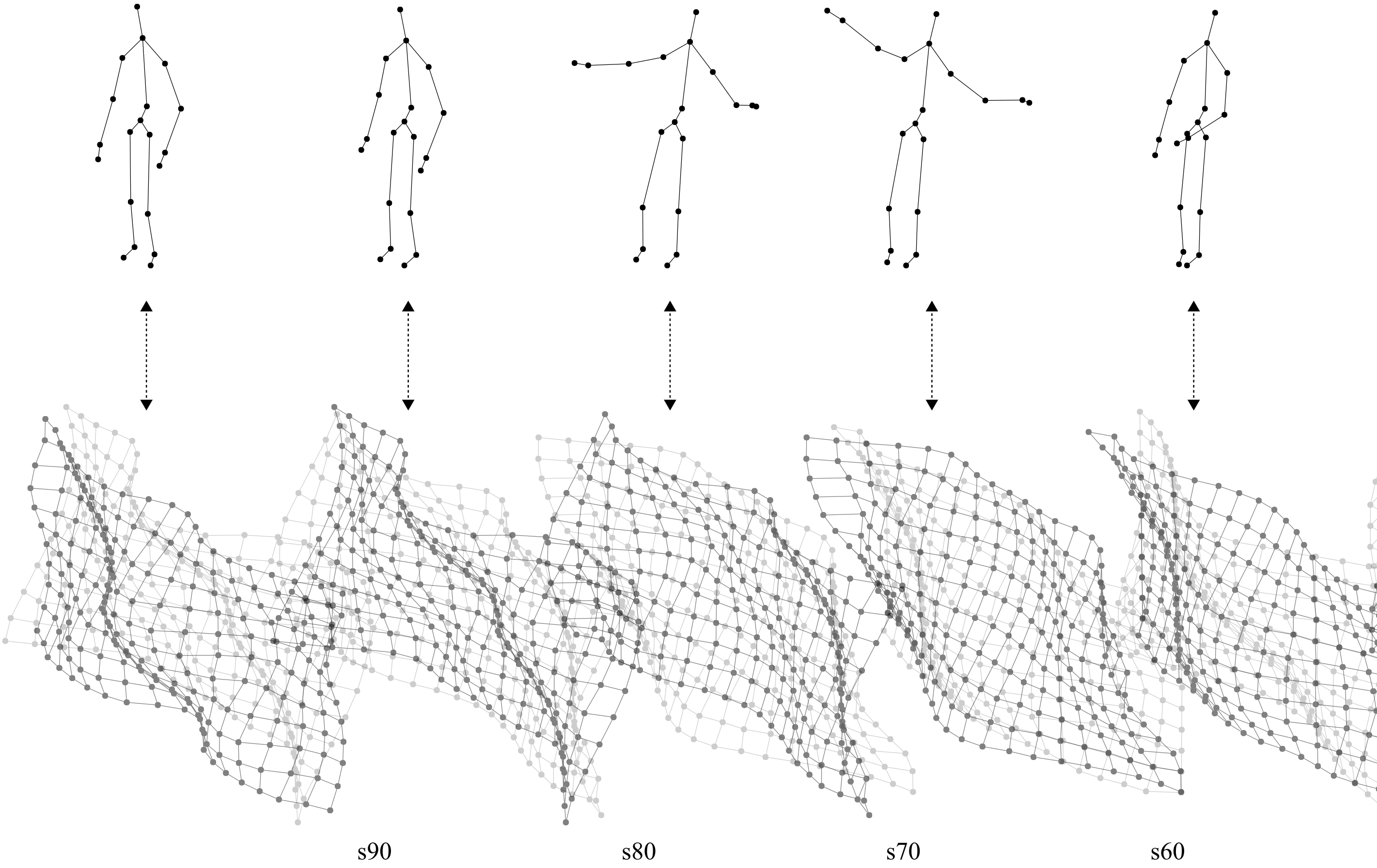
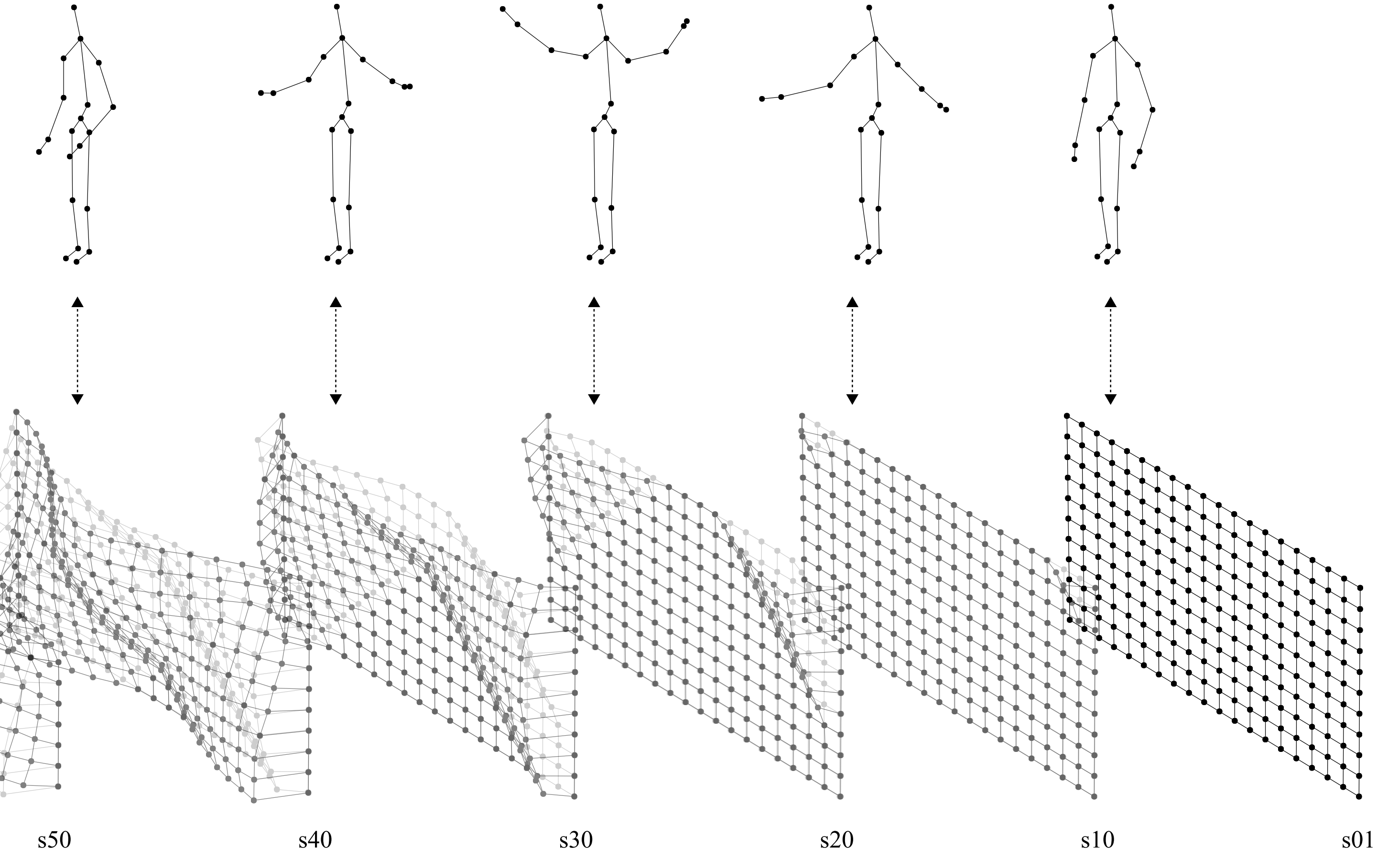


Fig.3.10 Joyful Motion Sequence


s50
s40
s30
s20
s10
s01

Movement Sequence 02
Emotion Type: Excited
Movement Features: Fast, Open, Smooth

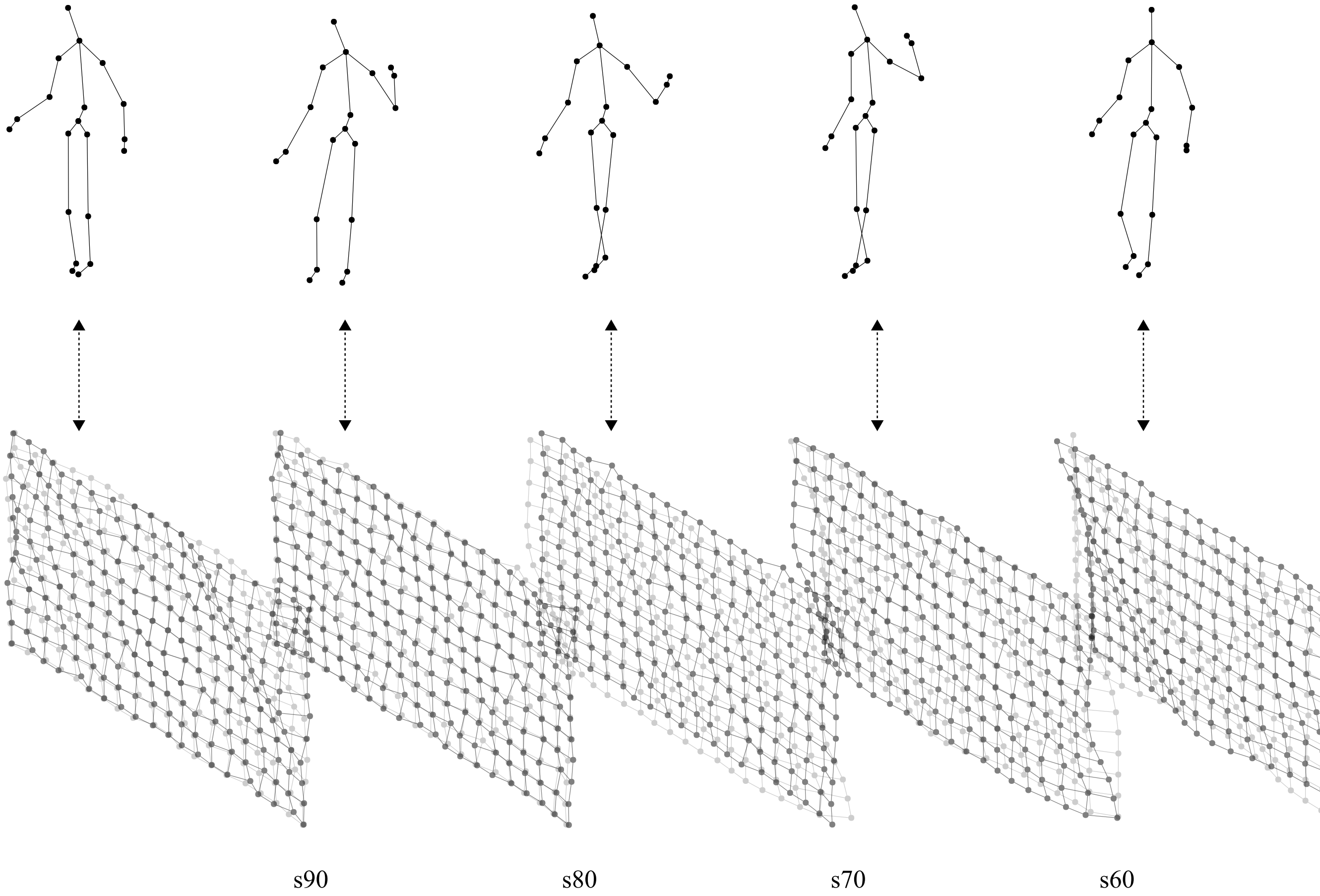
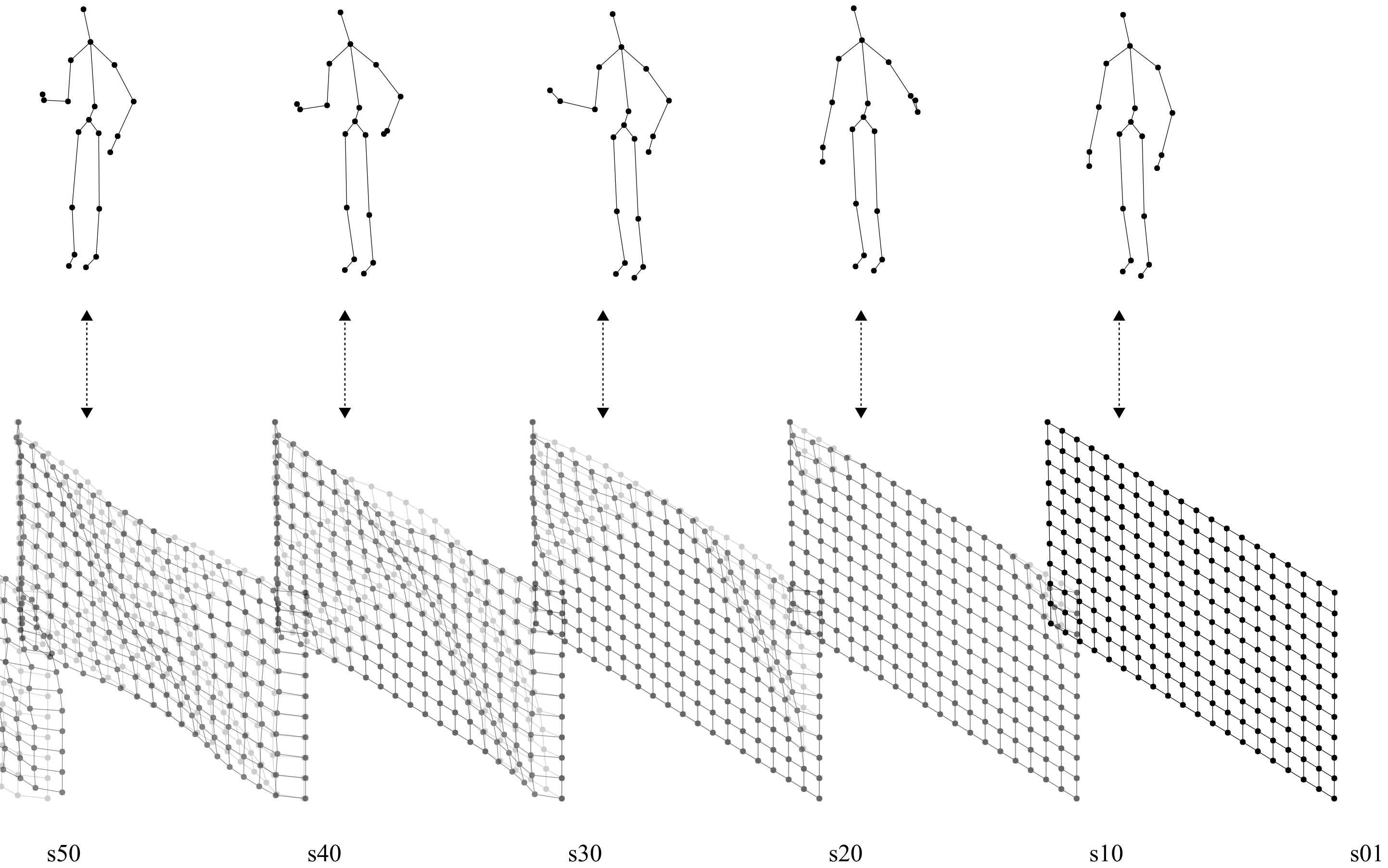


Fig.3.11 Excited Motion Sequence


s50
s40
s30
s20
s10
s01

Movement Sequence 03
Emotion Type: Anger
Movement Features: Fast, Open, Jerky

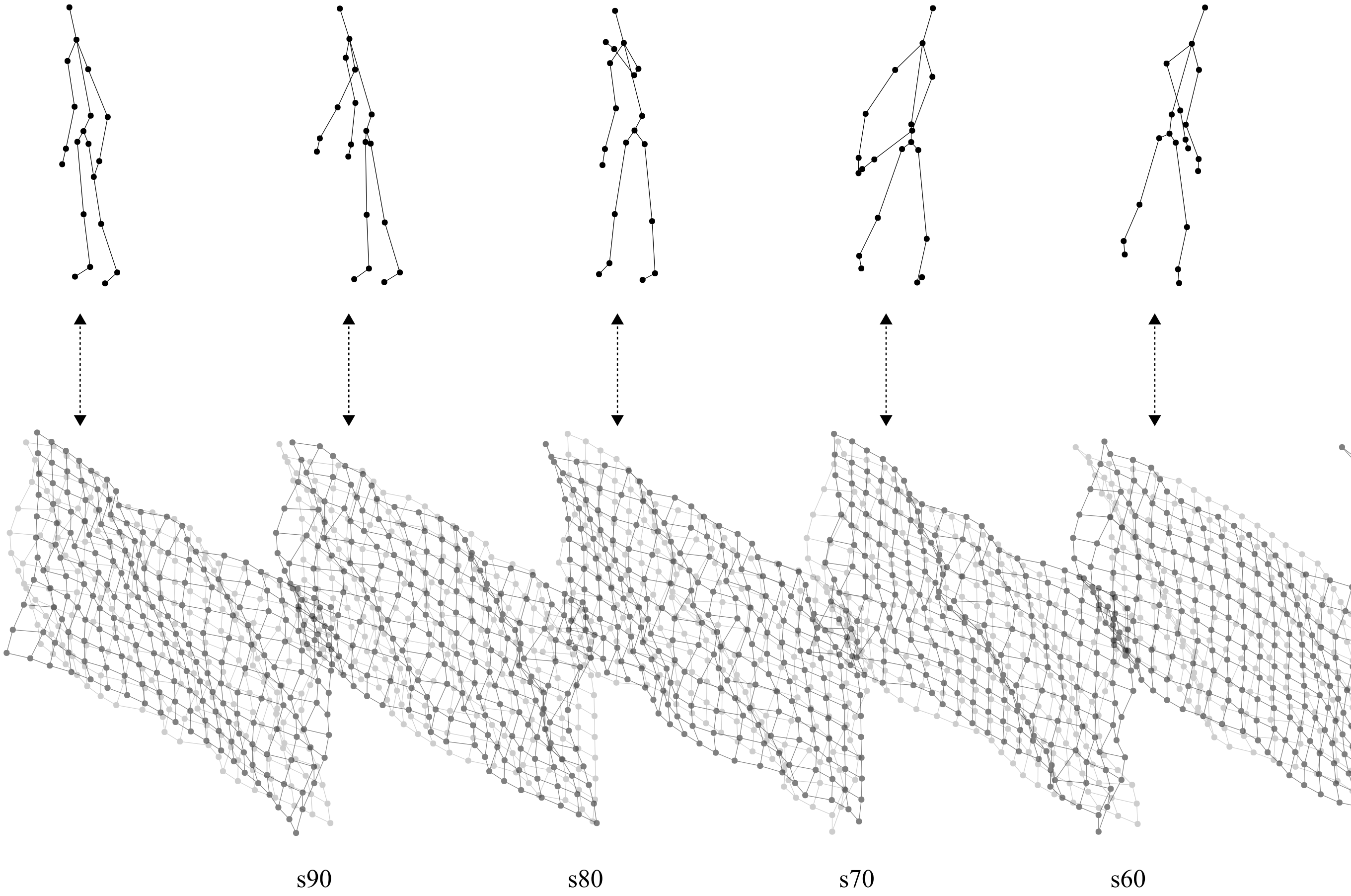
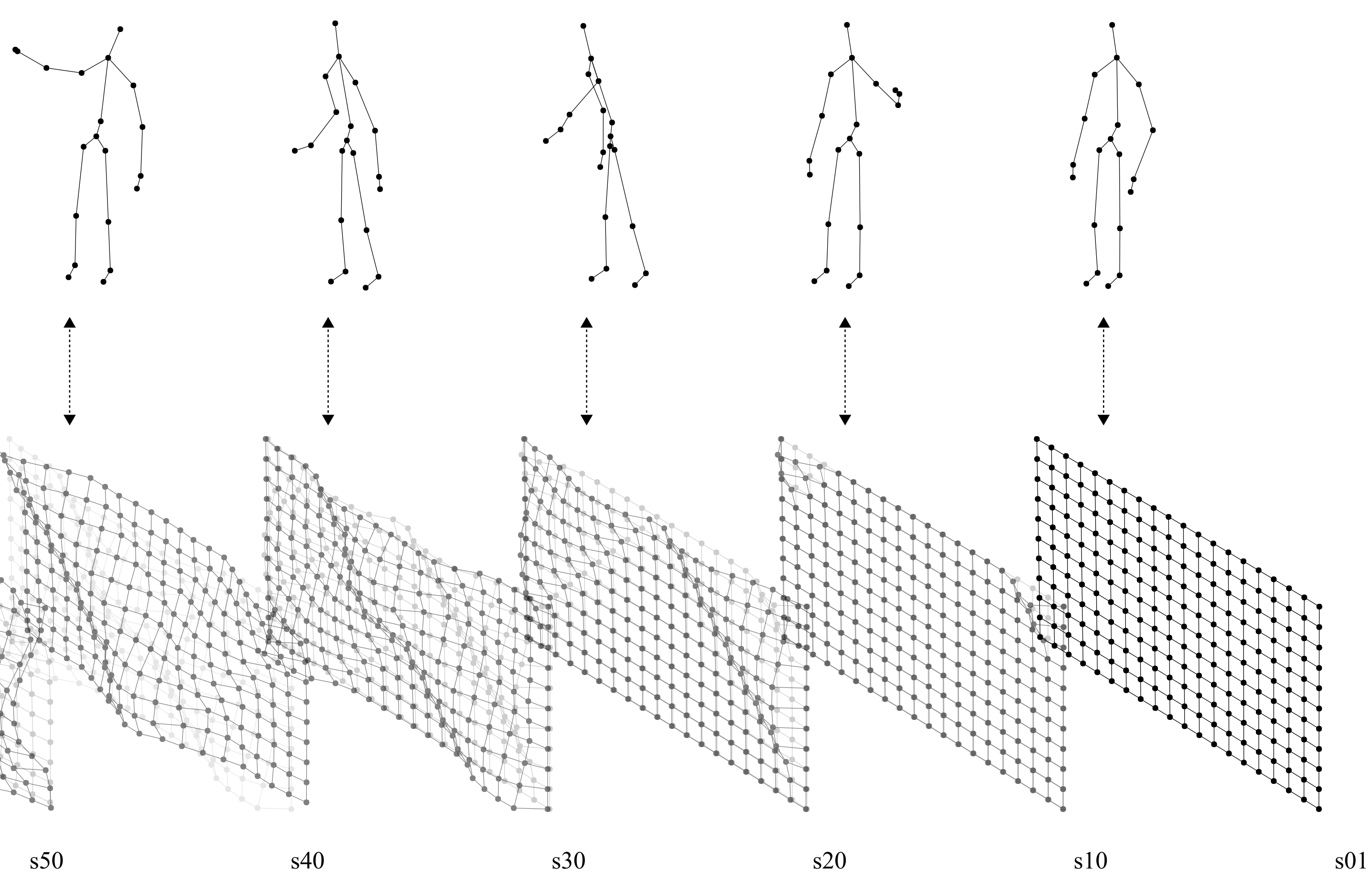


Fig.3.12 Angry Motion Sequence


s50
s40
s30
s20
s10
s01

Movement Sequence 04
Emotion Type: Sandness
Movement Features: Slow, Close, Jerky

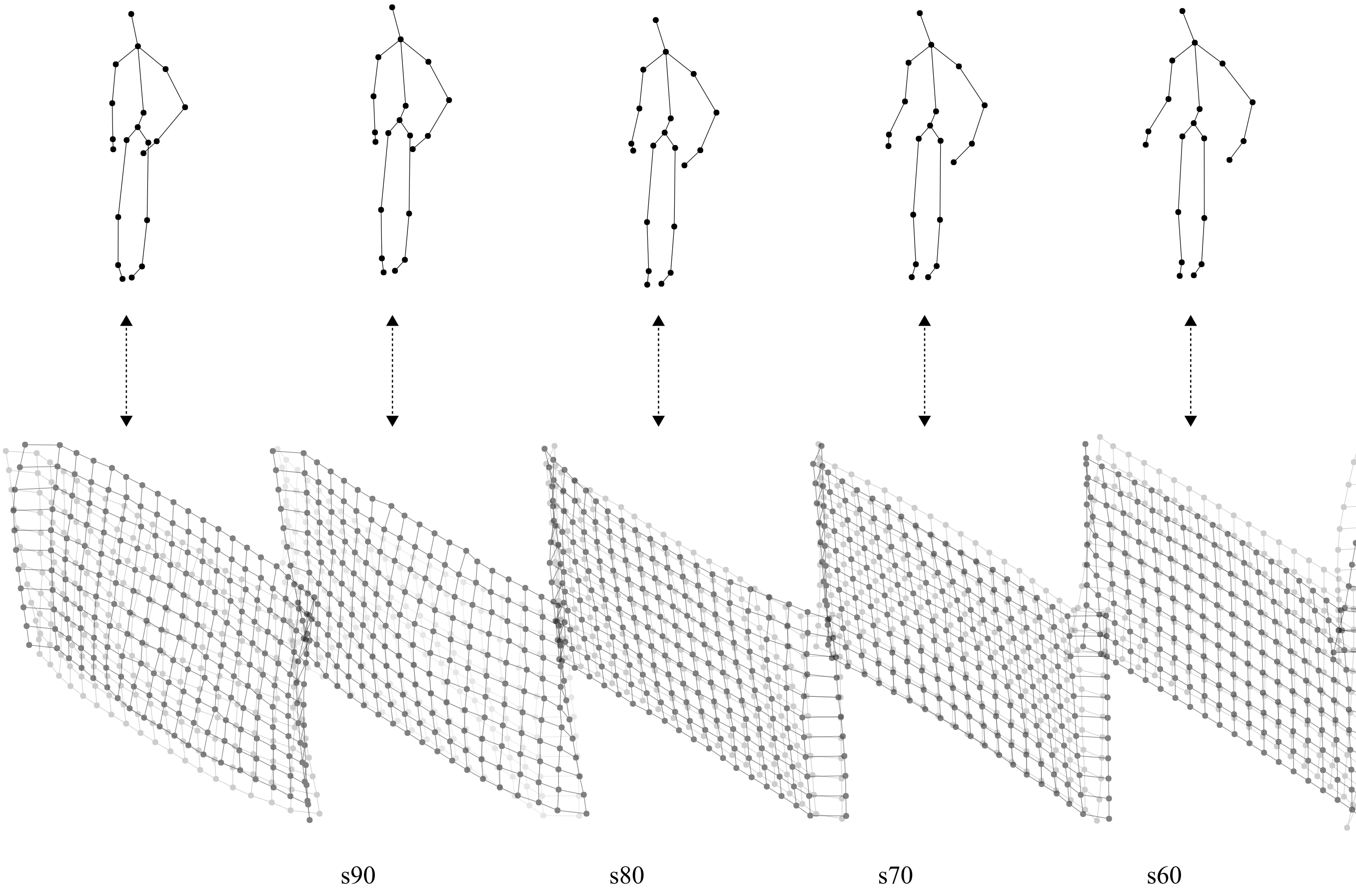
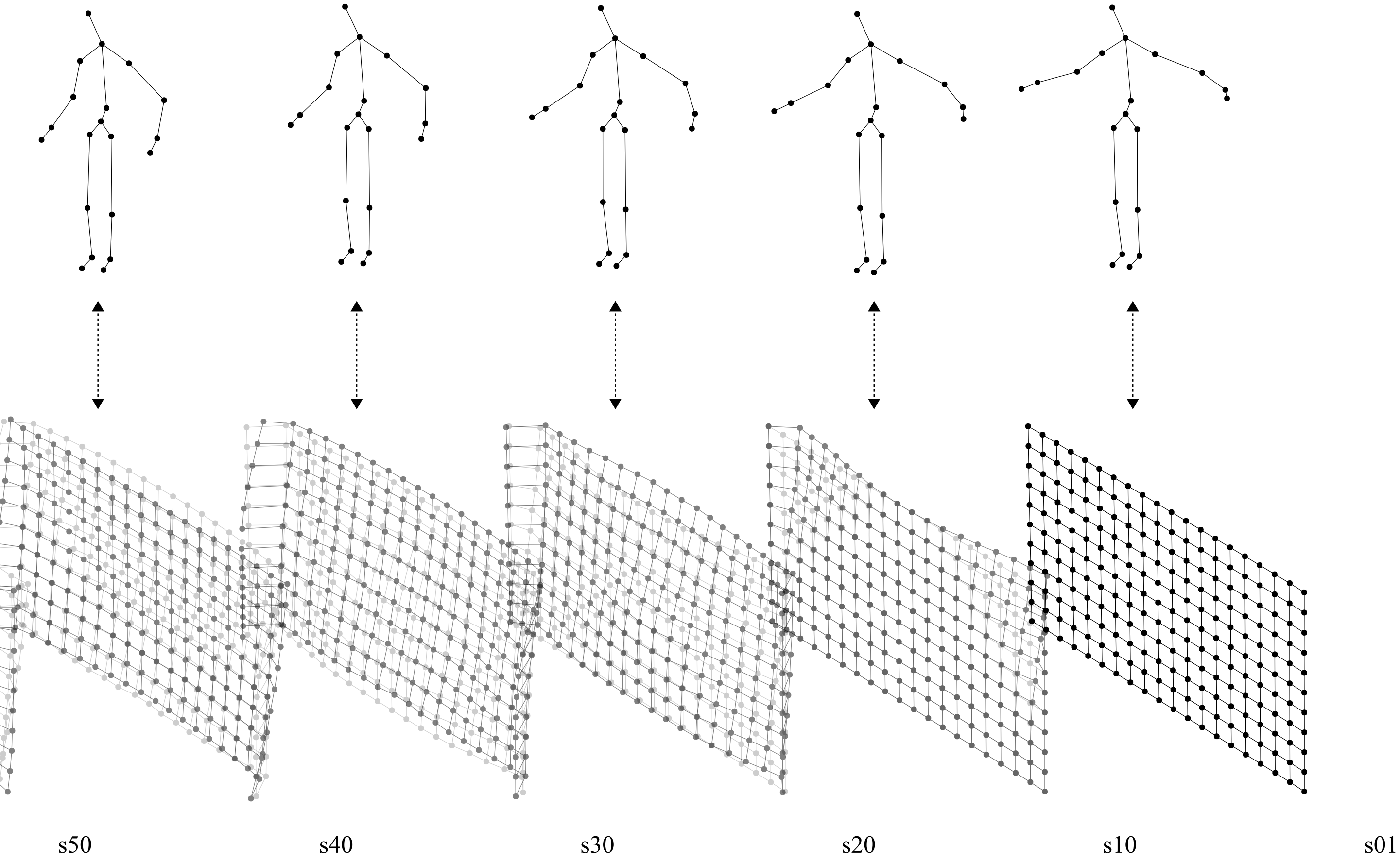


Fig.3.13 Sad Motion Sequence


s50
s40
s30
s20
s10
s01

3.4 As a control system

Turning back to the context of architecture, collaboration with architecture elements is a task that is of heavy concern in this session. As shown in the previous study, this interactive system is dependent on a mathematic model, not a physical model. This is equal to say that the square wave and the emotive movement data library have the potential to be developed as a control system, which fits into most kinetic architectures and variable kinetic types. To approve this potential, three scenarios are introduced as follows.

3.4.1 Scenario one: Stadium

A stadium is a place to play and view sports. During the games, fans usually demonstrate enormous passion and various emotions, such as those shown in the following pics. Home court fans, especially, exhibit highly coherent emotions and are unified, corresponding with the situation on court. What if the stadium can be reflexive to this collective emotion?


Anger


Sad


Shocked

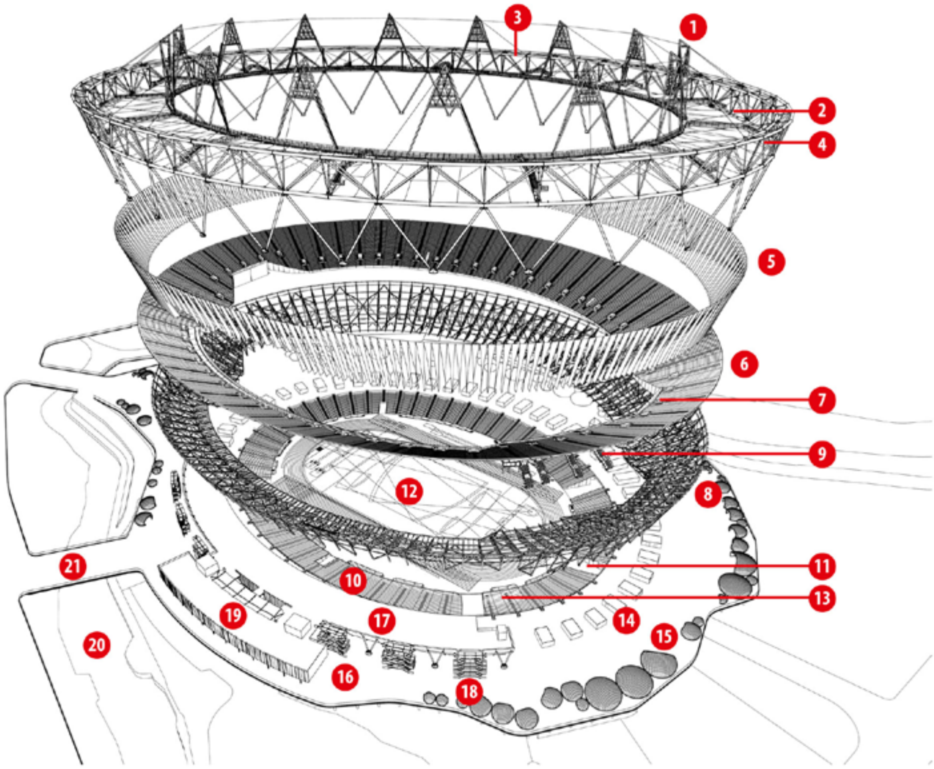

Excited

Fig.3.15 Anger: An Arsenal fan, angry at someone, David Rawcliffe / Propaganda

Fig.3.16 Sad: A child fan cries as Germany trounced Brazil in the first half, BBC

Fig.3.17 Shocked: Spanish fans react while watching their team play against the Chile,Gonzalo Arroyo Moreno/Getty Images

Fig.3.18 Excited:An Arsenal fan celebrates in the stands,Alan Duffy



1 Sportslight towers
2 Access gantries over roof fabric for access, maintenance and ceremonies activities
3 Roof tension ring
4 PVC coated polyester fabric membrane roof supported by cable net structure
5 336 Wrap fabric panels, each 25m high and 2.5m wide twisted by 90º
6 Upper tier, gross capacity: 55,000
7 Large format video screens and scoreboards
8 Upper tier supporting steel structure
9 Stairs to the upper tier from concourse level
10 Lower tier, gross capacity: 25,000
11 Field of play access tunnels for athletes, officials and ceremonies
12 Athletics field of play
13 Head-on photographers' platform
14 Internal toilet pods
15 External 'Pod Village' for spectator concessions, being developed by Locog
16 Public circulation podium
17 Level 02 concourse and hospitality terrace
18 West stand external escape stairs
19 Tensile fabric canopy over the escalator void areas for hospitality and VIP
20 River Lea
21 Venue entrance bridge

Fig.3.19 London Olympic Stadium, NSC Archives

Based on this assumption, I take the London Olympic Stadium as an example. As the diagram shows, the facade is composed of 366 fabric panels twisted in 90 degrees (although in the original project, the facade is static). By adding controllers in the each panel, the facade would become a kinetic surface to suit this interactive system. During the game, fans' emotions are detected. Meanwhile, the algorithm would select a registered kinetic pattern to augment this emotion, no matter if it is happiness, anger, or sadness.

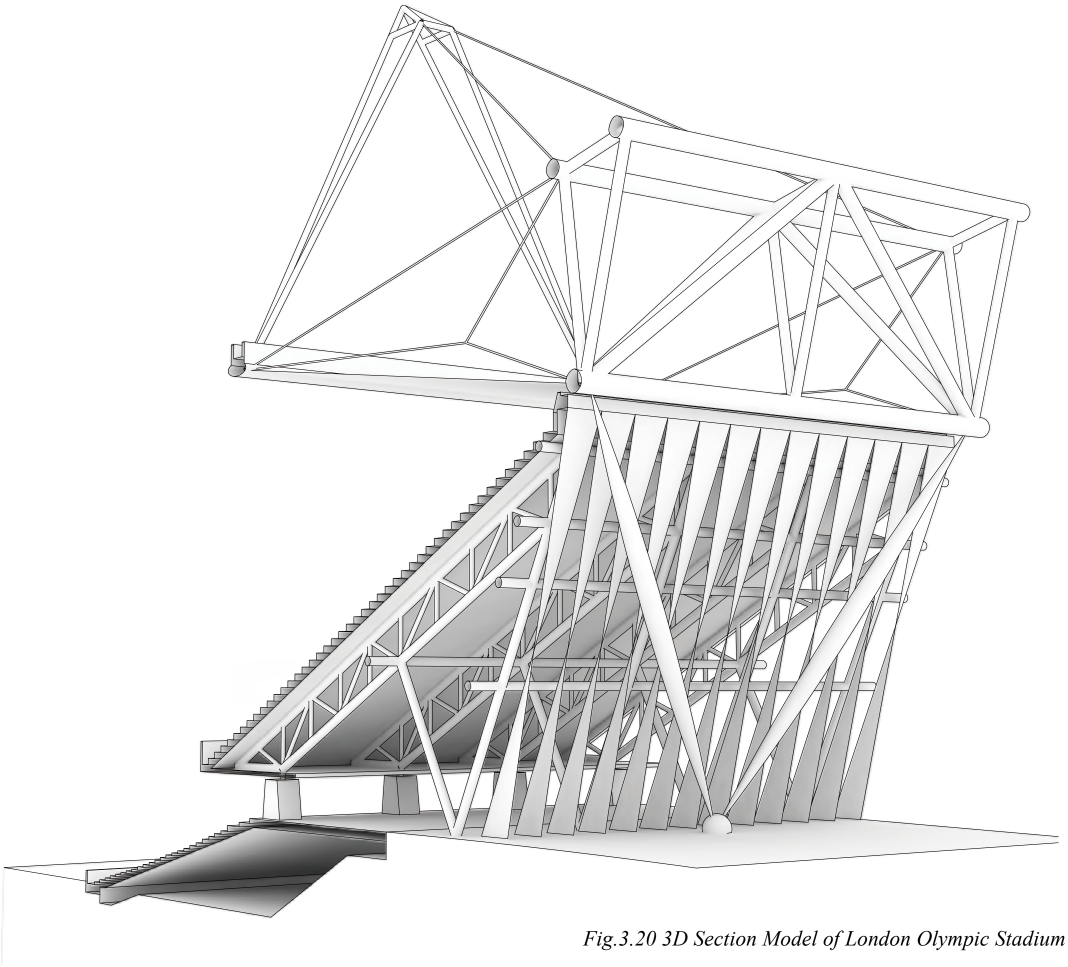


Fig.3.20 3D Section Model of London Olympic Stadium

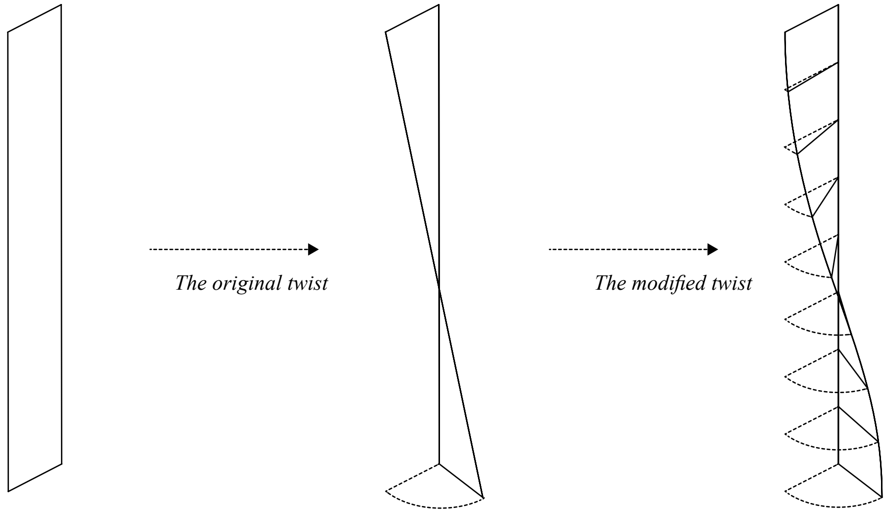


Fig.3.21 Kinetic Modification of Orinigial Fibre Panel

In the original project, the facade is static. To deploy the affective kinetics on this facade, the first step is to turn it into a kinetic surface. As the diagram shows, adding control points to each of the fabric strips achieves a dot matrix similar to the wavy surface. In this study model, there are 13 panels in total; each panel has 20 control points. Instead of the vertical displacement, the movement data from the Kinect inputs leads to a flexible twist transformation. One tip noticed in this process is that the movement data need to be adjusted to adapt to the limitation of a certain kinetic type. In this case, the limitation ranges from half pi to negative half pi.

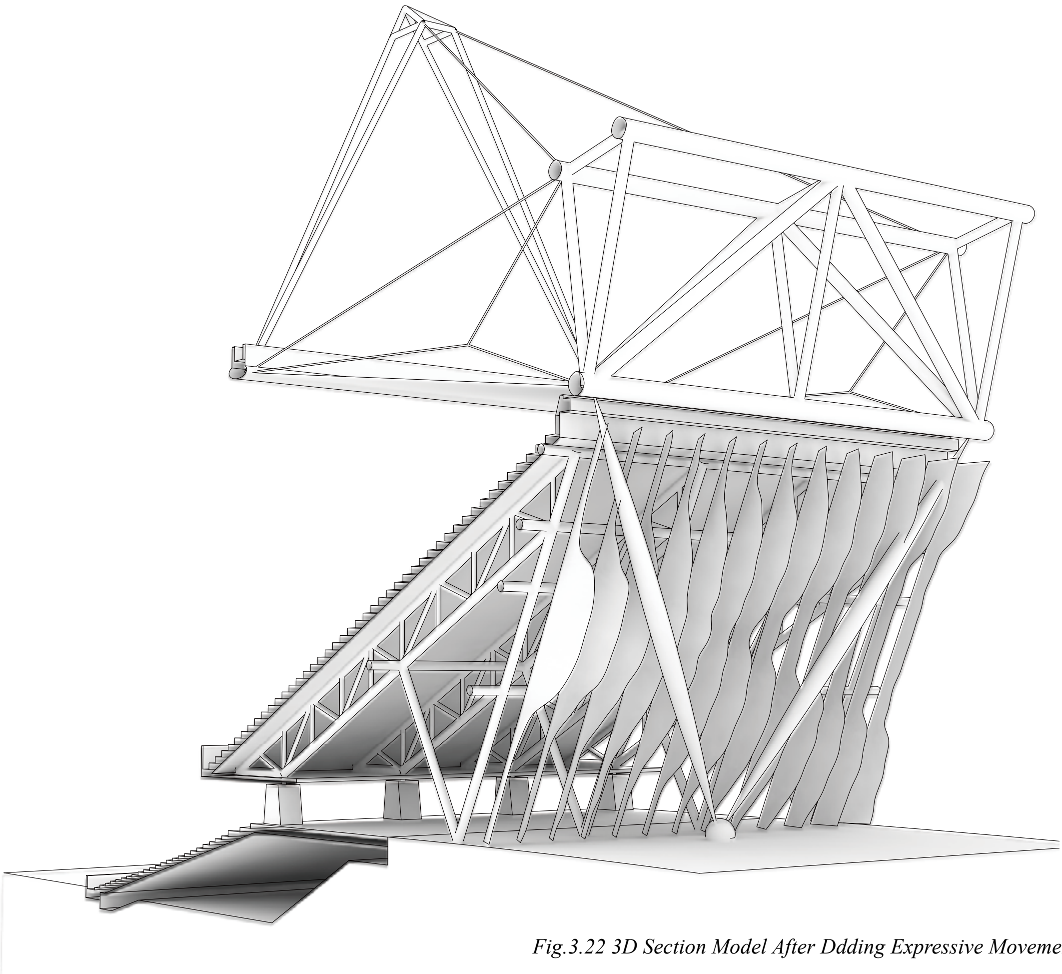


Fig.3.22 3D Section Model After Ddding Expressive Movement

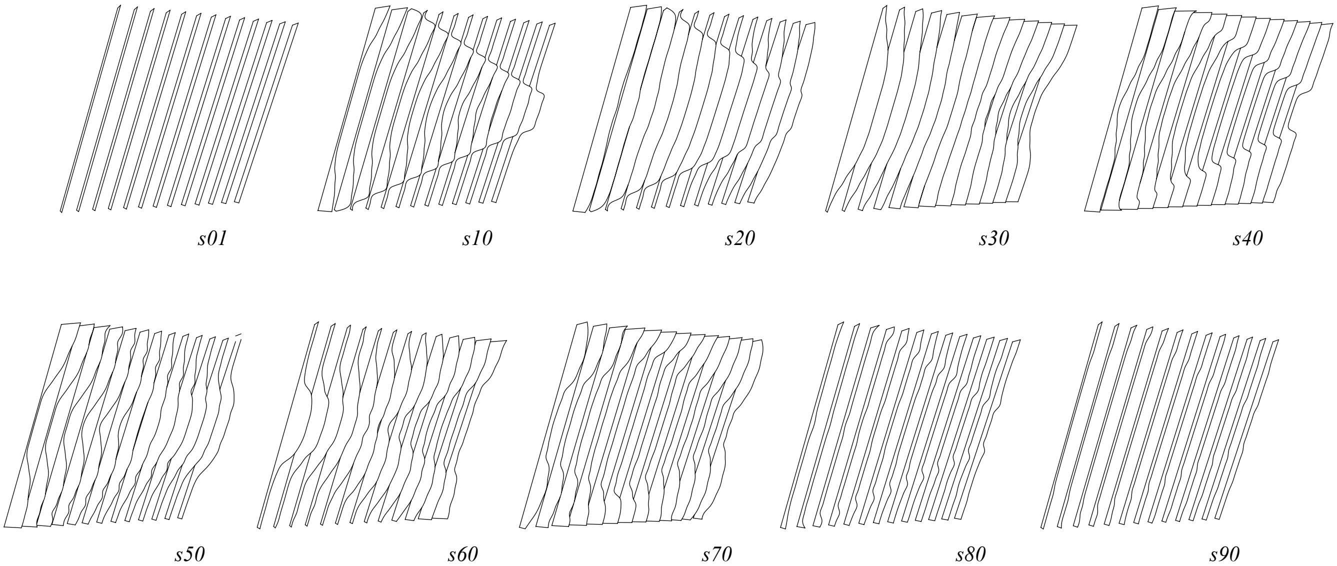


Fig.3.23 Joyful Movment Sequence Displayed on The Facade

Once the emotions that happen in the stadium are identified, the system will choose a corresponding registered kinetic pattern from its data library to enhance this emotional context. As illustrated, the joy movement sequence is adopted to this twist transformation. As opposed to the wavy surface, in this case, the shape of the original body movement in terms of openness or directness is becoming vague and abstract during the transcode process, but the effort value such as rhythm, velocity, and smoothness is nicely preserved, which is convincing enough to interpret the affective content.

Fig.3.24 Conceptual Effect of The Reflexive Behavior

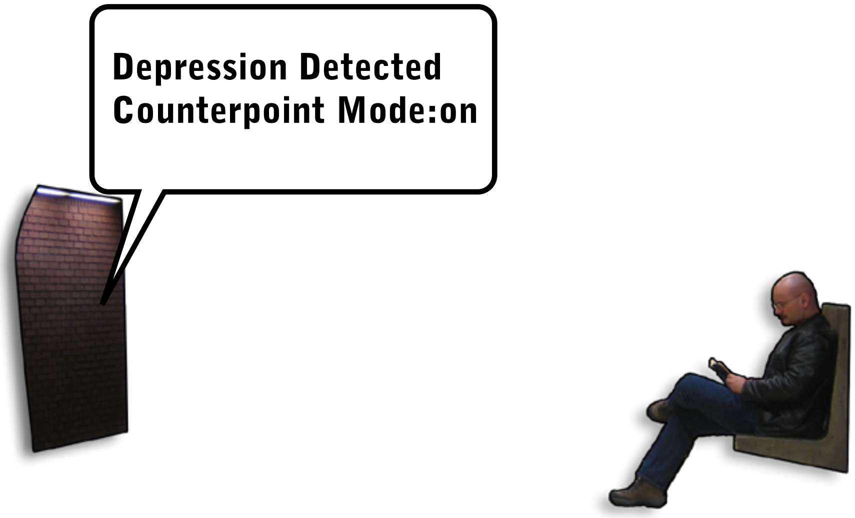
Fig.3.25 Tokyo Compression #86, Michel Wolf

3.4.2 SCENARIO TWO: SUBWAY PLATFORM

As known by all, a subway is a part of an urban transit system as well as a part of daily life. It might not be relevant to some special events, but it does not mean people have no feeling or emotion to the place. Photographies below from Michel Wolf document the experience and suffering of commuters of a Tokyo subway. The photographer focuses on their faces and lets viewers directly perceive the emotions such as discomfort, depression, and even anger. Those emotions may be caused by many possible reasons, like the rush hour, the limited capacity. But, in their perception, the subway station has become to a place that is tagged with unhappiness.

Nevertheless, in the winter 2014, the Toronto Observer reported shocking news between 7 pm November 10 to 11 am November 11. Three suicide attempts happened on TTC, and one person died on track. Ashleigh Dalton, Health Policy Specialist of Toronto Public Health, believes this is heavily linked to seasonal depression (better known as seasonal affective disorder). Those situations are extreme cases, but to handle and dissipate negative emotions, these emotions should be identified first.[8] From the perspective of this thesis, what if the interactive system can take those emotions into consideration, detect the depression in the occupancy and then counteract with joyful, delight behaviors?

8.Seasonal depression linked to subway suicide attempts, by Christine Hogg, The Toronto Observer, Nov 14 2014; http://torontoobserver.ca/2014/11/14/seasonal-depression-linked-to-subway-suicide-attempts/



First of all, an estimation of depressive behaviors, which may be performed in a subway platform environment, is required. As the above image shows, commuters are usually bored by the unexciting space. They do not have much to do except to stare at their own stuff or barely a wall while waiting for the subway train. Therefore, their behaviors are normally present as frozen gestures rather than movement. Because the counterpoint mode is selected in this scenario, it means the system will work against unmoving gestures. By observing this behavior, the system will activate a delightful opening and joyful movement to minimize the emergence of potential depression.

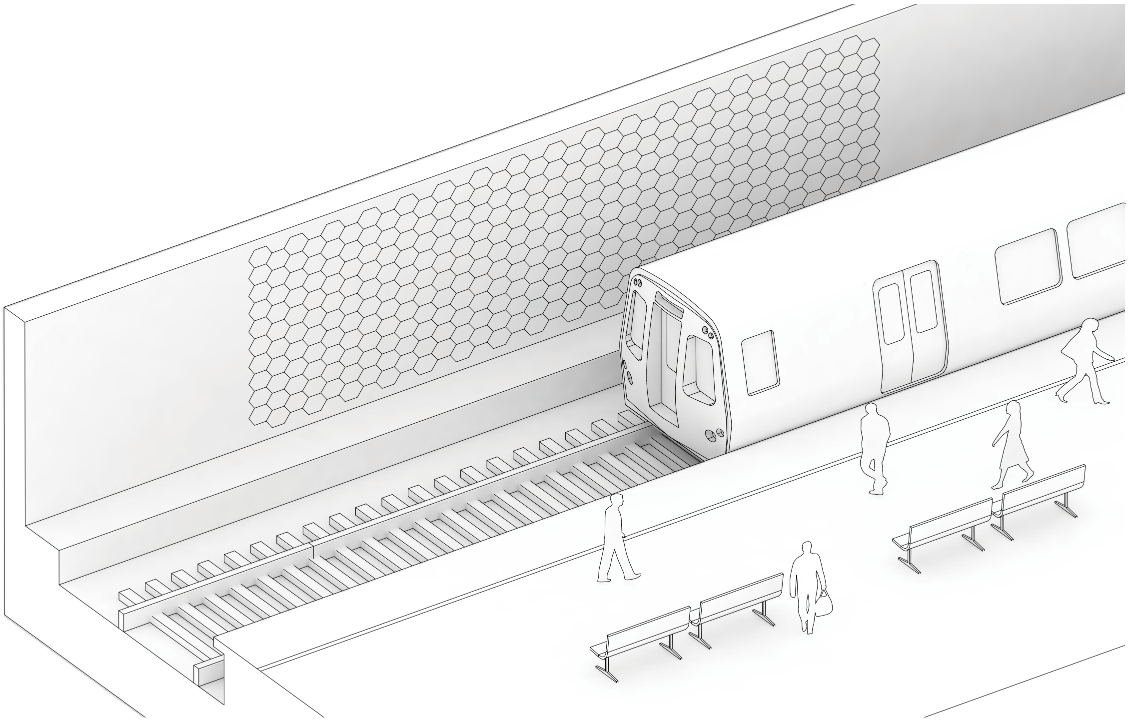


Fig.3.26 Axonometric Model of The Subway Platform (Deactivated)

In the specific design process, a wall that faces the platform would be an ideal interface. A possible interaction would be like what is shown in these two diagrams. During the time commuters wait for the subway, this kinetic surface would perform a delightful rhythmic movement to counteract the commuters' static gestures. Conversely, when the train comes or when everybody is moving, the surface will be deactivated to react to people's movement.

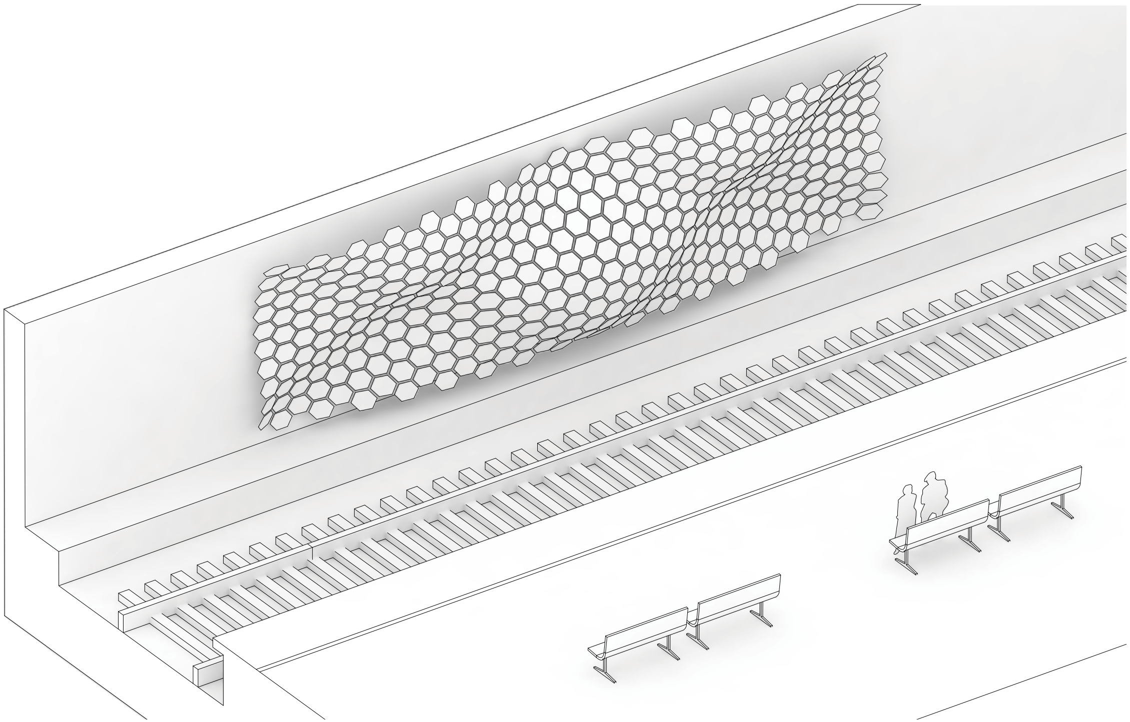
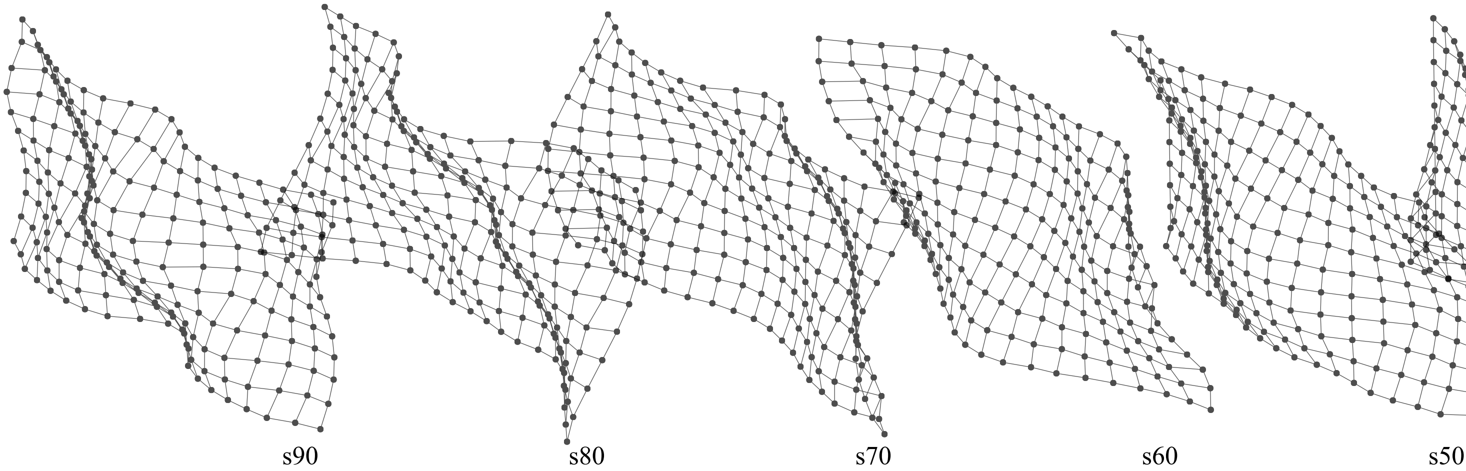


Fig.3.27 Axonometric Model of The Subway Platform (Activated)

This strategy may contribute a lot of unexpectedness during the dialog between people and interactive architecture. It aims to let architecture inform its participants on how their performance can significantly affect their surroundings. When the architecture is aware and learns from our depressive actions and adjusts itself accordingly, it also reminds us of how we are attached to the environment and to society. Moreover, as the building does more than just being responsive and ultimately becomes cognitive, we are aware of our respective behaviors.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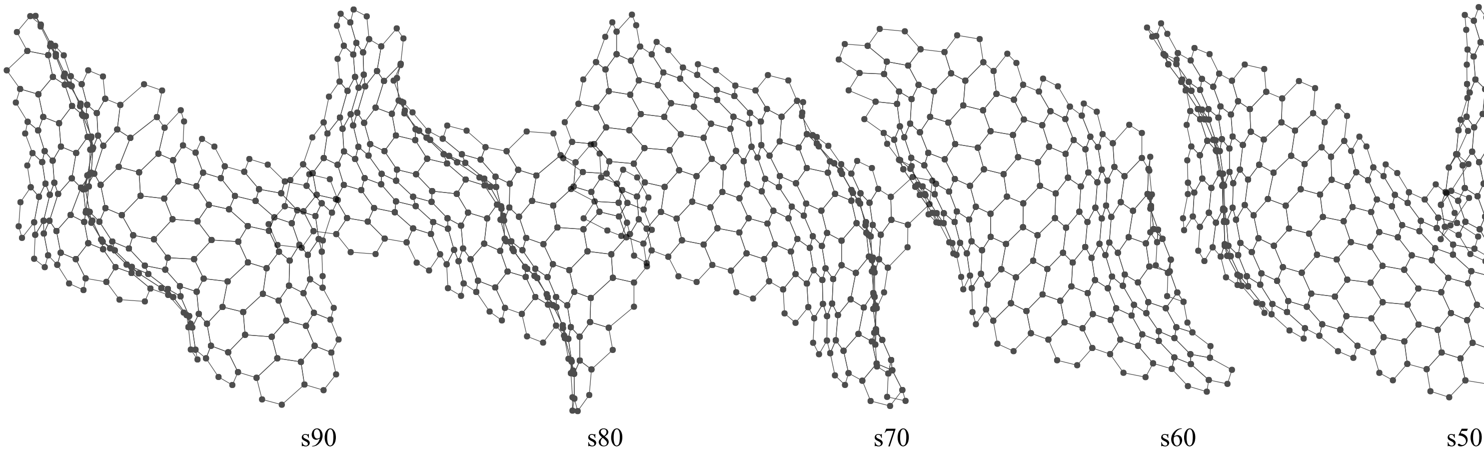
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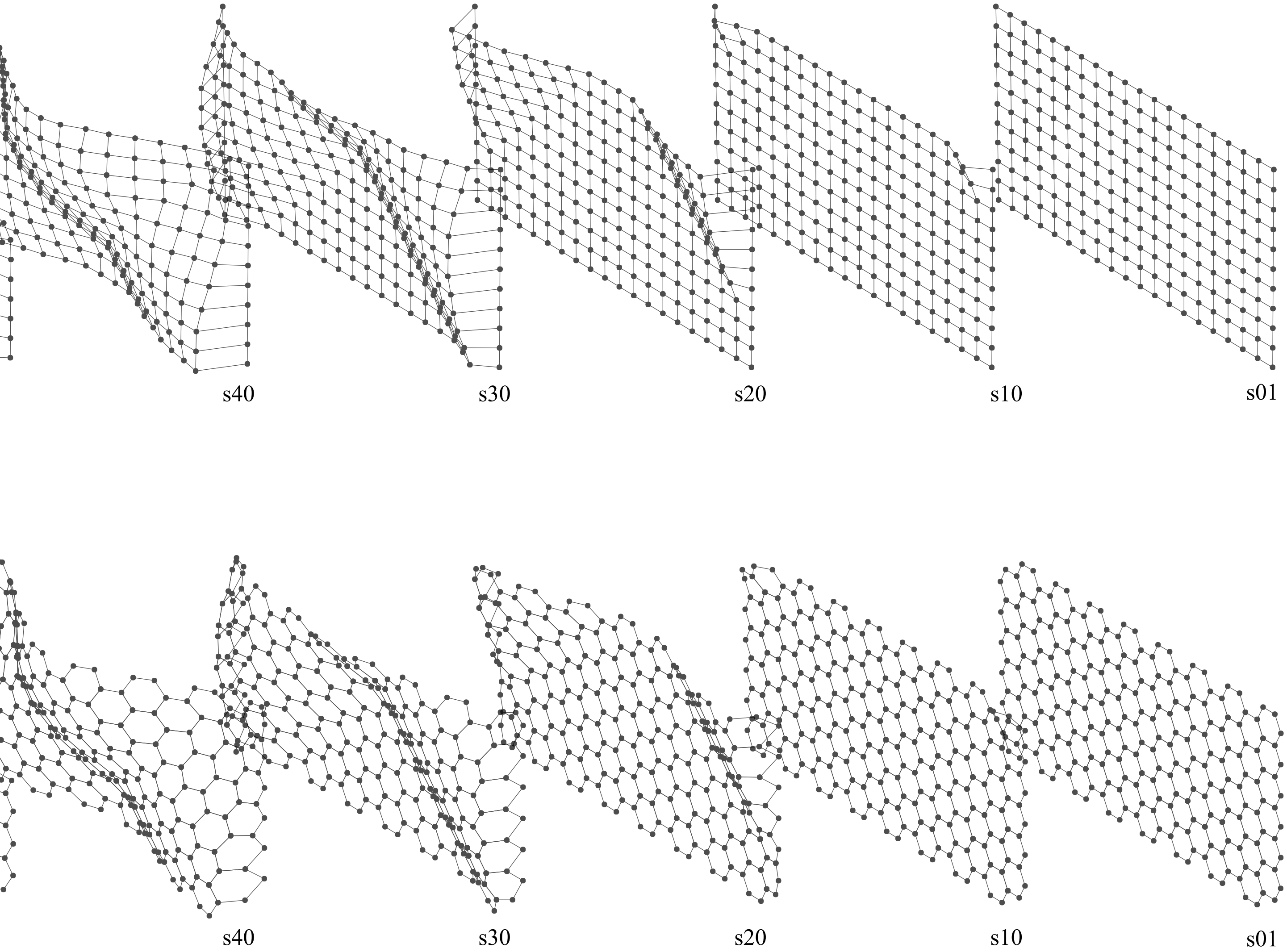


Fig.3.28 Compiration Between Square Grids and Hexagonal Grids

In the design of this prototype, a hexagonal grid kinetic mesh is adopted, as the diagram shows. Different to syntheses of twist transformation, in this scenario, the kinetic type is still manifested as a stretching surface. Through a surface reconstruction algorithm, a hexagonal dot matrix replaces the original square dot matrix. The movement, however, is still the same as the original wavy surface. This reconstruction algorithm allows the system to manipulate a variant geometry organization, no matter if it is triangular, hexagonal, or Voronoi. In the diagram, a joy movement sequence is displayed through this kinetic surface.

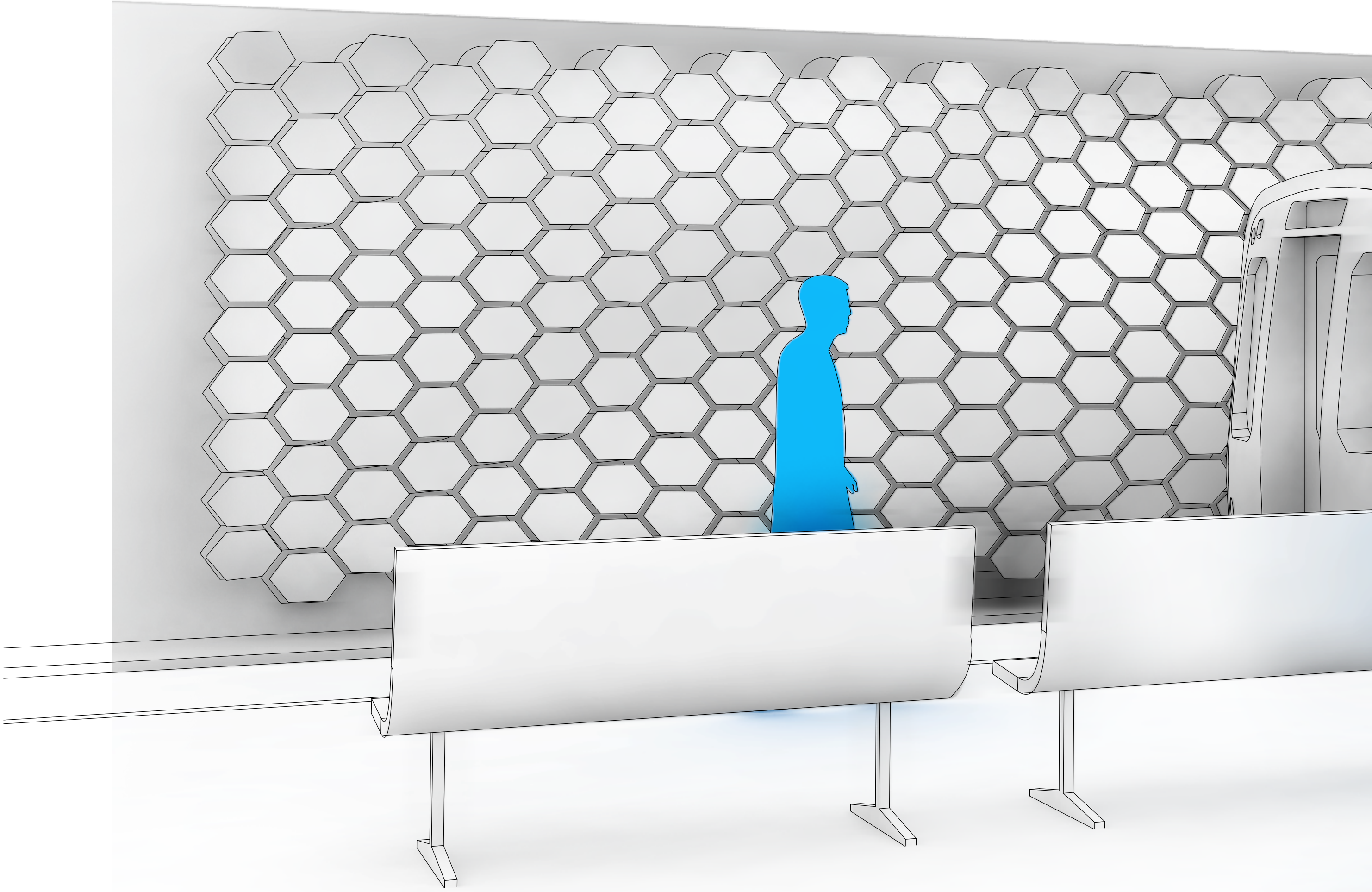
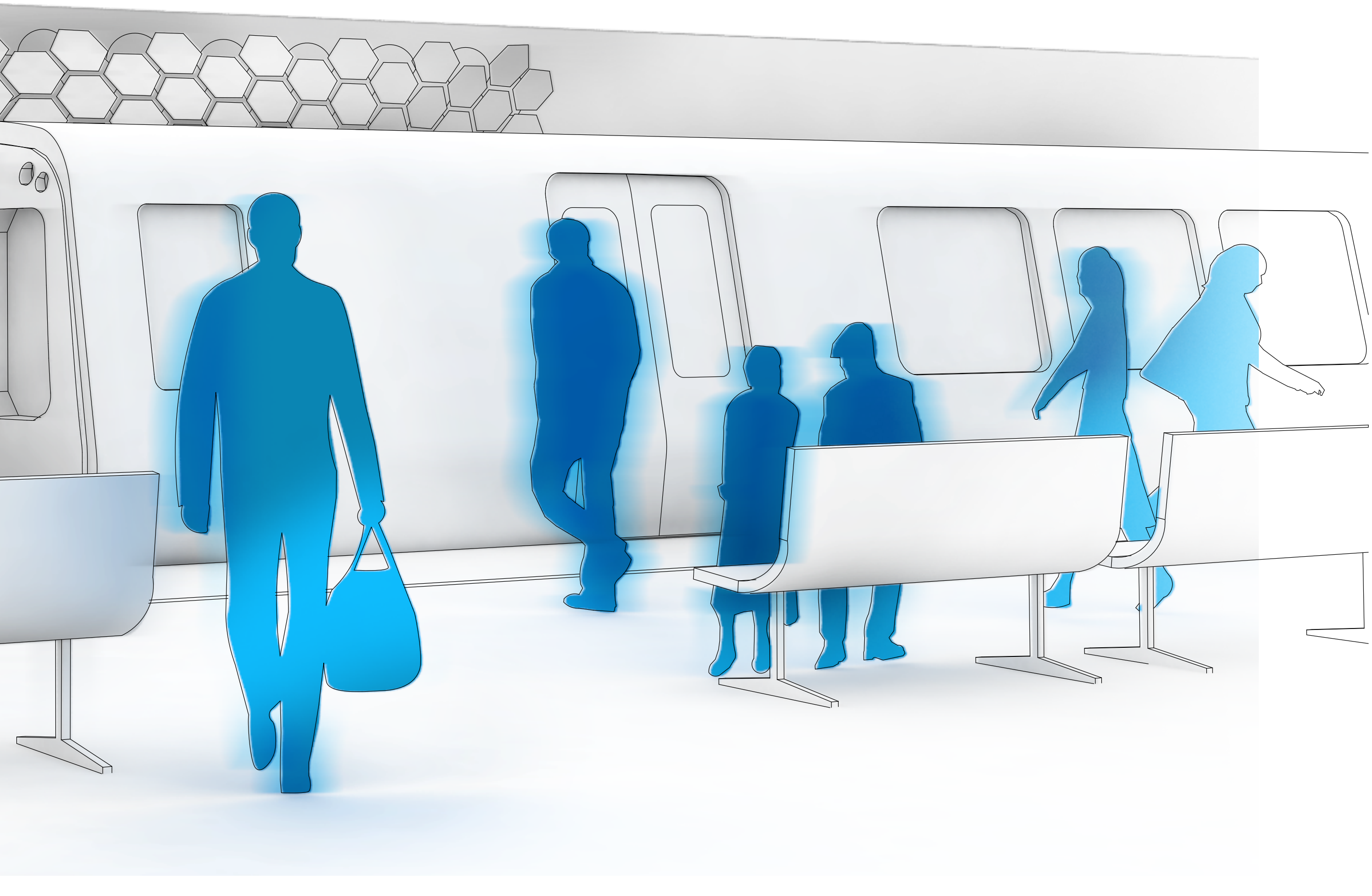


Fig.3.29 Conceptual Effect of The Subway Platform



3.4.3 Scenario Three: DMT Clinic

Dance movement therapy (DMT) is the psychotherapeutic use of movement and dance to support intellectual, emotional, and motor functions of the body. As a form of expressive therapy, DMT looks at the correlation between movement and emotion. Marian Chace is known as the leading lady in the field of dance and movement therapy. Chace used four major classifications in her therapy sessions:

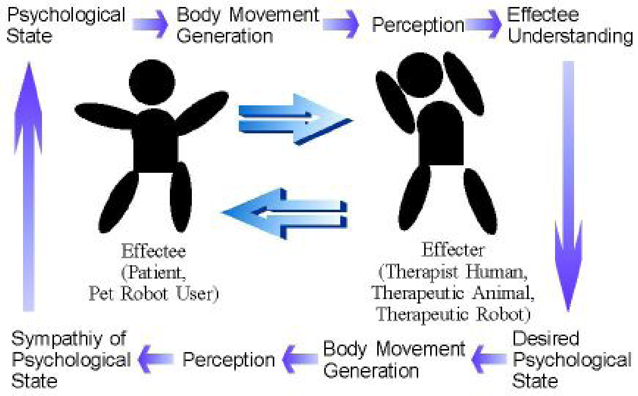


Fig.3.30 Diagram of Dance Movement Theraph Process, ADTA

1. Body Action: Being able to recognize the body parts, stress levels, and breathing patterns that may cause a patient to block out certain feelings and emotions without ever realizing it. These physical actions are seen as clues to finding the emotional feelings of a patient.

2. Symbolism: Through symbolism, a dance therapist and his or her patient can form a new type of interaction. If the patient is performing one movement and suddenly holds back, the therapist recognizes this and is then able to suggest another image for the patient to follow. By doing this, the therapist also begins to gain the patient's trust.

3. Therapeutic Movement Relationship: This refers to the method of

Fig.3.31 The Rhythmatic Group Dance,ADTA's 50th Annual Conference, ADTA

reenactment. The therapist may reenact his or her patient's movements, not necessarily as a mirror (exact movement), but the therapist may switch it up from time to time by making it broader, smaller, faster, or slower. This gives off the feeling of acceptance. The patient can take risks with movements and know that he or she will have no judgment from the therapist who is right there moving along with the patient.

4. Rhythmic Group Activity: "Rhythm permeates every aspect of human life" (Chace, 80) Everyday life revolves around rhythm. Chace looked at rhythm as being a key tool for communication through the body and as the perfect way to connect people due to the fact that everyone uses rhythm.[9]

Desired psychological state, body movement, and rhythmic activity also appear in the composition of our interactive system. Thus, it is natural to imagine that the system can work as an implement that takes the role of an effector. Moreover, during interaction with people or patients, the system will take up a predominant position, hence leading the interaction to a desired goal.

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[9] *About Dance/Movement Therapy, American Dance Therapy Association; http://torontoobserver.ca/2014/11/14/seasonal-depression-linked-to-subway-suicide-attempts/*

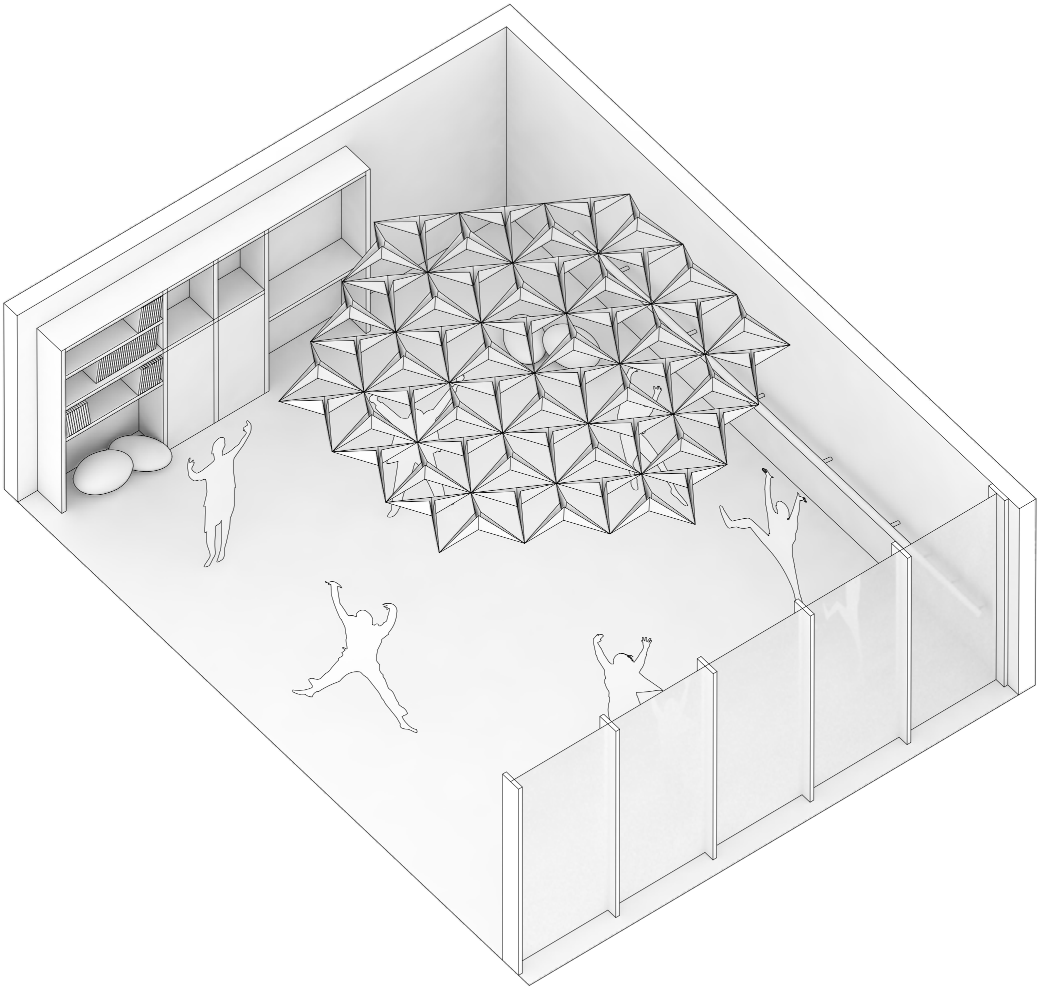


Fig.3.32 DMT Ceiling Struction (before initiate)

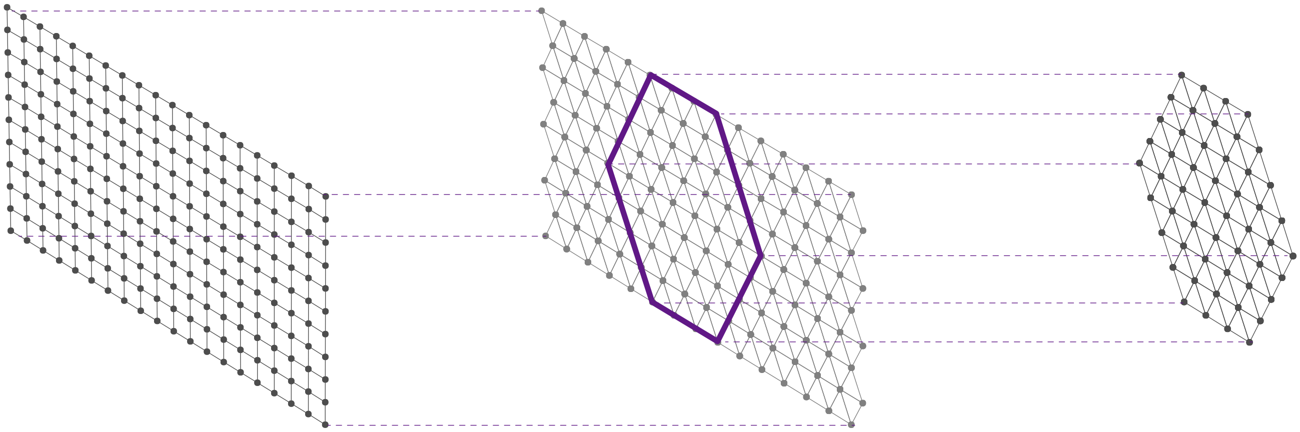


Fig.3.34 The Syntheses of Hexagonal Structure

In dance movement therapy treatment, a leader verbally prompts the participant to go into subconscious, open-ended imagery, which is used to create an internal environment that is catered to the participant in a relaxed atmosphere with symbolic movements by gathering the patients in a circle and following the effector's movement, which is the general method. To support this treatment, which augments the leader's effect or even replaces the leader, a proper presence of this interactive interface could be a ceiling structure, as shown in the above illustrations. With the reconstruction of original square grids, this prototype results in a hexagonal shape that consists of multiple triangular components.

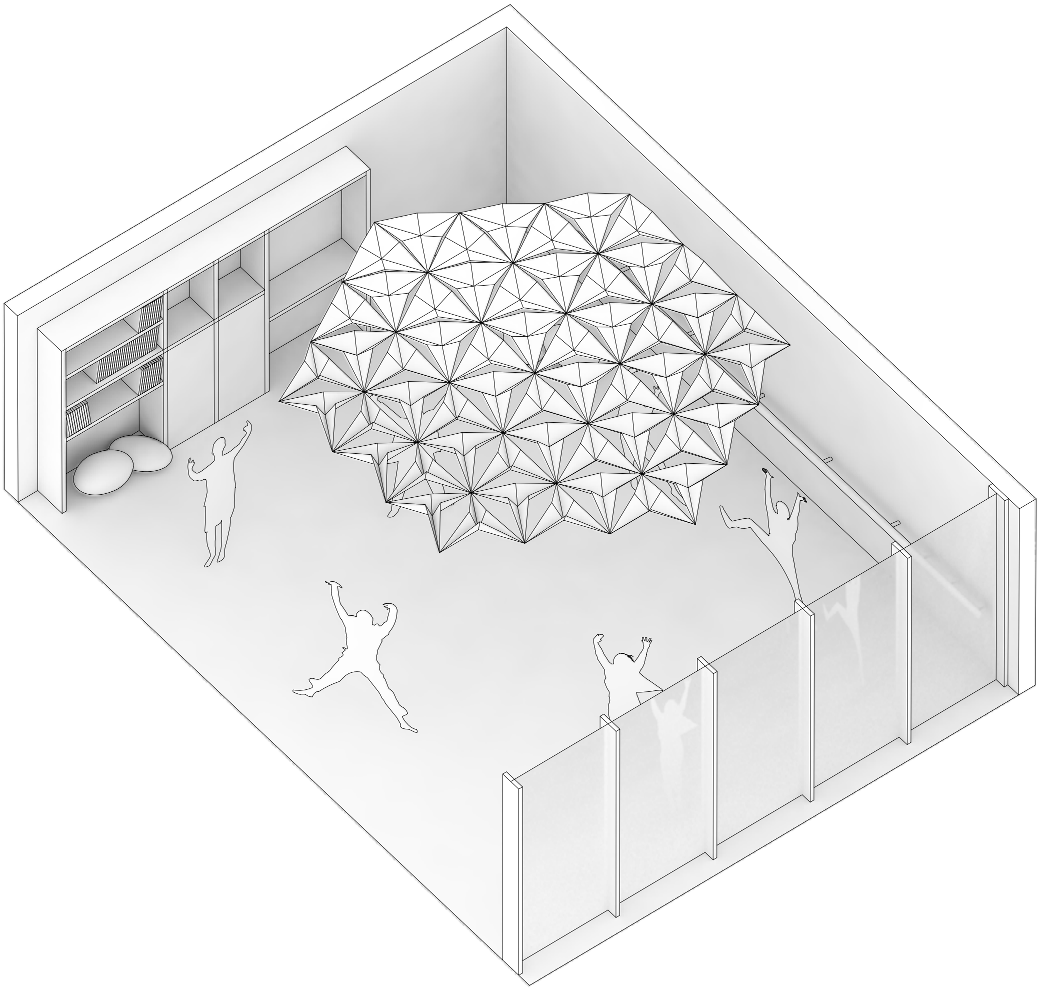
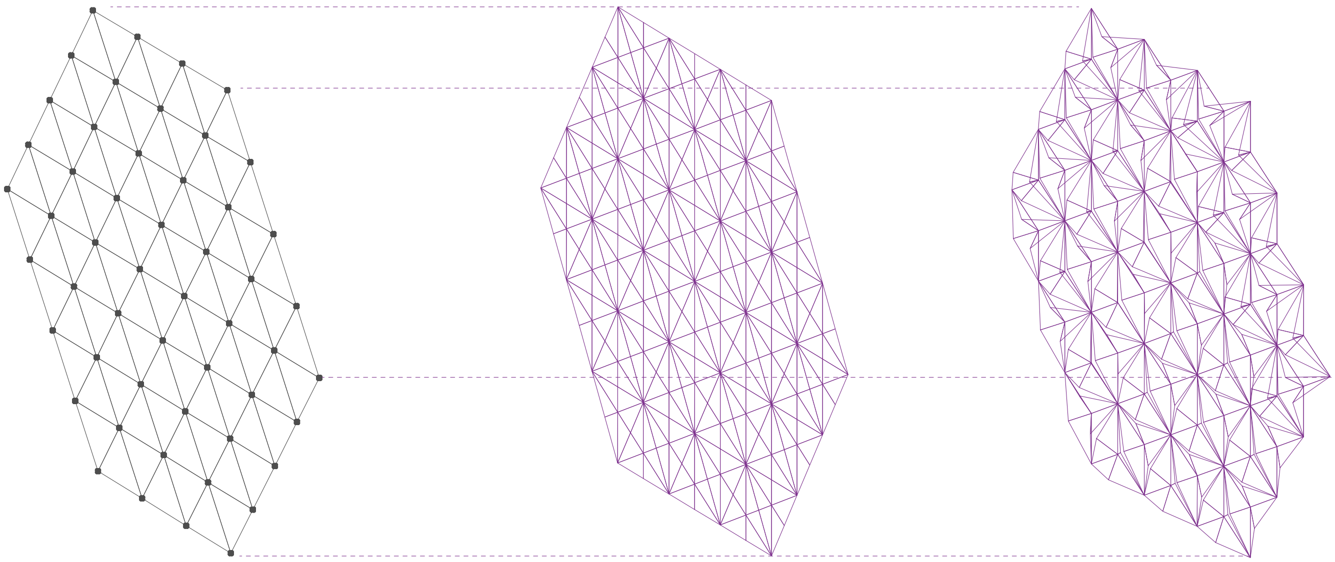


Fig.3.33 DMT Ceiling Struction (after initiate)



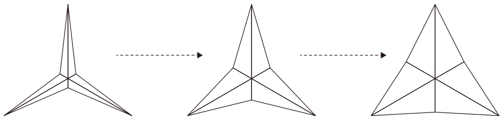
Extract and connect centerpoint with mid points of edges from each triangular cell

Thus split the triangular cell to six minor triangles.

Rotating the center point connections forms the opening kinetics

Fig.3.35 The Syntheses of Opening Kinetics

Similar to the synthesis of twist kinetics, the kinetic type of openness is adopted in this ceiling structure prototype. This task involves a delicate effort in geometry. Specifically, the tip points and the midpoints of the edges of each triangular cell are connected to the center point and, thus, split the cell to six minor triangles. Through rotating the connection of midpoints and center point, the movement of those six minor triangles forms the opening or shrinking of the whole cellular component.



The control element of these opening kinetics comes from the Kinect movement data as well. As with previous kinetic syntheses, this transformation also has a limitation from 0 to half pi. The movement data needs to be first adjusted to a proper range and then facilitate the openness of each component. Though there is a huge difference in terms of kinetic types and geometric organization between the ceiling structure and the original wavy surface, the expressiveness within movement can remain preserved.

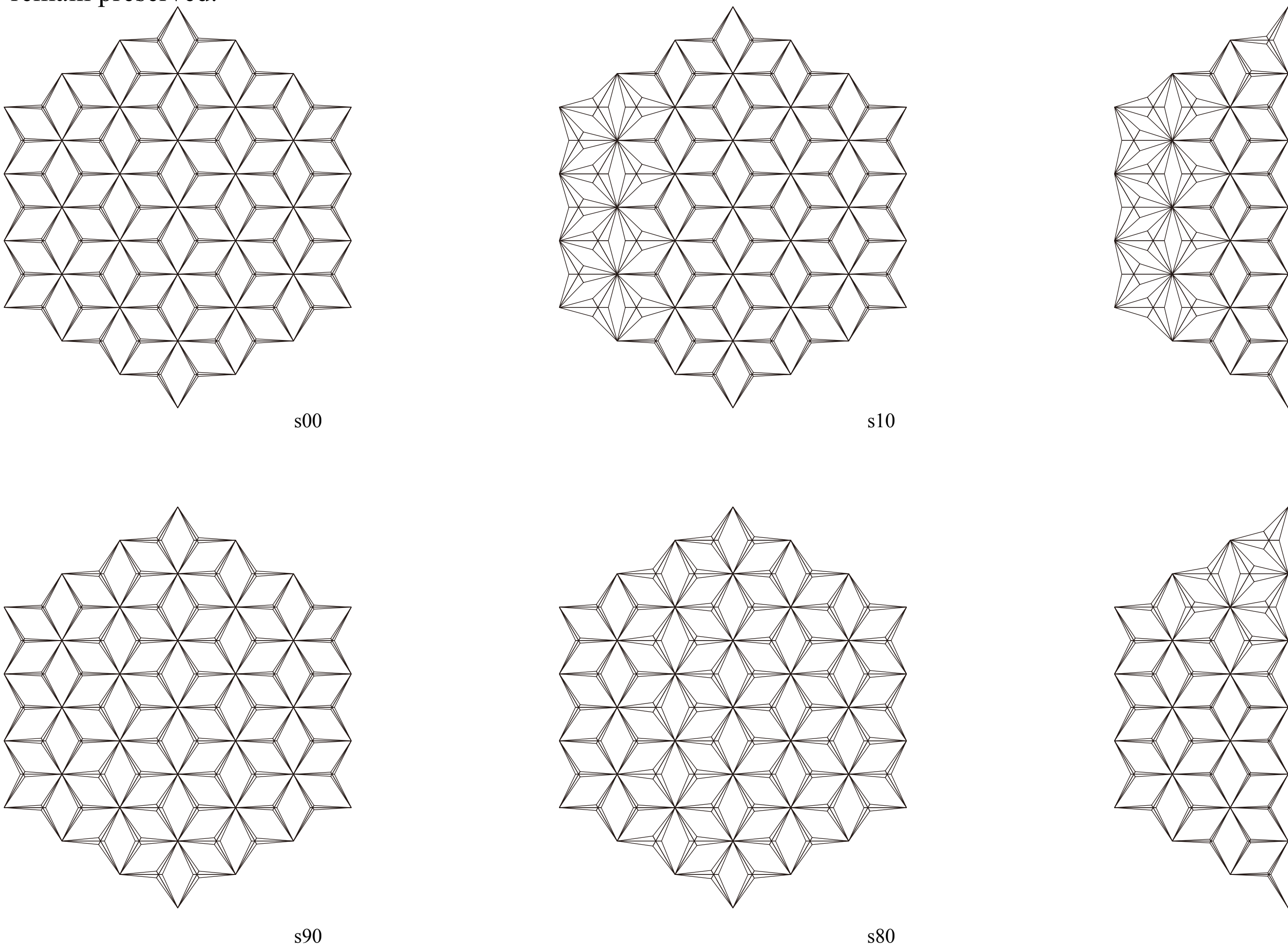
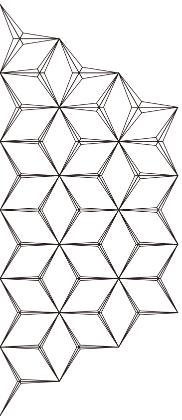


Fig.3.36 Sequence of diplaying Joyful movement



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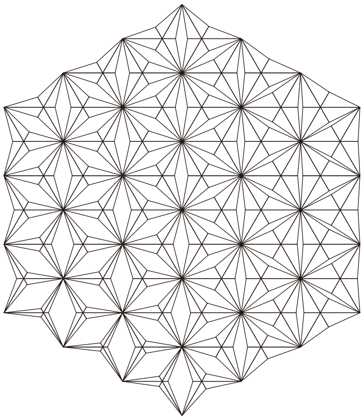

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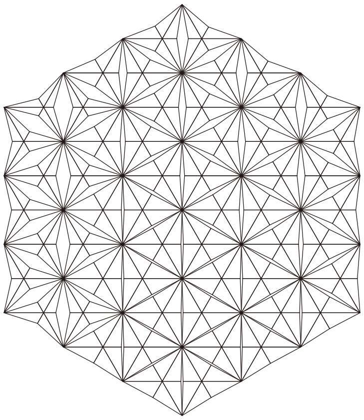

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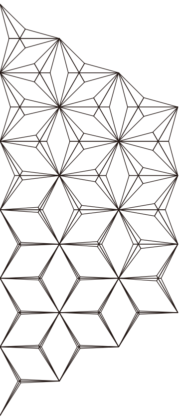

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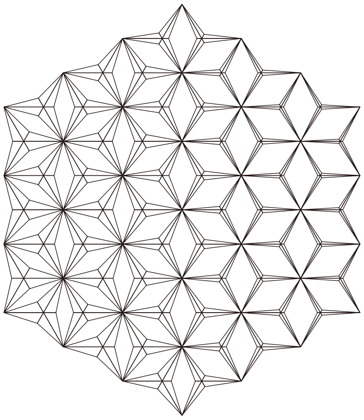

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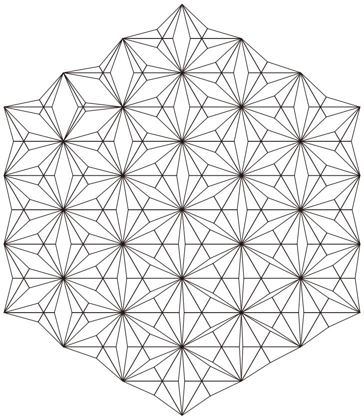

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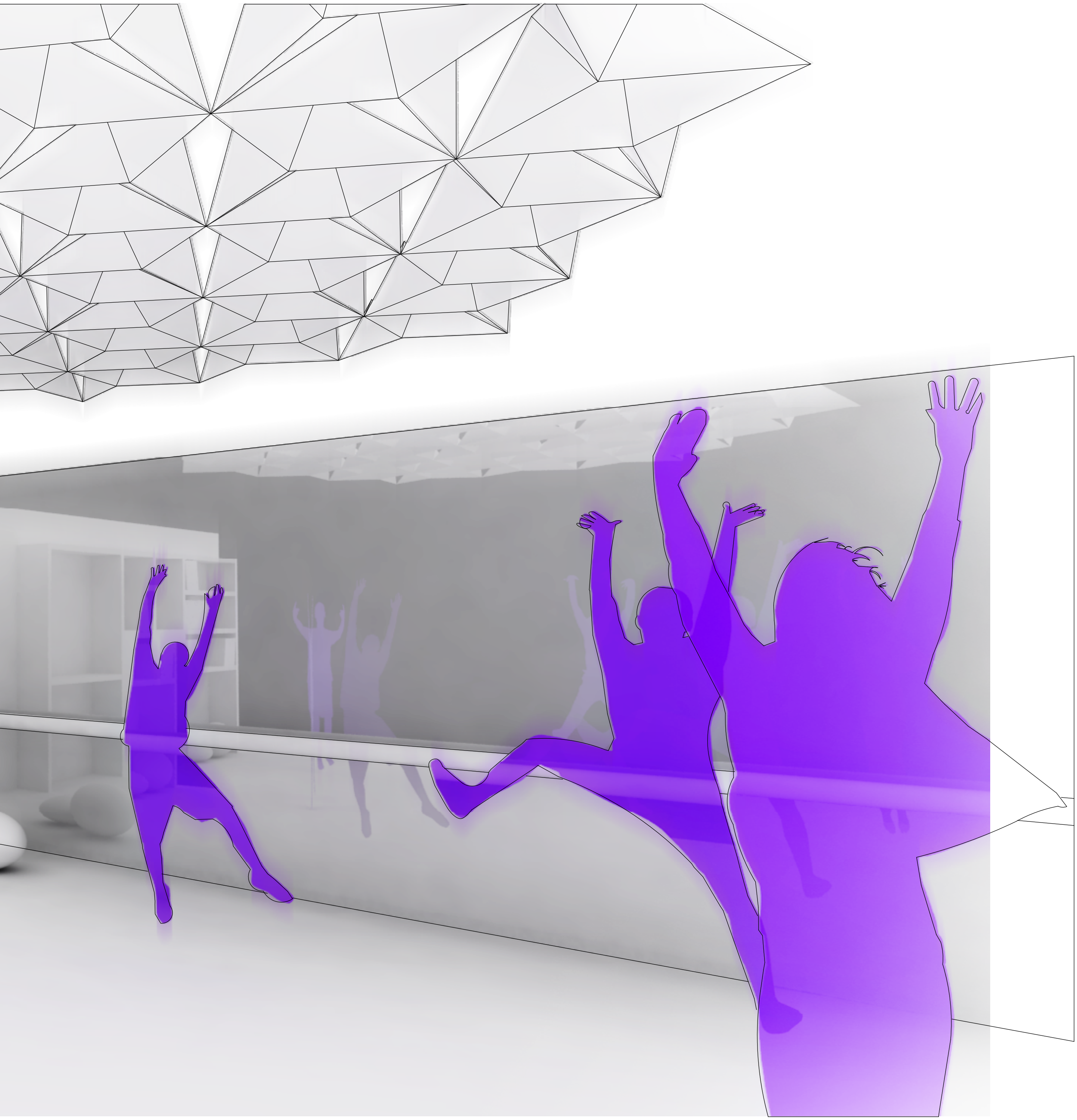
Fig.3.37 Conceptual Effect of DMT Ceiling Structure



CONCLUSION

Sentient matter is aimed at creating an intuitive, effective, and engaging human architectural interaction. By first asking questions such as "Why is emotion significant to the facilitation of affective interaction?" "How we could identify emotion during the interaction?" and "How does this idea influence the future development of architecture?" thus, we may reconsider the relationship between architecture and ourselves. Just as Mark Novak stated, "As people interact with architecture, they should not be thought as users but participants,"[1] interactive architecture becomes powerful when there is a continuous exchange of constructive information that transacts and transforms the participants and the architecture itself. The purpose of interactive architecture is to allow participants to integrate and contribute to a hybrid-built environment. Therefore, a current architectural model of the status quo becomes obsolete due to its inability to process the flow of exchanging information between participants and the space. Thus, a new model must emerge from the exchange.

From the legacy of the conversation theory, we realize that interactive architecture is not merely about a mechanical paradigm. Instead, it is always embedded with a shared cognitive structure that enables the "mutual comprehension" with the capacity of interpreting and creating conscious actions. Coherent with that, the investigation of the emotion appraisal theory indicates a more detailed framework of how we can affect and be affected through the interaction with the build environment. This insight encourages us to believe that a continuous enrichment of this cognitive structure could lead the interaction to an unknown territory in which human-like communication could happen. Therefore, it is no longer about aesthetically pleasing high-tech lobby art that unconsciously responds to people through complex programming. Instead, the system becomes the embodiment of empathy or even intelligence where a fluid flow of emotion is directly proportional to the permeability and

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1.Marcos Novak, interview by Alessandro Ludovico; Neural (Spring 2001); http://www.neural.it/english/marcosnovak.htm.

transparency of both parts.

However, to express cognitive structure in architectural form is always a tough task for all designers. It contains mainly two challenging aspects: the capacity for recognition and for expression. Laban Movement Analysis and Russell's emotion circumplex play an indispensable factor that unveils the correlation between motion and emotion and, at the same time, contributes a method to support the object of recognition. The shape and effort value would resonate with our innate ability to discover unexpected possibilities. These results lead us to the assumption that the absorption and dissipation of emotion could be reflected by physical motion and vice versa. Furthermore, combined with the application of the Kinect senor, a real-time movement analysis is approach is used. Through a two-level translation, the live performance will be first decomposed to three low-level quantitative characteristics: velocity, openness, and smoothness. Subsequently, we can conduct the emotional content of the body movement by having those characteristics identified in Russell's circumplex. Furthermore, this process also implies a learning capacity that allows for infinite possibilities to the system. The data library of human movement will be labeled with corresponding emotion categories and meanwhile evolve with every interaction with users. Eventually, those experiences will manifest as affective architectural behaviors.

Thus, the integration of the connotative meaning of movement into design awareness becomes a fundamental layer within the syntheses of sentient matter. The "indeterminacy" variables indicate three strategies of interactive behaviors that reflect discrete inherent cognition: reflexive, counterpoint, and creation. These modes can evolve into a database of affective kinetic patterns, which fuel the creation or reflection of movement to transform normative physical awareness into surprise and knowledge. This way of thinking about interactive systems is in regards to designing tools that people may use to construct their environments and, thus, to build their own sense of agency. It is about developing ways to engage people so that they ultimately may be responsible for the space in which they inhabit. Thus, architecture informs its participants about how their performance can significantly affect their surroundings. When the architecture is aware and learns from our actions and adjust itself accordingly, it is also reminding us how we are attached to the environment and to the society.

The syntheses of affective kinetics make sentient matter ambitious, regardless of the barrier between different kinetic types and the limitation of certain prototypes. It is made possible because it is initially based on a mathematic model rather than a physical model, though inspired by Margolin's kinetic sculpture. After having a wavy surface prototype from the sine function, movement data from the Kinect sensor provides input that facilitates as the controlling factor of affective expression. The motion trajectory algorithm traces an actor's wrist movement and reconstructs it as a "motion trajectory" to replace the original sine wave. With that sense, human contribution can directly influence architectural behavior in real time. The advantage of having all these syntheses in a digital dimension implies that the movement data is capable of affecting several kinetic types whether the motion is rotating, stretching, or opening.

After understanding where I stand and how I came to be here, I believe the future development of this proposition is heavily dependent on the adaptation of new emerging technologies. As with Kinect, MYO, and so forth, these innovations have completely shifted our ways of interacting with computers and hard devices as well as with each other. Plus, due to the impact of the Internet, this interaction will not be limited to local occupancy but rather everywhere in the cloud and end up with a shared and evolving intelligence. In the future, interactive technology will spread to every aspect of our lives, which will become more accessible and sensitive enough to allow participants to become involved in and eventually thrive in the system. In his book, Interactive Architecture, Fox says that, “Technology transfer from similarly integrated interactive developments in other fields will continue to predicate, impact and evolve with interactive architecture.” The day that computation is seamlessly used, the recent development in the area of interface design will eventually have an impact on interactive architectural environments.

Sentient matter is a process-oriented guide to create the route of futuristic architectural explorations. It even shifts how we think about the role of designers and participants and challenges conventional concepts of architectural, which is determinate and restricted, by offering control from the few to the many, instead of claiming that architect can control the ultimate form of architecture and then subsequently restrain peoples’ social behaviors. The entire process invites participants’ contribution in creating reconfiguration and awareness to architecture. This dissipative system shares responsibility and provides a niche where each individual’s actions matter. This concept will propel us to an open system future, just as Fox says: “As our building do more than respond and becomes truly interactive, we are in relatively unknown territory with respect to our behavioral awareness.”[2]

In the largest sense, the success of interactive design is dependent on its capacity to hear us, stop us, and validate our emotions. In spite of our current technological limitations, we can still mimic and reflect upon physical behaviors to attach participants to the space. Its contribution resides in recognition and generation of physically affective movement. In these two fields, we could conceive many exciting directions into their respective contextual variations. Although it is difficult to anticipate when the type of interactive system in this thesis will be widely adopted, I do believe this trend is inevitable because if this specified subject is yet to be discovered, we owe it to ourselves to explore its potentials. Hence, in the future, it is paramount that we will not ask, “What is that building?” Instead, we will ask, “What is that building doing?”

2.Micheal Fox; Interactive Achitecture; Princeton Architectural Press, 2009

BIBLIOGRAPHY

CHAPTER 1

1. Interactive architecture; Michael Fox, Robert Miles Kemp; Princeton Archit. Press, 2009
2. Usman Haque; Architecture, Interaction, Systems; Responsive Textile Environments; Tuns Press, 2007
3. Danielle Wilde, Thecla Schiphorst, Sietske Klooster; Move to Design/ Design to Move: A Conversation About Design for the Body; ACM, 2011
4. Technology latency: from autoplastic to alloplastic; Digital creativity; 2000, vol11:134, 135
5. B. Jean Nouvel: Architecture and Design 1976-1995, Milan: Skira Editore, 1997
6. Beesley, p., Hirosue, S. and Ruxton, J., Towards responsive architecture, in Beesley, Hirosue and Ruxton "Responsive architecture subtle technologies.", Cambridge, ON: Riverside Architectural Press. 206.p.3
7. SMART's Dancing Traffic Light; Urdesign; Lisbon; 2014
8. http://www.urdesignmag.com/design/2014/09/17/smarts-dancing-traffic-light-manikin/
9. Luciana Parisi; Contagious Architecture: Computation, Aesthetics, and Space; The MIT press, 2013
10. Wiener, N.; Cybernetics: Or Control and Communication in the Animal and the Machine. Cambridge, MA,MIT Press, 1965
11. Hayles, N.K.; Boundary Disputes: Homeostasis, Reflexivity, and the Foundation of Cybernetics, 1996
12. Maria Femandez; Gorden Pask: Cybernetic Polymath; Leonardo,

Volume 41 #2 ; The MIT press, 2008

13. John Hamilton Frazer; The Cybernetics of Architecture: A Tribute to the Contribution of Gordon Pask; Kybernetes 30, nos.5-6 (2001), 641-651
14. Usman Haque; The Architectural Relevance of Gordon Pask; Article first published online: 9 JUL 2007, DOI: 10.1002/ad.487
15. Pickering, A.; Cybernetic Brain: Sketches of Another Future, Chap 7, University of Chicago Press, 2010
16. Jeffrey I. Krichmar and Gerald M. Edelman; Machine Psychology: Autonomous Behavior, Perceptual Categorization and Conditioning in a Brain-based Device; Cereb. Cortex 2002 Volume 12, Issue 8
17. Alva Noe; Action in Perception; The MIT press, 2005
18. Kynan Eng, Andreas Bäbler, Ulysses Bernardet, Mark Blanchard, Marcio Costa 1, Tobi Delbrück, Rodney J Douglas, Klaus Hepp, David Klein, Jonatas Manzolli, Matti Mintz , Fabian Roth, Ueli Rutishauser, Klaus Wassermann, Adrian M. Whatley, Aaron Wittmann, Reto Wyss, Paul F M J Verschure; Ada-Intelligent Space: An artificial creature for the Expo.02; To appear in : Proceeding s of the 2003 IEEE/RSJ International Conference on Robotics and Automation (ICRA 2003)
19. P. Inderbitzin, Wierenga, S., Väljamäe, A., Bernardet, U., and Verschure, P. F. M. J., “Social Cooperation and Competition in the Mixed Reality Space eXperience Induction Machine”, Virtual Reality, vol. 13, no. 3, pp. 153-158, 2009
20. Francisco J. Varela, Humberto R. Maturana; Autopoiesis and Cognition: The Realization of the Living; 1980
21. Evan Thompson; Mind in life; 2007
22. Rodney A. Brooks; The Intelligent Room Project; MIT Artificial Intelligence Lab
23. Studio Roosegaade; DUNE 4.2: The interactive landscape of light alongside the Maas River in Rotterdam NL; https://www.

studioroosegaarde.net/project/dune-4-2/

24. Helen Castle; Alice in Technoland; AD, 4dspace: interactive architecture, V75-01; 2007
25. 1.3 Design for emotion
26. Simon Droog, Paul Derives; Emotion in Architecture: the experience of the user; 2009
27. P.M.A Desmet, P.Hekkert; The Basis of Product Emotions; Delft University of Technology, Department of Industrial Design; 2002
28. Roseman I.J., Smith G.A; Appraisal theory: Overviews, Assumption, Varieties, Controversies; New York: Oxford University Press; 2001
29. Frjida N.H;The emotions; Cambridge University Press; 1986
30. Gregg Lynn Form; Predator; 2001; http://glform.com/environments/predator/

CHAPTER 2

31. Ali Rahim; Catalytic Formations: Architecture and Digital Design; Taylor & Francis Press; 2007
32. William M. Lam; Perception and lighting as a formgiver for architecture;McGraw-Hill Inc; 1977
33. Bartley S. Howard;Principles of Perception; Harper & Row Publishers; 1958
34. Vischer Robert; Empathy , form and space: problems in German aesthetics, 1873-1893; Chicago Press c1994
35. Dezheng Feng, Kay L. O'Halloran; Representing emotive meaning in visual images: A social semiotic approach; Journal of Pragmatics 44, 2012
36. Michelle Karg, Ali A. Samadani, Rob Gorbet, Kolja Kuhnlenz, Jesse Hoey, and Dana Kulic; Body Movements for Affective Expression: A Survey of Automatic Recognition and Generation; IEEE transactions

on affective computing, Vol 4, No.4; 2013

37. Akinleye A.; Watching Dance: Kinesthetic Empathy; Geography of the body, DanceUK News, Issue 70; 2008
38. Diana F. Green; Quality of Movement-Emotions; Choreographing From Within: Developing the Habit of Inquiry as an Artist; 2010
39. Martha Graham Dance Company's "Political Dance Project";
40. Martha Graham voice record; https://www.youtube.com/watch?v=ut9XjQ8RESE
41. Ann Hutchinson Guest; Dance notation: the process of recording movement on paper;Dance Books, 1984
42. J. Burgoon, L.Guerrero and K. Floyd; Nonverbal Communication; Allyn and Bacon, 2010
43. Guest, Ann Hutchinson; Labanotation: the system of analyzing and recording movement; New York; London : Routledge 2005
44. Maletic Vera; Body, Space, Expression: the development of Rudolf Laban's movement and dance concepts; Berlin; 1987
45. Rudolf Laban, F.C Lawrence; Effort: Economy of Human Movement; London; 1974
46. Preston-Dunlop Valerie, Sayers Lesley-Anne, Alton Hampshire; The dynamic body in space: exploring and developing Rudolf Laban's idea for the 21st century; Dance Books; 2010
47. Antonio Camurri, Ingrid Lagerlof, Gualtiero Volpe; Recognizing emotion from dance movement: comparison of spectator recognition and automated techniques; Int.j. Human-computer Studies 59; 2003
48. Tino Lourens, Roos van Berkel, Emilia Barakova;Communicating emotions and metal states to robots in a real time parallel framework using Laban Movement Analysis; Robotivs and Autonomous System 58, 2010, 1256-1265
49. Doyun Park and Ji-Hyun Lee; Investigating the affective quality of motion in user interfaces to improve user experience; 2010

50. James A. Russell; Core Affect and the Psychological Construction of Empotion; Psychological Review 2003, Vol. 110, No 1, 145-172
51. James A. Russell; A Circumplex Model of Affect; Journal of Personality and Social Psychology 1980, Vol.39, No.6, 1167-1178
52. Edith Van Dyck, Pieter Vansteenkiste, Matthieu Lenoir, Micheline Lesaffre, Marc Leman; Recognizing Induced Emotion of Happiness and Sadness from Dance Movement; VU university Amsterdam, NL; 2014
53. Petra Fagerberg, Anna Stahl, Kristian Hook; Designing Gesture for affective Input: An Analysis of Shape, Effort and Valence; Stockholm University; 2010
54. T. Shawn Every Little Movement: A Book About Franc¸ois Delsarte; Dance Horizons, 1968.
55. R. Thomas Boone and Joseph G. Cunningham; Children's Decoding of Emotion in Expressive Body Movement: The Development of Cue Attunement; Brandeis University, Developmental Psychology 1998, Vol. 34, No. 5, 1007-1016
56. Liwei Zhao; Synthesis and Acquisition of Laban Movement Analysis Qualitative Parameters for Communicative Gestures; University of Pennsylvania; 2001
57. Ali-Akbar Samadani; Automatic Recognition and Generation of Affective Movements; University of Waterloo, 2014
58. Misako Sawada, Kazuhiro Suda, Motonobu Ishii; Perceptual and Motor Skills; Expression of Emotions in Dance: Relation Between Arm Movement Characteristics and Emotion; 2003, 97, 697-708
59. Bjorn Harmann, Mazurizio Mancini; Implementing Expressive gesture synthesis for embodied conversational agents; GW'05 Proceedings of the 6th international conference on Gesture in Human-computer interaction and simulation, Pg 188-199, 2006
60. Jessica K. Hodgins, James F.Orien; Perception of Human Motion with Different Geometric Models; IEEE transaction on visualization

and computer graphics, Vol.4, No.4, 1998

61. Martin Saerbeck, Christoph Bartneck; Perception of Affect Elicited by Robot Motion; IEEE 2010
62. Aryel Beck, Brett Stevens and Kim A Bard, Lola Canamero; Emotional Body Language Displayed by Artificial Agents; ACM 2012
63. Jong-Hoon Lee, Jin-Yung Park, Tek-Jin Nam; J. Jacko (Ed.); Emotional Interaction Through Physical Movement; Human-Computer Interaction, Part III, HCII 2007, LNCS 4552, pp. 401–410, 2007.
64. Michelle Thrasher, Marjolein D. van der Zwaag, Nadia Bianchi-Berthouze and Joyce H.D.M Wsterink; Mood Recognition Based on Upper Body Posture and Movement Features; S. D´Mello et al. (Eds.): ACII 2011, Part I, LNCS 6974, pp. 377–386, 2011.
65. Andrea Kleinsmith, Nadia Bianchi-Berthouze, and Anthony Steed;Automatic Recognition of Non-Acted Affective Postures; IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS—PART B: CYBERNETICS, VOL. 41, NO. 4, AUGUST 2011
66. Emilia I. Barakova, Tino Lourens; Expressing and interpreting emotional movements in social games with robots; 2010
67. Maurizio Mancini, Roberto Bresin, and Catherine Pelachaud; A Virtual Head Driven by Music Expressivity; IEEE TRANSACTIONS ON AUDIO, SPEECH, AND LANGUAGE PROCESSING, VOL. 15, NO. 6, AUGUST 2007
68. Afra Foroud, Ian Q. Whishaw; Changes in the kinematic structure and non-kinematic features of movements during skilled reaching after stroke: A Laban Movement Analysis in two case studies; Journal of Neuroscience Methods 158(2006) 137-149
69. Behnaz Farahi Bouzanjani, Neil Leach, Alvin Huang; Alloplastic Architecture: The Design of An Interactive Tensegrity Structure;

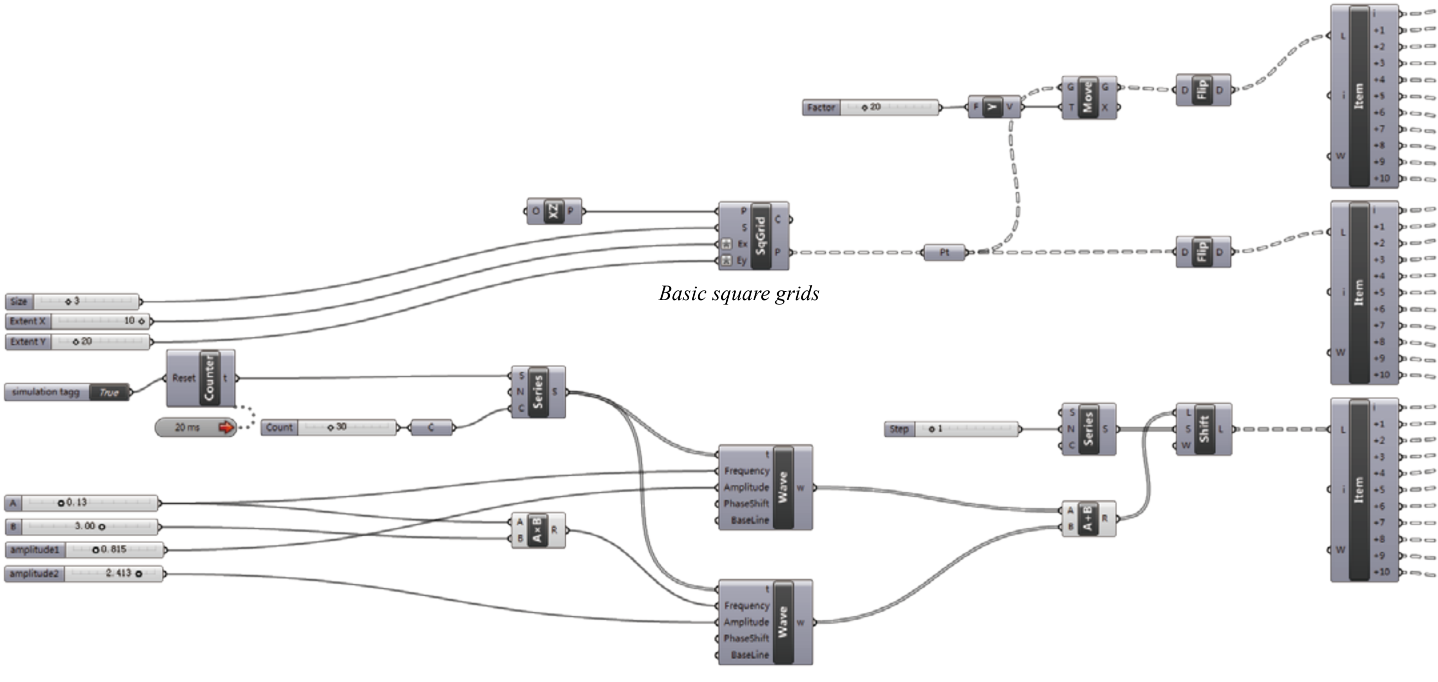
University of Southern California School of Architecture; ACADIA 2013

70. Andy Payne; Kinect+Firefly; http://www.grasshopper3d.com/profiles/blogs/firefly-1-0066-and-kinect-0-0003-now-available

CHAPTER 3

71. Reuben Margolin; Waves; http://www.reubenmargolin.com/waves/index.html
72. Mark Goulthorpe; Hyposurface: from Autoplastic to Alloplastic Space; DECOI Architect, Paris; http://www.generativeart.com/on/cic/99/2999.htm
73. ART+COM studios; Kinetic Rain; https://artcom.de/en/research_focus/kinetics/
74. Cuppetelli and Mendoza; Nerous Structure (2012); http://cuppetellimendoza.com/transposition/
75. White Void Studio; Living sculpture 3d module system; http://www.whitevoid.com/2012/07/24/whitevoid-designs-livingsculpture-3d-modular-system-for-philips/
76. Jules Moloney; Designing Kinetics for Architectural Facades: State Change; Routledge (July 12 2011)
77. Seasonal depression linked to subway suicide attempts, by Christine Hogg, The Toronto Observer, Nov 14 2014; http://torontoobserver.ca/2014/11/14/seasonal-depression-linked-to-subway-suicide-attempts/
78. Superposition of waves, Daniel A. Russell, Acoustics and Vibration Animations ; http://www.acs.psu.edu/drussell/Demos/superposition/superposition.html
79. About Dance/Movement Therapy, American Dance Therapy Association; http://torontoobserver.ca/2014/11/14/seasonal-depression-linked-to-subway-suicide-attempts/

Appendix



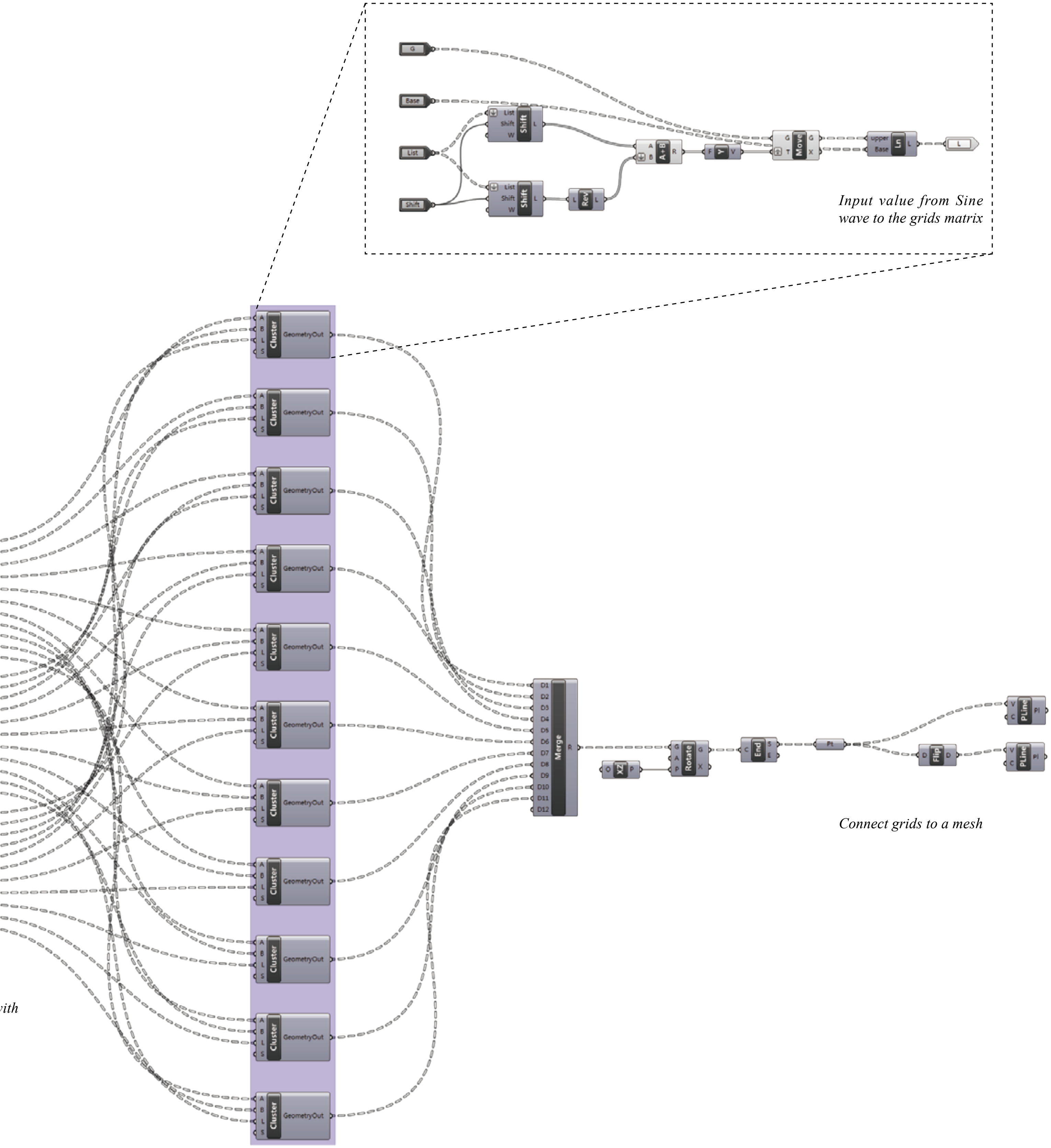
Basic square grids

Two sine wave
with different frequncy
and amplitude

The summation of two
different waves

Shift the waves w
a series of φ

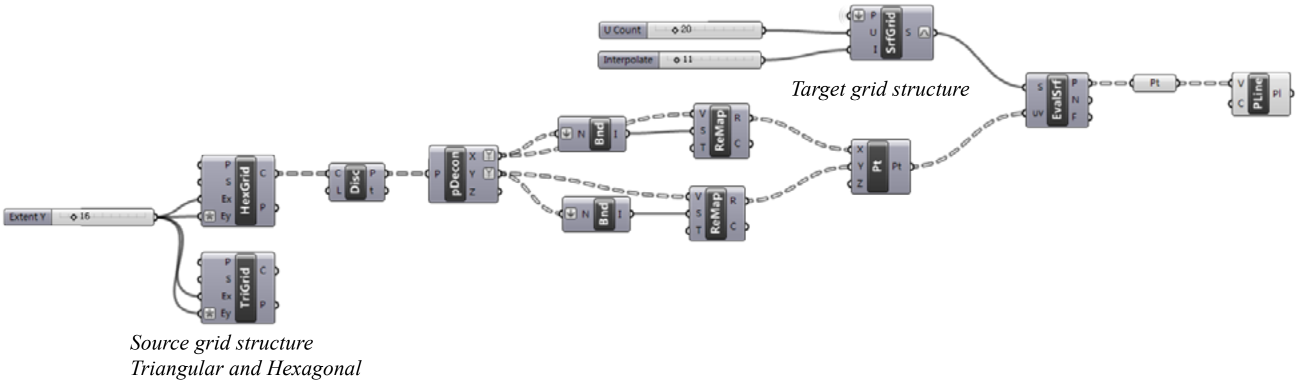
Appendix 1: Wavy Surface and Superpositon of Waves



Input value from Sine wave to the grids matrix

Connect grids to a mesh

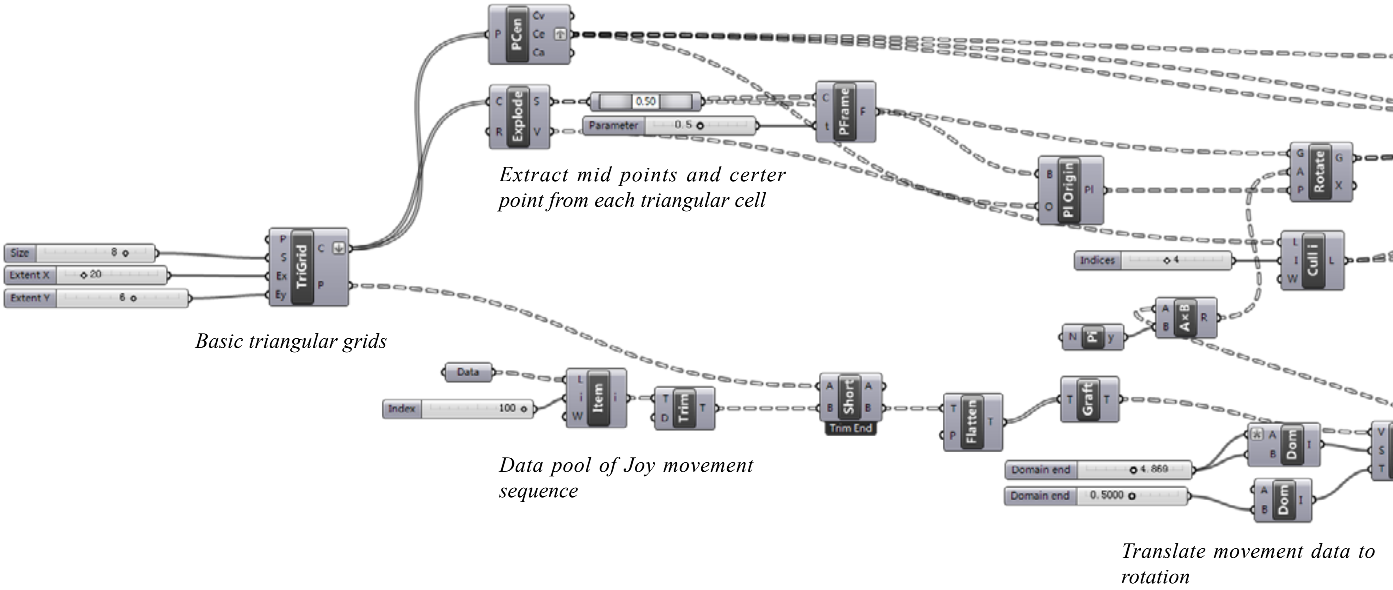
ith



Target grid structure

Source grid structure
Triangular and Hexagonal

Appendix 2: Reconstruct Square grids to Hexagon and Triangle



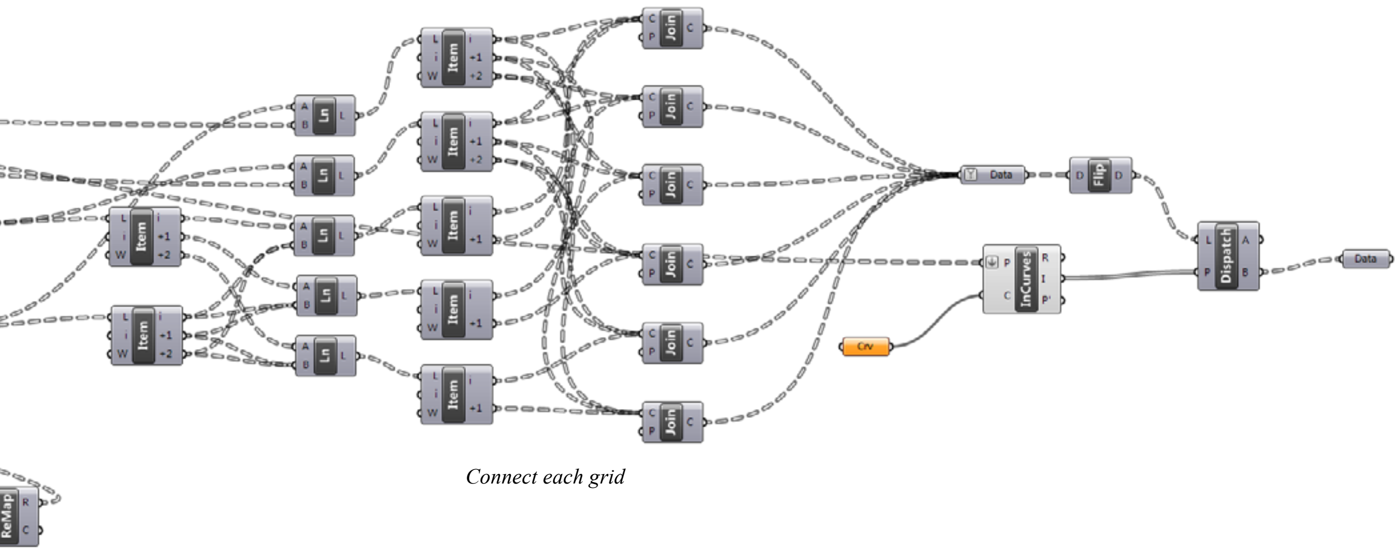
Extract mid points and certer point from each triangular cell

Basic triangular grids

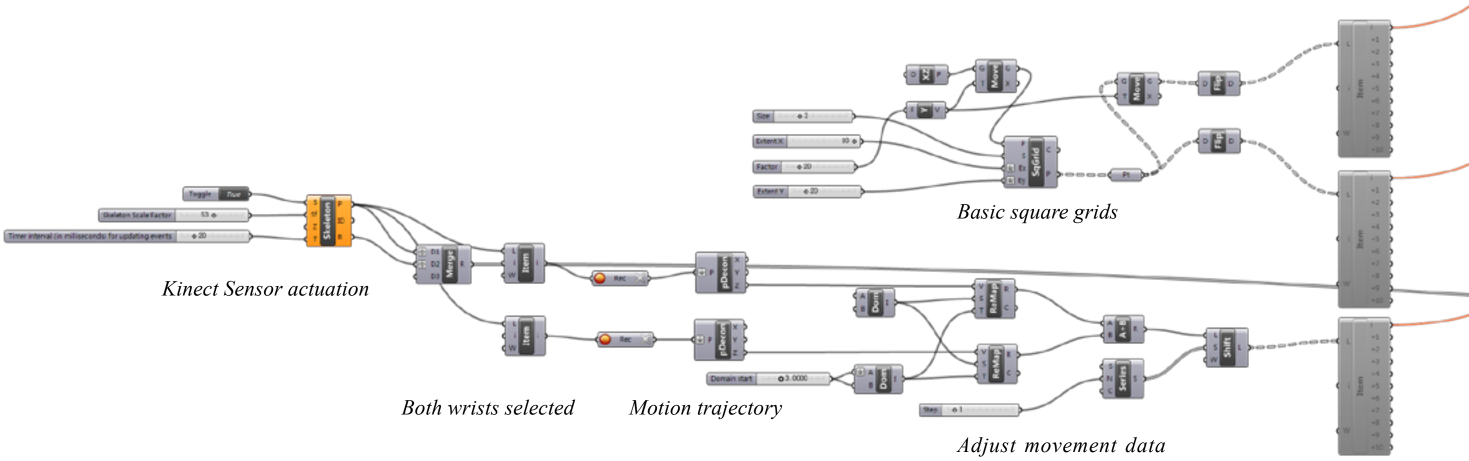
Data pool of Joy movement sequence

Translate movement data to rotation

Appendix 3: Triangular Folding Component for DMT Ceiling Structure



Connect each grid



Basic square grids

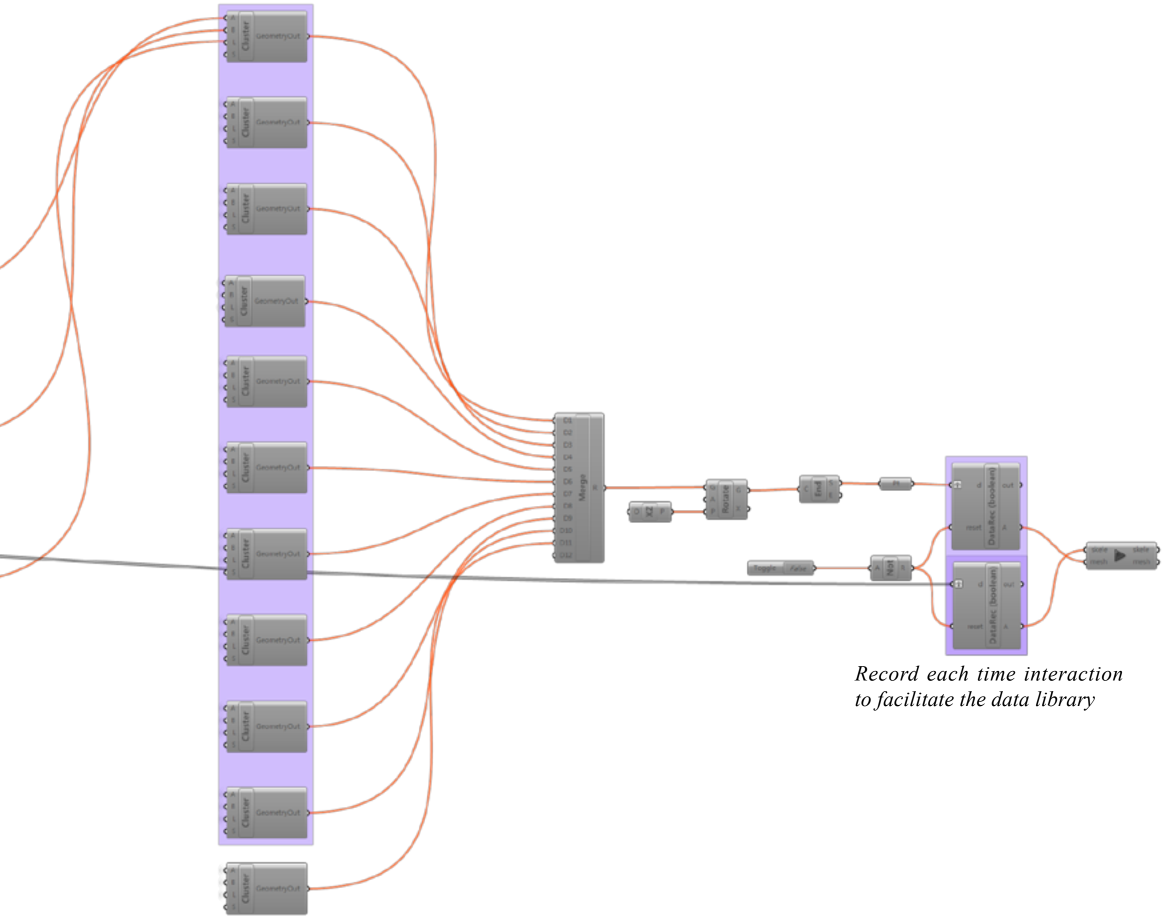
Kinect Sensor actuation

Both wrists selected

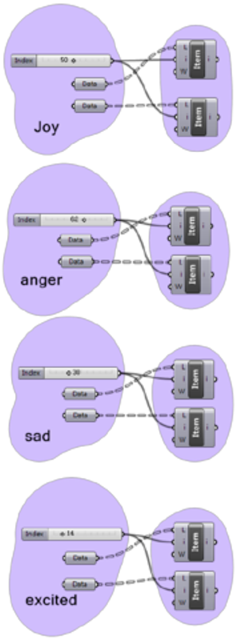
Motion trajectory

Adjust movement data to fit the limitation of wavy surface

Appendix 4: Collaboration of Wavy Surface and Kinect Sensor



Record each time interaction to facilitate the data library



The entire algorithm result in these labled emotive kinetic data clusters