A Tectonic Approach for Integrating Kinesis with a Building in the Design Process of Interactive Skins

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Abstract

Today, interactive architecture plays an increasingly important role in urban milieus. However, in terms of design principles and guidelines in the age of digital architecture, the design and construction of interactive skins has been under-explored. A new design approach to integrate interactive skins and architecture is needed. Certainly skins with interactive and kinetic properties need to be designed and constructed with a new approach for physical and content integration, instead of the traditional design approach. Thus, the ultimate objective of this study is to formulate a suitable design method in order to integrate kinesis with a building. Furthermore, this research aims to establish effective tectonics for interactive skins through the exploration of different state-of-the-art interactive skins. For this study, according to essential design factors that come from the definition of interactive architecture, such as interaction, display, and content, interactive skins are classified in order to build up controllable, available design parameters of interactive skins. This study also proposes designing an effective tectonic model for the integration of kinesis with a building through in-depth case studies. Moreover, in order to prove the viability of these proposed models, this research provides a prototype of a multi-agent-based interactive skin system using Delta robot kinematics, by which designers can quickly design and effectively simulate feasible interactive skins.

Keywords: interactive skins; multi-agent system; tectonic model; design parameters; Delta robot

1. Introduction

The shift from the Information Age to the Electronic Age today is aided by information theory and the cybernetics movement. A few years ago, Neil Gershenfeld wrote a book entitled When Things Start to Think. In this book, he delineates a world in which everyday objects and devices are embedded with computational power (2000). Today, precisely such a world has come into being. Most importantly, these systems are now becoming increasingly pervasive and embedded into architecture (McCullough, 2005). Nowadays, interactive architecture is playing an increasingly important role in urban milieus. However, as a design principle and method in the architecture of the digital era, the design and construction for interactive skins has been under-explored. A new design approach to integrate interactive skins with architecture is demanded in order to generate better design products. It is obvious that these skins with interactive and kinetic properties need to be designed and constructed with a new approach, rather than the traditional design approach.

With this new architecture, however, a new range of design problems is being confronted. How can a new approach to architectural design be created when objects are conventionally static and responsive adaptability is typically unexplored? How can the design product of interactive skins from the early design stage be effectively designed and generated? More specifically, how do architects visualize, imagine, and design the interaction and kinesis of interactive skins for suitable integration with buildings? And how is the metamorphosis of interactive skins constructed through time and space?

While designers have numerous techniques for improving the appearance of architectural forms, they lack design methods for creating ways to model interaction and kinesis on feasible architectural skins via space and time. The design method for interactive architecture creates a foundation by which architects can be guided through the design process of interaction and kinesis.

With the advent of parametric control, some architects have been trying to look for suitable design solutions in order to satisfy new variable conditions. The challenge of interactive skins posited here is a
shift in the design objective toward the production of a whole system instead of a single object. As a creative design approach to produce interactive skins, this research provides different applicable, controllable design parameters based on an interaction mechanism and a tectonic model to effectively construct interactive skins.

This study will start by investigating the definition of interactive architecture and media skins in order to extract important design factors that designers should consider. This study explores different state-of-the-art interactive skins in order to build design parameters in terms of such factors as interaction, display technology, and content. Case studies are also conducted through in-depth interviews and various references in order to investigate different design methods for interactive skins. Through these explorations, this research presents an effective tectonic method for modeling interactive skins. Furthermore, to prove the viability of these proposed models, a specific design tool for interactive skins is offered. This design tool, which is capable of handling interactions between autonomous digital objects, can supply an effective solution providing a complex design scenario that considers the numerous complicated, interdependent relationships.

As a result, the ultimate objective of this research is to formulate a suitable design method for interactive skins—this is certainly new and uncharted territory. Therefore, this research contributes to providing the framework for guiding designers as they design their interactive skins and aiding researchers when they develop design tools for interactive skins.

2. Media Facades as Interactive Architecture

Interactive architecture is a newly emerging concept in architectural design due to developments in ubiquitous technology and the increasing availability of new materials, which permit the extension of buildings via information sensing, processing, and actuating (Jaskiewicz, 2008). In their book, Interactive Architecture, Fox and Kemp write, "The current landscape of interactive space is built upon the convergence of embedded computation (intelligence) and a physical counterpart (kinetics) that satisfies adaptation within the contextual framework of human and environment interaction" (2009).

Usman Haque tries to extend the fixed definition of "interactive" in order to make it useful. He divides it into three levels based on the historical development of interactive technologies: reacting, single-loop interaction, and multi-loop (iterative, evolving) interaction. He then argues that an authentic interactive system is a multi-loop system, a "conversation" in which information exchange is dynamically constructed (Hague, 2007). As MaCullough comments, "Only when technologies make deliberative and variable responses to each other in a series of exchanges is it at all interactive. Such exchange is like a conversation" (MaCullough, 2005). Oosterhuis also says that "interactive architecture (iA) is not simply architecture that is responsive or adaptive to changing circumstances. On the contrary, iA is based on the concept of bi-directional communication, which requires two active parties" (2007). Thus, in opposition to traditional architecture, the design essence of interactive architectural objects lies not only in their physicality, but also in their motion. They are densely interwoven with each other, being based on relations not only between built components and people, but also between the built components themselves.

Today, some building types such as department stores, cineplexes, wedding chapels, and galleries do not demand a relationship between inside and outside. The exterior allows for more specialized attention, so the aesthetic importance of the building facade accordingly increases (Moussavi & Kubo, 2006). With this bifurcation, the development of media facades is given a great deal of weight in this interactive architecture. Since the first media facade appeared in 1928—the famous "Zipper" sign in Times Square, which was an illuminated bulletin board that conveyed the day’s headlines on a building facade—it has gone through many stylistic developments, featuring interaction beyond simply the application to a facade (Hall, 2006). Accordingly, it should be considered as an interactive skin.

From the definition of interactive architecture, three essential controllable factors can broadly be considered in terms of a time scale: display, interaction, and content (Fig.1.). Based on these three factors, designers can start their interactive skin design by asking: What kind of content will designers use as input data? What interaction should take place between the built components and the people or circumstances? And what kinetic form will designers generate?

3. The Classification of Related Works

There are currently two approaches to the understanding of interactive skins: "intelligent facades that are designed with an environmental science agenda" and "media facades that are recognized by data-driven screens" (Moloney, 2009). That is to say, intelligent facades mainly make functional, mechanical kinesis by sensing environmental data, while media facades communicate an image or graphic by interacting with elements in their environments, such as people or ambiance. These two approaches can be characterized by the style of display technology,
interaction, and content. Accordingly, this study will explore related works through detailed classification based on the three pivotal factors. These are driven by the definition of an interactive skin in order to systematically investigate what elements are used to design interactive skins.

3.1 Content in Interactive Skins

The content as input data comes from a range of physical sensors, RFID (Radio Frequency Identification), and digital devices, such as a kiosk or a cell phone. The data is collected from environmental stimuli, such as weather, lighting conditions, sounds, user movement, the direct interaction of users, traffic density, population density, and other socio-cultural quantitative data. The content can be divided by the degree of user engagement because the content imports factors in deciding the types of user engagement in a HCI environment (Gillispie & Calderon, 2007).

User engagement is divided into an active system, requiring users to intentionally choose to engage with the interactive system, which in turn needs to grab the user's attention and work with it. Moreover, the active system based on "playful" interaction can be categorized as content generated by either a single person or multiple persons. Table 1. presents the example of the classification by content.

<table>
<thead>
<tr>
<th>Content Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive</td>
<td>Wind</td>
</tr>
<tr>
<td>Single Person</td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>Multi Person</td>
</tr>
</tbody>
</table>

3.2 Interaction in Interactive Skins

Most media facades have no interaction with users and environments. This digital content, which is made by designers and artists—content such as video, animated text and graphics—is directly displayed without any interaction. This is simply referred to as "expressive display" in this paper.

However, "interaction" today has become a key term for new media technologies. Today's urban space cannot be mediated by just the current levels of visual display (Townsend, 2004). That is to say, the visual display must be considered with interaction and communication. This has long been neglected by architecture. New forms of media display design are needed to keep pace with this new situation (Kronhagel & Hoffmann, 2006).

Interaction is constituted by the kind of hardware and algorithms of its software are available for media facades, rather than what will be displayed on the facade (Haeusler, 2009). Through different levels of "interaction," an umbrella term, digital media can satisfy the new requirements of media facade displays. There are three interaction forms for designing interactive skins based on system theory: linear, single loop, and multi-loop systems.

These systems globally and locally collect information by whether they are networked or not. A linear system directly translates information that comes from the surrounding environment onto the media facade through a camera and sensors that collect information in real time. The single loop and multi-loop systems have a goal, and they can be self-regulating. These systems try to achieve and maintain this goal in relation to input data, which is defined by the relationship between the system and its environment (Dubberly et al., 2009). However, because the single loop system has a fixed goal, this system is limited in attaining more intelligent skins. As the multi-loop system has more than one goal, its goal can be modified, and then, only more intelligent skins that have different possibilities can be generated. (Fig.2.)

3.3 Display Technology in Interactive Skins

Classification by display technology is the first step for understanding the properties of interactive skins, since they are made up of different technical components. A visual approach is most important when designing them. Interactive skins can be identified as data-driven characteristics. The classification of display technology is needed to distinguish between those media facades that interact with their environment using moving mechanical component elements, and those which use light and color to visually represent image, text, or graphics (Haeusler, 2009). Thus, categorizing the media skins can be considered into two types according to method-actuating kinesis: data-driven representation and data-driven embodiment.

Data-driven representation shows motion on an interface (skin) as a dynamic data representation on a two-dimensional surface using a lattice of LED's, windows with lamps, and projectors.
the skin system can be represented via changing the position, speed, direction or quality of motion. The embodiment of data utilizes actuation in which the motion itself embodies data. Users can interpret information based on the abstract visualization that is represented in the display. These skins mainly apply display technology as a component-based system that uses mechanical parts, such as pixels, to represent dynamic algorithmic patterns. The categorization of embodiment can again be done by only a few mechanisms: linear, radial, and rotate. Table 3. shows an example of the classification of display technology.

Table 3. The Classification by Display Technology

<table>
<thead>
<tr>
<th>Display Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projector</td>
<td>Digital Kakejiku, Akira Hasegawa, 2003</td>
</tr>
<tr>
<td>LED</td>
<td>Channel Tower, Peter Marino, 2004</td>
</tr>
<tr>
<td>Lamp</td>
<td>BIX, Realities:united, 2003</td>
</tr>
<tr>
<td>Vertical</td>
<td>Aegis Hyposurface, Mark Goulthorp, 2001</td>
</tr>
<tr>
<td>Data-driven Embodiment</td>
<td>Institut du Monde Arabe, Jean Nouvel, 1987</td>
</tr>
<tr>
<td>Radial</td>
<td>Interactive Façade, Fox and Kilian, 2000</td>
</tr>
<tr>
<td>Rotary</td>
<td></td>
</tr>
</tbody>
</table>

4. Design Parameters for Interactive Skins

By investigating these details of classification, design parameters with controllable factors are built. Interactive skins are products which incorporate a process of change, where information continuously flows by being instantly connected and having the potential to interact with dynamic variations within every single factor over a multiple time scale. These design parameters are considered over a period of time in which they continuously change (Fig.3.).

Designers seek to create interaction: they compose different scenarios according to the degree of user engagement. This can be decided by a passive or active system. From this, the designer can select suitable input devices for their design product. The data from the selected input device can be remotely or locally collected depending on the location of input devices.

Parameters in "interaction" have both a functional goal and an aesthetic goal: "intelligence" and "visualization." The data from input devices are controlled by their degree of "intelligence": linear, single loop and multi-loop. The multi-loop system as a learning system suggests new possibilities that can establish a meaningful dialogue between user and environment. Furthermore, visualizing data with motion properties such as speed and direction is represented both abstractly and concretely by controlling the electronic and mechanical movements.

The primary parameter in "display" is "physicality," which refers to the degree of physicality in the composition of the skins. This concerns whether architects use electronic components or mechanical components for their display technologies. The mechanical components have properties such as linear, rotational, and radial for their kinesis, while electronic components have properties such as color and light for their motion. These components have parameters such as granularity, which refers to their size, and continuity, which means they are continuously arranged for their shape and form.

5. Case Studies

In order to understand the different design methods of media facades and in order to investigate how to integrate building and interactive skin, case studies are conducted through in-depth interviews and various references. For this, four recent cases that were led by experts of various fields were selected: the Kumho building (by a lighting designer), Next Generation Media Facade (by a media designer), Seoul Square (by an art planner), and GreenPix (by an architect).

5.1 Analysis of Case Studies

The main purpose of the analysis of case studies is to know what design methods each project used for the physical and content-related integration of the architecture and media facades, as well as the degree of their integration. In addition, what was the role of the architects?
Media facades are made through the collaboration of different experts. However, according to the leading expert of the project, design methods for interactive skins vary. The common goal of media facade design is to integrate dynamic elements into static architecture. For this, media facade designers who come from different fields use the design methods and concepts of their own field in making media facades. For example, light designers create media facades via lighting design methods, analyzing the scenery from different viewpoints. Art planners consider the media facade as an urban canvas in order to exhibit art works on building facades. Thus, they are interested in better resolution rather than harmony with buildings. Media designers try to display animation with digitally represented stories. In these cases, architects typically play a role in the selection of the finishing materials that are seen during the day in the final design stage. Also, they try for a simple level of integration between the media facades and the buildings—matching, for instance, the color between tiles and electronic devices, hiding electronic control devices in space, and creating animations based on the subject of the building.

However, in the case of GreenPix, which was led by architects, the concept of the media facade becomes the main concept of their architectural design. That is to say, when architects consider the design of interactive skins in their total design process, more than simply adding electronic devices, it can be considered as the strongest physical integration between architecture and media facades. Moreover, Simone Giostra tries to fully integrate architecture and information technology in the urban context by providing new kinds of materials that represent unprecedented artistic forms. This is done through the integration between dynamic motions using interaction with the amount of heat emitted from the people inside the building and static materials which are comprised of photovoltaic cells. For effective integration, the simulation software for this skin was developed and used within the design process. Table 4. shows the results of the analysis of case studies.

### Table 4. The Result of the Analysis of Case Studies

<table>
<thead>
<tr>
<th>Building</th>
<th>Leading Designer</th>
<th>Physical Integration</th>
<th>Design Approach</th>
<th>Used Design Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kumho, 2008 Lighting Designer (Gang-un Kim)</td>
<td>Matching the color between tiles and electronic devices</td>
<td>Scenery Analysis / Selecting Finish Materials</td>
<td>Pre-made Electronic (LED)</td>
<td>Expressive, Concrete, Directed</td>
</tr>
<tr>
<td>Seoul Square, Art Planner (Gana Art Center)</td>
<td>Hiding electronic control devices</td>
<td>Art Planning / Selecting Finish Materials</td>
<td>Pre-made Electronic (LED)</td>
<td>Expressive, Concrete, Directed</td>
</tr>
<tr>
<td>Media Facade, Media Designer (d'strict)</td>
<td>Creating animation based on the subject of the building</td>
<td>Digital Storytelling / None</td>
<td>Pre-made Electronic (Projector)</td>
<td>Expressive Concrete, Directed</td>
</tr>
</tbody>
</table>

### 6. Tectonic Model to Construct Interactive Skins

Flow is the essential goal of interaction design and fixity is the essential goal of architecture. Now the two join (McCullough, 2005).

An interactive skin and a building can be fully integrated by considering interactive skins as a part of architectural design. These interactive skins are characterized as distribution, continuity, modularity, and modality by way of form. With this categorization, architects should design and develop new architectural material with kinesis from the early design stage. However, architects are generally not experienced in designing kinetic material, and they are interested in just inventing static aesthetic patterns. Moreover, without any knowledge of basic kinetic mechanisms, it is not easy for them to create aesthetic kinetic materials, since they have not been trained in the necessary principles of movement. Thus, architects typically play a role in the selection of finishing materials in the final design stage. How can architects extend their scope when creating interactive skins?

This study proposes a tectonic model of interactive skins in order for architects to effectively create interactive skins through the analysis of many related works and case studies. The tectonic model provides a framework for the construction of the interactive skins as well as the basic layered structure (Fig.4.).

This important basic model can show us that...
interactive skins can be constructed by a combination of three controllable categories: "materiality," "visualization," and "physicality." That is to say, the reciprocity of the basic three elements allow us to create higher level design parameters, which help designers translate logical, concrete design agendas into abstract design concepts. The motion properties for "visualization," such as speed acceleration, direction, delay, and twitter, are closely related to the "interaction" part of the above design parameters.

Thus, the "materiality" and "physicality" can be considered as tectonic elements in constructing the physical model. The "materiality" refers to a skin design that creates shapes, invents patterns, and selects materials. On the other hand, the "component" is about whether designers should use electronic components or mechanical components. If one considers the mechanical component, that which is for existing interactive skins can be simplified as several axes of kinesis: radial, vertical, and horizontal.

If controllable components that provide the basic kinesis to architects are offered, architects can then quickly and easily build interactive skins by designing only a form (cover) with specific limitations on each motion. The specific limitations driven from each motion function as design constraints to deal with how to effectively integrate the component and the form. In addition, these logics have the potential to advance as a computational algorithm.

By separating the technical element from the design method for interactive skins, designers can effectively design component-based interactive skins. However, the interactive skin design needs to be considered in total with the kinesis that designers select as well as with the tectonics for full integration between a building and an interactive skin from the early design stage.

7. Interactive Skin System

7.1 System Overview

Based on the design parameters and the tectonic model, a prototype is proposed: a multi-agent-based interactive skin system. This system is composed of five parts: a form-making module, a component module, a simulation module, a fabrication module, and a user interface module. Fig.5. illustrates the system structure and the data model.

The component module of this system is developed by the algorithms of parallel Delta robot kinematics which can provide three translational degrees and one rotational degree of freedom by using parallelograms (Clavel, 1988). This one component as a structure can integrate all the forms of kinesis which the interactive skin requires. In other words, users can make all of the feasible, controllable motions with just one component, without switching any components. Thus, they can immediately generate and test diverse motions in their interactive skin design alternatives.

7.2 Multi-agent Systems as an Implementation Model

Computational agents are defined as computing entities that perceive its environment and carry out goal-directed action (behavior). An agent-based digital model has the potential to represent the appearance of the complex behavior patterns of its agents and provide useful insight into the dynamic system based on its reciprocal relationships that evolve over time (Felsen, 2007). Technically, agents "perceive their environment through sensors and act on that environment through actuators" (Russell & Norvig, 2003).

In the context of interactive skins, agents can be used as architectural components, individual units or humans that have different information, such as a desired goal that agents have and data that designers input. Thus, through agents responding to their environments and having interrelationships that exist between agents, new shapes or forms can emerge.
Fig. 6. shows a model that applies a multi-agent method to an interactive skin system.

In this proposed model, the interactive skin consists of each component: intelligent agents that know how to act upon the activity of the user or the change of environments. Likewise, skin components have flexibility in that they perceive contextual changes in their environments. The application of multi-agent systems as an implementation model has some advantages: representing intelligent visualization through an interactive topology, generating different scenarios based on the level of interaction, and providing useful insight into the dynamic simulation.

7.3 An Algorithm for the Integration between Movements and a Form

How designers apply kinesis derived from components to the form that they design and how they create more complex kinetic forms from a simple shape are both important for kinetic forms. In this skin design, hinged and slide joints are usually used to construct kinetic elements. Connected with the basic movements, these function as design parameters or design constraints for movable elements.

Mechanical motions such as rotational and transitional movements occur on the basis of specific controllable points. For example, a linear actuator that performs a vertical movement (such as a piston) moves on one point. That is to say, these components need standard controllable points, such as moving ones for a linear actuator and a hinge, a slide or a fixation. Thus, because standard controllable points that come from each movement are provided for the form, designers can combine both. Similarly, geometric complexity with motions can be constructed by adding controllable vertexes on basic shapes and by applying a hinged or slide joint on the vertexes. This process increases the geometric complexity of movements, forming the chain of movements which have a hierarchical relation between divided shapes such as superordinate elements and subordinate elements (Schumacher et al., 2009). Therefore, this process allows designers to make useful design decisions through detailed kinetic forms in the early design stage. Fig. 7. illustrates the algorithms to combine a form and a vertical movement.

7.4 Implementation

This interactive system was developed with a Java language that includes a processing library by an author. First of all, users continuously or discontinuously add components, which can generate different movements and lights on the underlaid building sketch or image that they design. Users can create non-standard forms as they adjust their height. After setting the components, users can test different movements by controlling the moving points. Each component can all have the same movements or different movements. And then, the default form of the low level of detail is created according to the feature of each moment. Users can control the style, the size, and the color of shape. Also, as users add control vertexes on the shape, they can generate the complex kinetic patterns or forms that they want.

This system provides attributes for different representations such as video, text, wave, and algorithmic motions for which designers directly set up specific goals of each component. This system then recommends input devices which facilitate the display and provide some options for them. For example, if users display a video on the skin, this system suggests the camera as an input device and some options such as face detection or human behavior awareness. Moreover, users can have useful insights through visualizing algorithmic motions differently by selecting the manner of interaction between each component. Accordingly, users can invent feasible interaction scenarios based on the attributes of this system from the initial design stage. Fig. 8. shows the interface of an interactive skin system developed by an author and the examples which are created in this system.

8. Conclusion and Future Works

This study proposes a theoretical framework to design interactive skins by classifying the related works and building the design parameters for a decision plan. This research also presents a tectonic model for feasible, buildable interactive skins. Moreover, to prove the viability of these proposed models, a specific multi-agent-based design tool for interactive skins based on components is offered. The common goal of interactive skins is to integrate media and information technology and architecture. It is possible for architects to regard interactive skins as parts of architectural design. That is to say, architects need to consider it as architectural design with kinesis beyond simply adding electronic or mechanical devices to their design. Accordingly, this proposed tectonic model, which separates design and technology, and then re-combines them, is valuable for design and for constructing feasible interactive skins.

The proposed prototype, the interactive skin system, was developed by the logic of the tectonic model and different design parameters that were extracted from diverse interactive works. This prototype enables the
designer to quickly create feasible interactive skins with kinetic representations. However, this prototype has some limitations for creating kinetic forms, with just one free axis of rotation and is unable to generate complex geometric forms (such as double layered and organic forms). Moreover, physically fabricated alternatives using this system do not work in the physical, remaining stationary. To compensate for these limitations, physical robotic blocks are currently being developed as the counterpart to this system; they are based on the tectonic model as the extension of this research. These robotic blocks will strengthen the viability of this model.

In conclusion, the ultimate objective of this study is to formulate a suitable tectonic approach to integrate kinesis and buildings in the design process for interactive skins. This is a new and unexplored area. Thus, this research will provide a theoretical framework and tectonic model to guide designers and researchers.

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