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Chapter 6

Bio-Inspired Adaptable Façade Control Reflecting User's Behavior

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Additional information is available at the end of the chapter

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Abstract

The purpose of this research is to develop the process of methodology in designing adaptable façade. This study focuses on the processes of façade operation control for each resident's unit according to the user's lifestyle. This study aims to develop the design methods that are applicable to the adaptable facade, which is inspired by the design inspiration of the biomimicry. The ideal façade to increase comfort in internal space is an adaptable façade that can constantly respond to changes in the environments. This chapter attempts in active adoption of adaptable facade that makes it possible to respond to changing requirements and environments, eventually enabling the creation of customized services for users. This chapter explores the processes of designing an adaptable façade controlled by three rules inspired by the behaviors of flocks of birds. This chapter shows how adopted bird intelligence can produce various façade controls. Also, this chapter demonstrates biomimetic façade control that has been implemented by behavior-based design. Through this demonstration, this chapter identifies the potentials of biomimetic design in facade using rules of bird flocking as source of design inspiration. This study concludes that a behavior-based approach provides flexibly responding façade to environments increasing users' quality of life.

Keywords: biomimicry, adaptable facade, responsive architecture, behavior-oriented design, kinetic façade, façade control, bird flocking

1. Introduction

What is a façade? A façade is generally one exterior side of a building, usually the front, and the word comes from the French *façade*, which means "face." In architecture, the façade remains, from a design perspective, the most important aspect of a building. It is an essential architectural element, because a building's façade determines the initial impression that a building

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makes. In addition to the role it plays with regard to esthetic design, the building façade also serves to divide external and internal space and plays an important role in interacting with the outside environment. However, the environment is constantly changing. In arts, Monet painted a series of expressions of the ever-changing world. Monet painted images that change over time. This is the reason why Monet painted his *Rouen Cathedral* series more than 30 times, always at different times of the day and year. The series reflects many views of the same subject under different lighting conditions. Through this artwork, Monet would have wanted to prove that constant change is the truth of the world. In this regard, a good building must be capable of changing itself by accepting and responding constant variations in the environment [1, 13, 14].

In the ever-changing environment, the architectural façade should have functional performances to protect human beings inside. The external environment changes continuously. One of the architectural elements to meet the functions is a facade. When designing the façade, architects need to consider external factors such as natural sunlight, temperature, humidity, precipitation, wind, and earthquake. The façade protects people by creating a boundary between the inside and the outside. It is also important because it provides thermal comfort. For example, the façade of *Notre dame du Haut*, a Catholic chapel in Ronchamp, France, built in 1954, presents a picturesque image and also helps to fulfill peoples' psychological needs by allowing a generous amount of natural light to reach those inside the thermal insulation of the external wall, saving energy as well providing a comfortable environment. However, this building has limitations: the curtain walls of the building are fixed, and it cannot respond flexibly to the fluctuating environment. We believe that the ultimate façade should be able to respond adaptably to the ever-changing environment. Although the ideal is that a building should respond to changes in the environment like a living creature, most buildings are not satisfactory in this regard. For example, one of the most representative modern buildings is *Lake Shore Drive Apartments* in Chicago, designed by Mies Van Der Rohe. This skyscraper exhibits both the spirit of the twentieth century machine esthetic and minimalism; the building has no decorative elements and is simply made of glass with metal structures. However, a weakness of this building's façade is that it seems very static, and there is no user control of the façade. That is, it is impossible for residents to control the function of the façade at the level of the individual apartment unit. The building offers spectacular views to residents through transparent glass, but the level of thermal comfort is not optimal. In other words, fixed windows that cannot open and close have reduced the building's ability to respond to the environment.

An ideal facade must be able to respond to changes in the environment [18]. An adaptable façade does this, and since it can extend the life of a building, it contributes to the development of sustainable architecture [21]. An adaptable façade is able to interact with natural adaptive systems in order to respond continuously to the environment [9]. Typically, these buildings efficiently utilize windows in order to optimize façade illumination and building performance by interacting with the environment [8]. The drawback of previously built façades is that they do not provide people with the ability to control the environment [10]. Most buildings focus primarily on performance-oriented design rather than user-oriented design. Previous studies have emphasized technical, performance-based facade design, and it is difficult to find adaptable façades that respond to users' lifestyles and behaviors. Many architects have difficulty in designing façades that are responsive to users' various lifestyle requirements and in incorporating these into façade design [5]. The building façade should have features to optimize environmental performance as well as to consider the esthetic of building. The façade, in particular, should take into consideration the user's individual lifestyle and preference [19]. In order to overcome the limitations of existing buildings, this study explores user-oriented façade design.

The main purpose of this research is to develop a methodology for designing adaptable façades. This study focuses on the processes of façade operation control for each resident's unit, allowing the user to adjust the façade to match the user's lifestyle. This study aims to develop a design method inspired by the concept of biomimicry that is applicable to the development of adaptable facades. The study's first objective is to propose applicable methods of façade design based on an interpretation of the rules of bird flocking. The second objective is to develop a design process that can be applied to a façade's louver controls. The last objective is to develop an application example and identify the potential of the design process developed by this study.

2. Theoretical background

2.1. Adjustable façades and adaptable façades

The concept of adaptation in architecture aims to increase the usability of building functions in response to the external environment or the user's behavior [22]. In other words, adaptable architecture results in sustainable buildings with extended lifespans by allowing buildings to make flexible changes to adapt to changing exterior environments [21]. The positive consequences of using methods to design adaptable façades include extending the lifespan of the building as well as improving the quality of human life. Designing adaptable façades not only prolongs the lives of buildings that use them but also improves the quality of human life. In this chapter, the types of adaptable façade design are divided into two types: adjustable façades and adaptable façades. To provide people with the ability to control the environment, we must plan for an adjustable façade. In an adjustable façade, the user can open and close the window or rotate the louvers to respond to the environment. It is a façade type that has been in existence for a long time and users manually control it. Adjustable façades allow for the manipulation of architectural elements by, for example, opening or closing windows and changing the angle of a louver.

An adaptable façade is a façade that can automatically adjust the environment using technology, whereas an adjustable façade provides the user with manual control over the environment. An adaptable façade differs from a traditional façade; in that it incorporates adjustable devices whose capacity for interactive control enables the building envelope to act as a climate moderator. By using the façade in this way, we can provide a building with the ability to accept or reject free energy from the external environment and, as a result, to reduce the amount of artificial energy required to achieve comfortable internal conditions. One notable example of an adaptable façade is *Al Bahr Tower*, located in Abu Dhabi. Al Bahr Tower designed by AHR studio has the world's largest dynamic façade, and this adaptive shading system of façade is designed to detect changes in the climate and save energy. The other building examples include *One Ocean EXPO pavilion* in Yeosou, Korea, *Syddansk Universitet* communications and design building in Kolding, Denmark, and *Media-TIC* building in Barcelona, Spain [12]. The façade of *One Ocean* EXPO pavilion 2012 by SOMA architect consists of 108 kinetic fins as the opening elements. These fins called lamellas are reinforced at the top and bottom edges of the façade and provide a high tensile strength as well as a low bending firmness. The advantage of this facade enables large reversible elastic deformations [24]. In case of *Syddansk Universitet* building designed by Henning Larsen architect, it has a sustainable feature in a climate-responsive kinetic facade that adjusts to the changing daylight and controls interior temperatures for occupants. The Media-TIC building designed by architects Cloud 9 is also a good example of an adaptable façade. Using technology of sensor monitoring including occupancy, light, temperature, and humanity as well as renewable energy generation, it consequently creates a near net zero energy in building [23].

Adaptable architecture offers an optimal environment for users inside. The façade is able to interact with natural adaptive systems to respond constantly to changes in the environment [9]. Typically, these buildings utilize windows efficiently to optimize façade illumination and to optimize building performance by interacting with the environment [8]. However, the problem with this façade is that it does not provide sufficient user control. Although adaptable building envelopes have positive aspects in achieving internal comfort for occupants and building energy efficiency, it still needs much more exploration in social and cultural aspects [12].

2.2. Façade design method using biomimicry

Principles of nature such as sustainability, bio-architecture, biophilia, biomimicry, and biomimetic architecture can help to address the environmental crisis of contemporary architecture and to provide more comfortable user spaces. Biomimetic architecture, which is the focus of this chapter, is a modern architectural philosophy that seeks to find solutions to architectural design challenges presented by every day changes in the environment around a given building [11, 15]. Biomimicry is not only a rapidly growing design principle in engineering, but it is also emerging as an important architectural principle. Problem solving by biomimicry is an approach that makes use of principles, mechanisms, and strategies found in nature [3, 4]. Janine Benyus, a pioneer in biomedical research in the United States, introduced the concept of biomimicry in 1997. Biomimicry is a concept that is inspired by nature, exploring sustainable solutions and applying them to design. The word is a combination of two Greek roots: *bios*, which means life, and mimesis, which means mimicry or imitation [23]. A typical example of an environmentally functional facade system utilizing a biomimicry design motif is the *Arab World Institute* designed by Jean Nouvel. The facade of the building measures and compares the luminance of the outside environment with the luminance inside the building and then adjusts the luminance using a window opening and closing device, providing an optimal illumination environment inside the building [17].

However, although this performance-based approach provides beneficial features for controlling facades, it is not feasible to satisfy all residents' individual needs or requirements of viable environmental performance. This is because it provides a standardized performance without considering individual preferences. Another limitation with the performance-based approach is that it did not take into account the psychological needs of residents. People do not always have the same demands and the degree of demand varies according to the change of mood and situation.

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This performance-based approach seeks for optimization to meet the building efficiency, but the optimized outcome might not be ideal for residents. In order to solve these drawbacks, this chapter proposes a behavior-based approach rather than performance-based approach. It is assumed that the control of the facade according to occupant behaviors such as lifestyles is more advantageous in terms of psychological and environmentally sustainable aspect for occupants. As a strategy to get inspiration for this behavior-based approach, the theory of the biomimicry is adopted. The biomimicry approach can improve the quality of the facade design by developing the facade control method based on the self-organization and collective behavior of the community [16]. In this study, as biomimicry approach, swarm intelligence theory is utilized. Terminology "swarm" has been wisely used to many areas including biology, engineering, computation and others. Swarm intelligence is firstly introduced by Beni and Wang, and it means the collective behaviors of self-organized system [2]. The collective behaviors include examples of army ants, bird flocking, animal herding, fish schooling, and collective swarms of bacteria and locusts [7]. Mainly, this study is focused on bird flocking behaviors.

3. Behavior-oriented adaptable façade

Based on the above background information, this research aims to develop a behavior-based adaptable façade. First, a set of rules inspired by the flying behaviors of flocking birds are established to apply to adaptable façade control. A set of rules of façade control were developed accordingly. By examining the application of the rules of façade control, this research is to verify and demonstrate the potential use of the behavior-oriented façade control system. There are three research components that we have chosen in order to resolve the façade design problem. To produce an adaptable façade, a bio-inspired design approach is adopted, using bird flocking intelligence [2], as our source of inspiration. The purpose of this research is to develop a façade control method that takes into account user behaviors.

In this study, three rules governing the flying behavior of birds inspire the control of the façade's louver. The first rule is that birds fly close to and in the same direction as neighboring birds. As shown in **Figure 1**, each bird follows the behavior of neighboring birds. It is an important goal of this study to attempt to adapt such traits to the behavior of residents in the

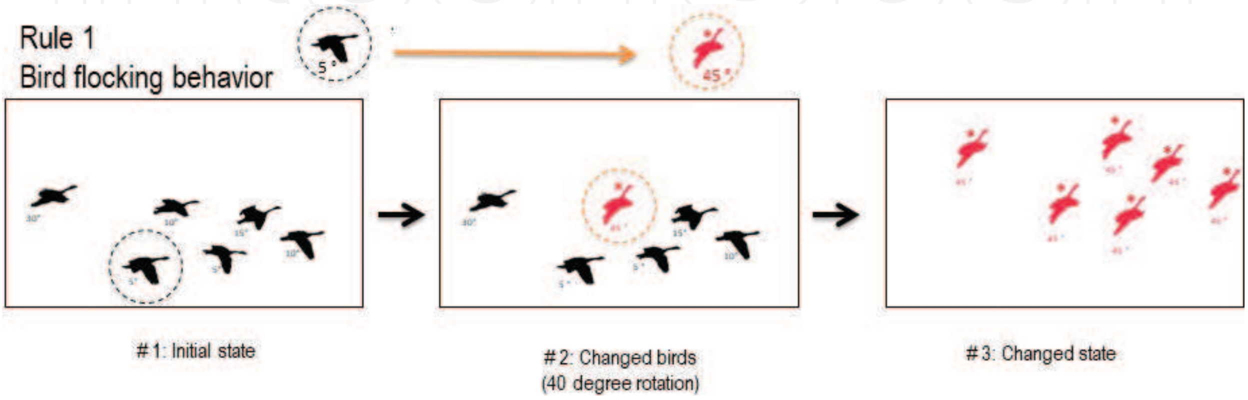


Figure 1. Rule 1: Adjacent birds react to each other in the same direction.

building. For example, if a person closes a window when it is raining heavily to prevent rain from entering the room, other people will tend to follow this person and close their windows as well. If a person is away and is not able to close the window by himself, it would be useful to set up a system that closes windows automatically when it is raining.

The second rule is that birds maintain a constant distance from neighboring birds when flying. Birds maintain regular intervals with their neighbors to avoid the collision. **Figure 2** is an example of the application of these laws. If a bird rotates by an angle of 30°, the rest of the birds can be interpreted as increasing its angle by 30° from its present angle. This principle can be used to increase the angle of each louver in the façade by 30° relative to the current louver angle.

The first and second rules described above might be too simple. We can apply more complex rules, but the complexity or simplicity of the rules applied is not important. The emphasis in this study is on architecturally interpreting the laws of bird behavior and thereby showing that the principles of these behaviors can be applied to architectural facades. However, an example of more complicated application method could explain the potential for the behavioral principle of birds. The third rule was developed with this perspective.

The last rule is to fly toward the central gravity in the groups of the same neighbors. As shown in **Figure 3**, birds tend to fly as groups. From this, it is possible to set the assumption that the same group behaves in the same way. Thus, if a group of members cause a change in behavior, birds in the other groups do not respond to the behavior, but it can be assumed that birds in the same group follow the same behavior. It can be considered that these subgroups exhibit the same behavior in some way similar to the first rule. However, the difference from the first rule is that it applies only to the group, not to the whole. These groups can be defined by the bird's flight, but they can be grouped into small groups according to lifestyle, age, and gender in a way that defines people. The characteristics of these residents are called residents' profiles in this study.

The last rule is to fly toward the central gravity in the groups of the same neighbors. As shown in **Figure 3**, birds tend to fly in groups. From this, it is possible to make the assumption that the same group behaves in the same way. Thus, if members of a given group change their behavior, birds in other groups will not respond to that change. However, it can be assumed

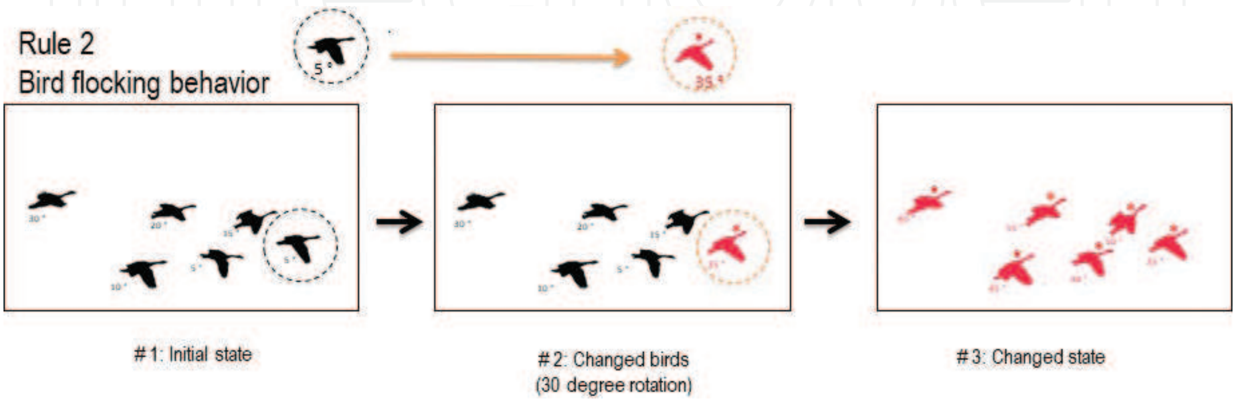


Figure 2. Rule 2: Birds' behavior keeping certain degree of flying angle.

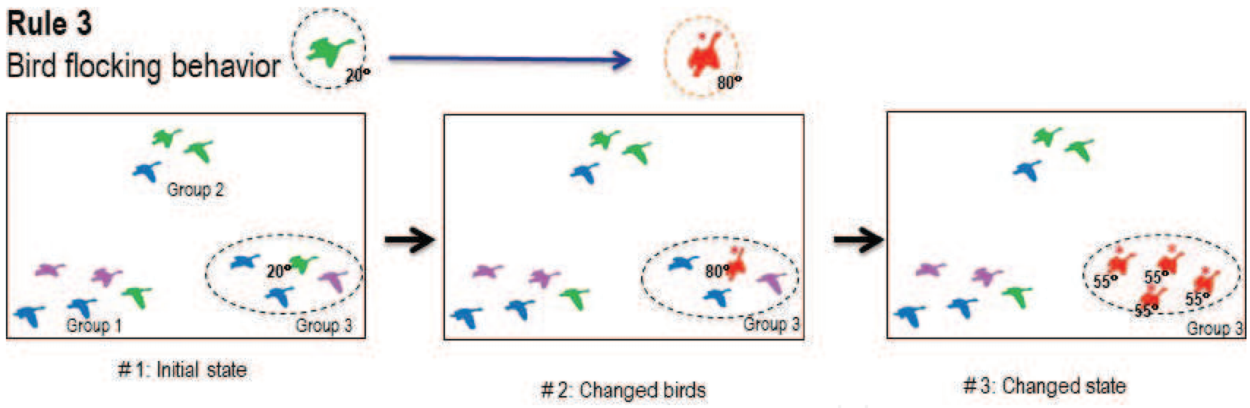


Figure 3. Rule 3: Birds' behavior to steer together average "center of gravity" of birds' group.

that behavior will change within a given group in response to changed behavior by one of birds. Thus, these subgroups appear to exhibit the same behavior, as in the first rule. However, the third rule differs from the first rule, and in that it applies only to the subgroups and not to the flock as a whole. These groups can be defined not only according to the birds' flight patterns, but also can be grouped into subgroups according to lifestyle, age, and gender, similar to human subgroups. In this study, these characteristics that define resident subgroups are called residents' profiles.

In this study, a case study was conducted to derive ideas about how to apply the three rules of bird flocking intelligence described above to façade control. As described above, we interpreted the birds' flying behavior and applied what we learned to the façade's louver control system. In other words, bird flocking behaviors were used as a source of inspiration for the creation of an adaptable façade corresponding to user's behaviors and lifestyles.

4. Bird flocking behavior-based adaptable façade design

Generally, architects or designers do not create designs in the absence of any reasons or inspirations. Many designs are inspired by something specific, and this is equally true for the design of architectural façades [25]. There are many things that inspire designers when designing a facade, but nature, in particular, is a frequent source of inspiration. In this respect, the biomimicry approach is very appropriate. In this chapter, we included two approaches to the design of an adaptable façade: a morphological design approach and a behavior-based design approach. **Figure 4** shows the morphological approach to biomimetic design described above. A morphological biomimetic design approach follows the form of life. In this example, a bird's profile and form are applied to an architectural façade. This method is straightforward and simple and therefore can be used easily by the designer. However, although this method has the advantage of providing a basis for façade design, it is not an effective example of using biomimicry.

Biomimicry design can be used to greater advantage by applying behavioral rules or rules inherent in living things rather than by applying such morphological methods. In this sense, the focus of this study is the behavior-based design approach. In this study, we propose a

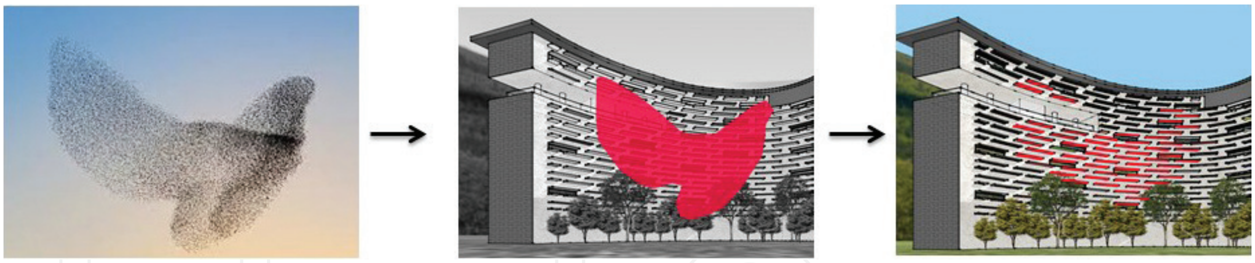


Figure 4. Morphological design approach: façade design inspired by bird flocking.

methodology of façade design based on bird flying behavior. We also conducted research on the assumption that behavior-based design controls are more effective than performance-based design controls. Most previous papers on façade design have adopted a performance-based design approach. However, the performance-based facade control is based on general services rather than on one-to-one custom services. As a solution to this problem, this study proposes a behavior-based design control method.

4.1. Façade control system

As shown in **Figure 5**, this study argues that residents' satisfaction can be improved by controlling the physical environment individually based on the occupant's behavior [25]. Our approach is to mimic the process of bird flocking and we developed control process of behavior-based physical environment. The idea is to interpret the behavior of the birds and create an adaptable façade that responds to the behavior of residents. Life-log data on residents' rules of behaviors in the building are the basis for making important decisions about controlling the physical environment. In developing such rules, we reinterpreted the behavior rules of birds and apply them to façade control. As shown in the figure, it is a process to control the façade louver based on using the user's life-log to control the physical environment. In this behavior-based facade control, the residents' life-log data play an important role.

As shown in **Figure 5**, this study argues that residents' satisfaction can be improved by controlling the physical environment individually based on the occupant's behavior. Our approach is to mimic the behaviors of flocking birds, and we developed a behavior-based process of controlling the physical environment. The idea is to interpret the behavior of the birds and to create an adaptable façade that responds to the behavior of residents. Life-log data on residents' rules of behavior in the building are the basis for making important decisions about how to control the physical environment. In developing such rules, we reinterpreted the behavior rules of birds and applied them to the façade control system. In this behavior-based facade control method, the residents' lifelog data play an important role to change the facade's louver.

4.2. Principle of facade application of birds' flocking pattern

In this study, we applied the three rules of bird flocking to the design of the façade pattern. **Table 1** shows the bird behavior-based rules applied to the facade louver controls. As shown in the table, the principles of bird flocking behavior are applied to the façade louver controls.

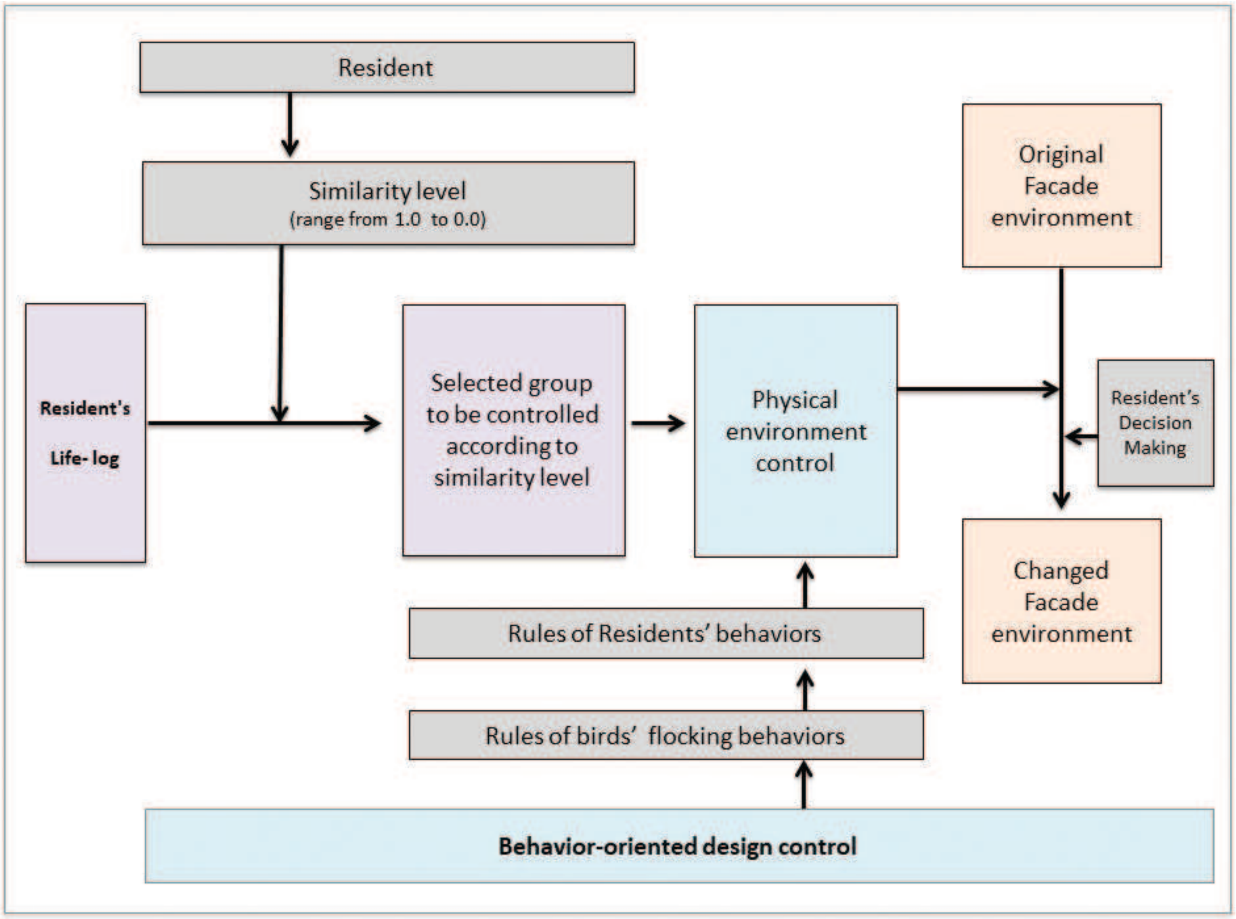


Figure 5. Control process of behavior-based physical environment.

	Bird flocking behaviors	Façade application
Rule 1	To align with same direction of bird's neighbor	To align with certain degree of louver
Rule 2	To keep certain degree of flying angles	To change certain degrees to adjacent louvers
Rule 3	To steer together average "center of gravity" of birds' group	To steer toward the "average of degree" of same group

Table 1. Bird flocking behavior and façade application.

5. Façade design process using bird flight rules

In this study, we will explain various methods of applying bird flight patterns to adaptable façades. We also developed a bird flight-inspired example of the process of finding design rules and applying them to façades. Through these applications, we have explained that principles of animal behavior can be used as a source of inspiration for biomimetic facades. This biomimetic façade design provides a systematic design framework for façades that responds to the user's lifestyle and preferences [9, 17]. Therefore, in this chapter, we prove that integrating design with the biological processes has the advantage of giving the architect more abundant design inspirations.

5.1. Case study

In this study, a *Lotte Buyeo Resort* building in the Republic of Korea was selected as a case study in order to apply the principles of bird flight to façade control. As shown in **Figure 6**, this façade has dozens of façade louvers. Although the actual building cannot adjust louver angles, this study assumes that the angle of louvers can be individually adjusted.

5.2. Residents' facade louver control data

In order to demonstrate how to control the facade louver, we have matched each bird and each facade louver corresponding to individual residents. The concept diagram is shown in **Figure 7**. This diagram is based on the lifelog data illustrated in **Figure 5**.

In order to create the behavior-based facade louver control proposed in this study [26], it is firstly necessary to collect the residents' behavioral data to control the angle of the facade louver. In this study, an imaginary lifelog data was used which is revised data of 24-hour self-diary to survey 53 residents in Korea [20]. Data collection of lifelog is a crucial research issue in behavior-based facade control. However, the data collection in this chapter is not the scope of the research. For the convenience of demonstrating the concept of the behavior-based facade control, an imaginary lifelog data is used. In this regard, **Figure 8**, which is revised and obtained based on the previous research [6], shows an illustrative example of how the louver of the facade is controlled based on the lifelog data. As shown in the figure, when the sensor detects illumination of daylighting, residents can make final decisions related to control on the facade using generalized behavior pattern. Behavior patterns include angle data of façade louver control made by residents. As shown in **Figure 8**, lifelog data may be accumulated by sensor technology. In future studies, based on the IOT, data collection for lifelog data needs to be further discussed.

Figure 6. Buyeo Resort building, Republic of Korea.

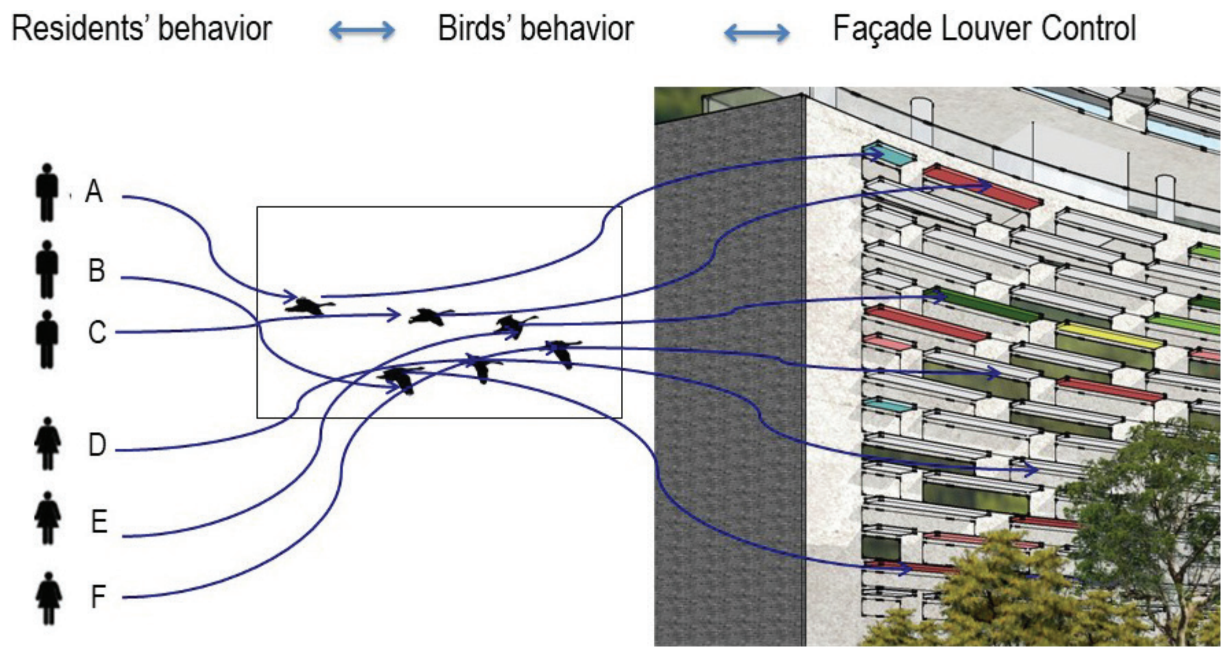


Figure 7. Conceptual diagram of residents' façade louver control.

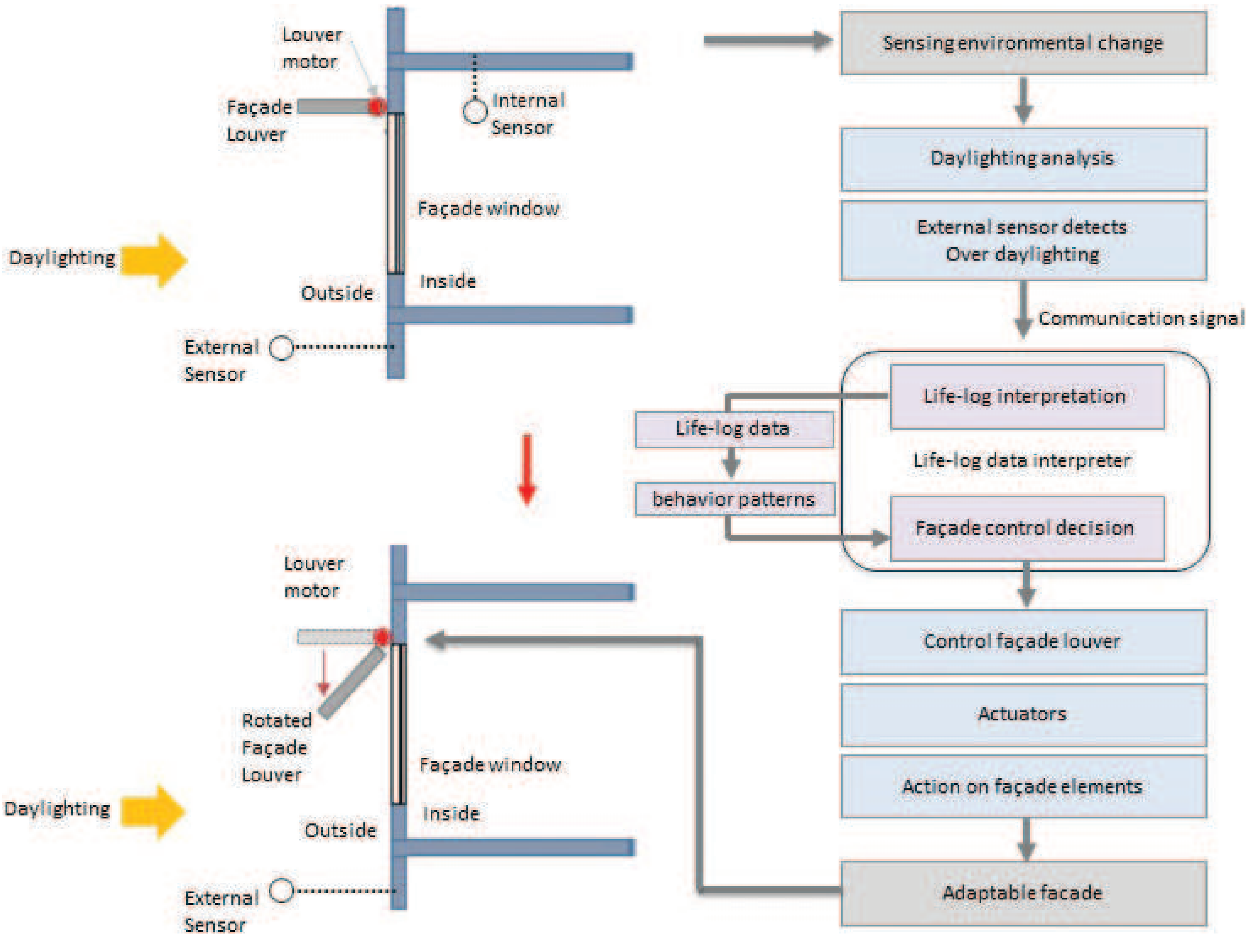
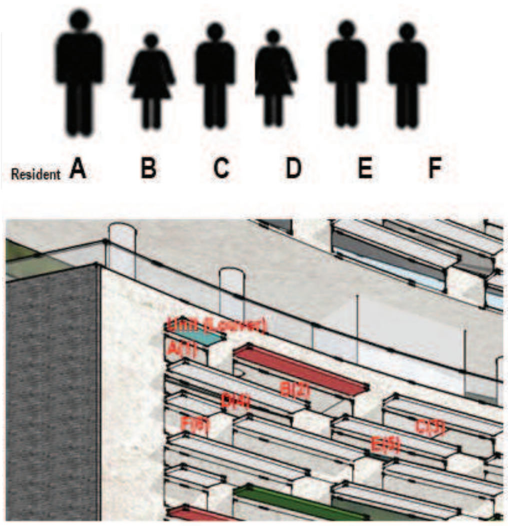


Figure 8. Diagram of sensor technology based façade operation system (modified from "Intelligent Envelopes for high-performance buildings" by [6]).

Figure 9 shows an example of collected data of the residents' previous behaviors pertaining to the façade louver angle. The lifelog is a record of user behavior. I argue that we should embed this behavioral data into a behavior-based adaptable façade design. After collecting previous lifelog data on the louver control angles used by the residents, we analyzed the residents who have similar behaviors based on this data.

Figure 10 is an example of data showing similar behavior among residents. For example, a similarity of 1.0 indicates the most identical behavior, and a similarity of 0.0 means that there is no identical behavior. The similarity of behavior is used to set the group of louvers to be controlled. The lower the similarity of behavior, the greater the number of louvers to be controlled. We created this similarity index in order to establish a basis for controlling the angles of louvers on a group-by-group basis.

The residents' façade louver control system determines whether louver control is required by sending a message to residents who show similar behavior, as shown in **Figure 11**, and asking them to make a decision. The reason to ask for the final decision on whether or not to change louver angle is that this individual user-oriented control is as important as group basis control. Although the system is pursuing automatic control on a group-by-group-basis, the ultimate goal is that the individual user eventually is able to decide that angles of louver in case of needs to change louver's angle.



Resident	Residence Unit	Time	Façade Louver #	Louver Angle
A	1	7:00	1	30 degree
	1	12:00	1	90 degree
	1	17:00	1	45 degree
	1	21:00	1	- 45 degree
B	2	7:00	2	70 degree
	2	12:00	2	80 degree
	2	17:00	2	- 45 degree
	2	21:00	2	- 35 degree
C	3	7:00	3	90 degree
	3	12:00	3	70 degree
	3	17:00	3	- 15 degree
	3	21:00	3	48 degree
D	4	7:00	4	60 degree
	4	12:00	4	90 degree
	4	17:00	4	- 45 degree
	4	21:00	4	45 degree
E	5	7:00	5	50 degree
	5	12:00	5	85 degree
	5	17:00	5	- 35 degree
	5	21:00	5	40 degree
F	6	7:00	6	55 degree
	6	12:00	6	90 degree
	6	17:00	6	- 55 degree
	6	21:00	6	45 degree

Figure 9. Residents' behavior data collection.

❖ Level of similarity in Behaviors: Highest= 1.0 , Lowest =0.0

Resident	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
A	1.0	0.5	0.4	1.0	0.2	0.5	0.8	1.0	0.9	1.0	0.8	0.7	0.3	0.2	0.1
B			0.8	0.9	0.3	0.9	0.2	0.8	0.5	0.2	0.9	0.5	0.7	0.4	0.4
C				0.7	0.9	1.0	0.3	0.7	0.2	0.5	0.2	0.9	1.0	0.5	0.7
D					1.0	0.4	0.9	0.9	0.3	1.0	0.3	1.0	1.0	0.9	0.9
E						0.1	0.7	0.1	1.0	1.0	0.9	0.8	0.8	1.0	0.1
F							0.6	0.2	0.2	0.8	0.2	0.7	0.7	0.8	0.2
G								0.8	0.7	0.7	0.3	1.0	0.2	0.5	0.3
H									0.6	0.3	0.9	0.2	0.3	0.6	0.9
I										0.5	1.0	0.3	0.9	0.4	1.0
J											0.8	0.9	0.8	0.9	0.8
K												0.7	0.7	0.9	0.7
L													0.6	1.0	1.0
M														0.7	0.9
N															0.3
O															

Figure 10. Similarity level in behaviors between residents.

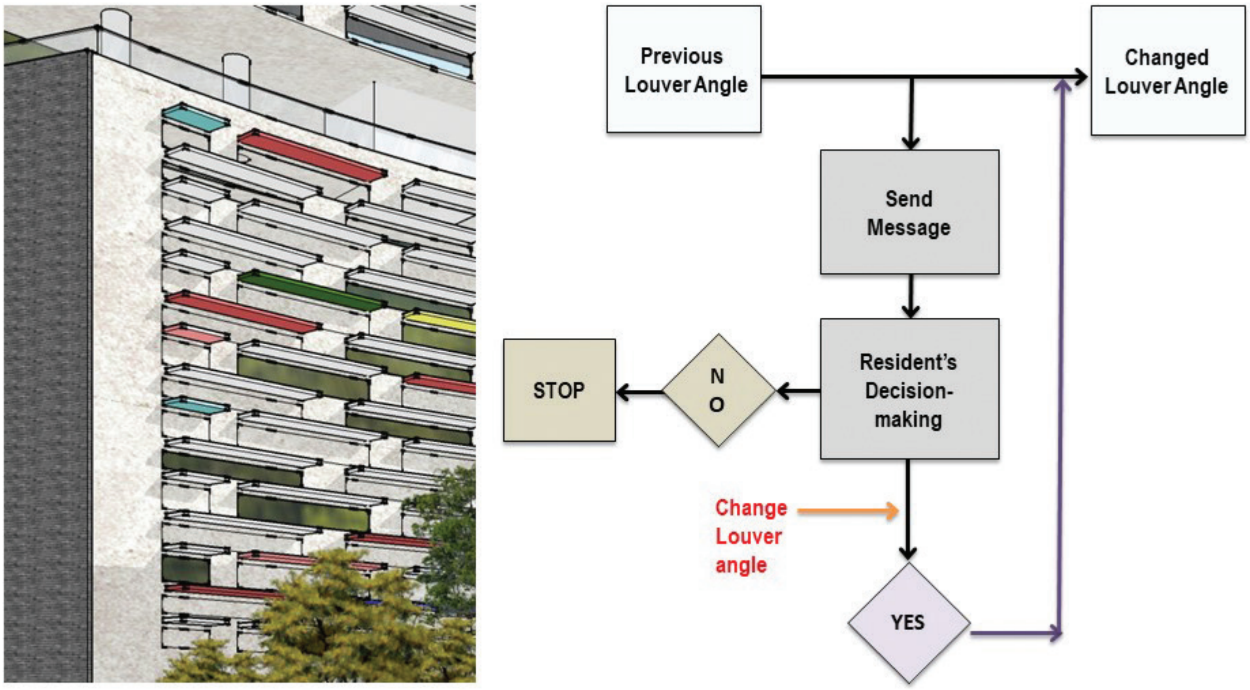


Figure 11. Façade louver control process by user's decision-making.

5.3. Behavior-based façade application

The first rule of bird flocking is that flocking birds align with a certain angle of flying. We interpreted this rule to mean that birds have a tendency to keep flying at an angle of the same degree. The first application example is shown in **Figure 12**. As shown in the figure, when the angle of one louver changes, the angle of another louver also changes to the same angle. This is an application of the principle described above that if one bird changes direction, the adjacent birds change direction, and the other birds change directions as they see the adjacent birds again. For facade applications, residents (A, E, J, L, and M) in a similar behavior pattern group also rotate 45° in the same direction if resident D changes the angle of the louver from 5 to 45°. In other words, all louvers of the same group will be changed to 45°, following the resident D. There is room for further study on the merit of the application of this principle in architectural performance. One of the advantages of applying these rules is that it creates a ripple effect through an entire group using one smart control. Currently, this represents only the beginning of the possibilities for control; this method will become more effective if it is refined by more advanced research on how to use it.

The bird flocking's rule 2 is that bird flocking keeps certain distance between birds to avoid collisions. Rule 2 interpreted in this chapter is that birds have a tendency to change flying with the angle of certain degree. The second rule is to control the facade louver by means of a bird's flight principle, which uniformly increases a certain angle of all current louver angles. As shown in **Figure 13**, if resident B rotates the louver angle by 30°, resident group (C, D, F, G, K) with similar behavior patterns also adjusts the angle by adding 30° from his angle. Therefore, each louver angle of user C, D, E, F, G, and K in group can be changed into 60, 50, 40, 35, and 45°. It is a principle that maintains a certain angle like keeping a certain distance of a bird.

The second rule of bird flocking described above is that flocking birds maintain a certain distance among themselves to avoid collisions. We interpret this to mean that birds have a tendency to change flying with the angle of certain degree. We applied this rule to the control of façade louvers by uniformly increasing or decreasing louver angles in a group in response to changes in an individual louver angle. As shown in **Figure 13**, if resident B increases the louver angle by 30°, the resident group (C, D, F, G, and K) with similar behavior patterns also adjusts the angle by adding 30° from his angle. Therefore, the louver angles user C, D, E, F, G, and K could, for example, change to 60, 50, 40, 35, and 45°, respectively. The principle is to maintain a certain angle the way birds in a flock maintain a certain distance among themselves.

The third rule of bird flocking is that flocking birds steer toward the average "center of gravity" of a given group of birds. We interpreted this rule to mean that birds have a tendency to keep flying at the same average angle. It is assumed that there are three groups of birds and only birds in group 3 have changed the angle from 20 to 80°. Then, whole birds in group 3 change flying degree into 55°. As indicated in **Figure 14**, if A changes the louver angle from 20 to 80°, the mean louver angle of residents A, D, H, and J is 55°. Therefore, the louver angles of unit A, D, H, and J in same group can be changed into 55° of average of louver angle.

The last rule is that it is assumed that the same group of the residents has similarity in their lifestyle. **Figure 14** shows an example of applying the louver control at the same angle after determining the average angle in the average louver direction of a similar group. The benefit of the third rule is that if you control according to a group of similar lifestyles, you are more likely to increase resident satisfaction. All of the abovementioned rules will be the same, but the third rule is more closely related to the concept of collective intellect.

Before

Resident	Residence Unit	Time	Façade Louver #	Louver Angle	
				Before	After
D	4	12:00	4	5	→ 45

❖ If the level of similarity in Behaviors =1.0

(40 degree rotation)

After

Resident	Residence Unit	Time	Façade Louver #	Louver Angle	
				Before	After
A	1	12:00	1	30	→ 45
E	5	12:00	5	5	→ 45
J	9	12:00	9	5	→ 45
L	11	12:00	11	15	→ 45
M	12	12:00	12	10	→ 45

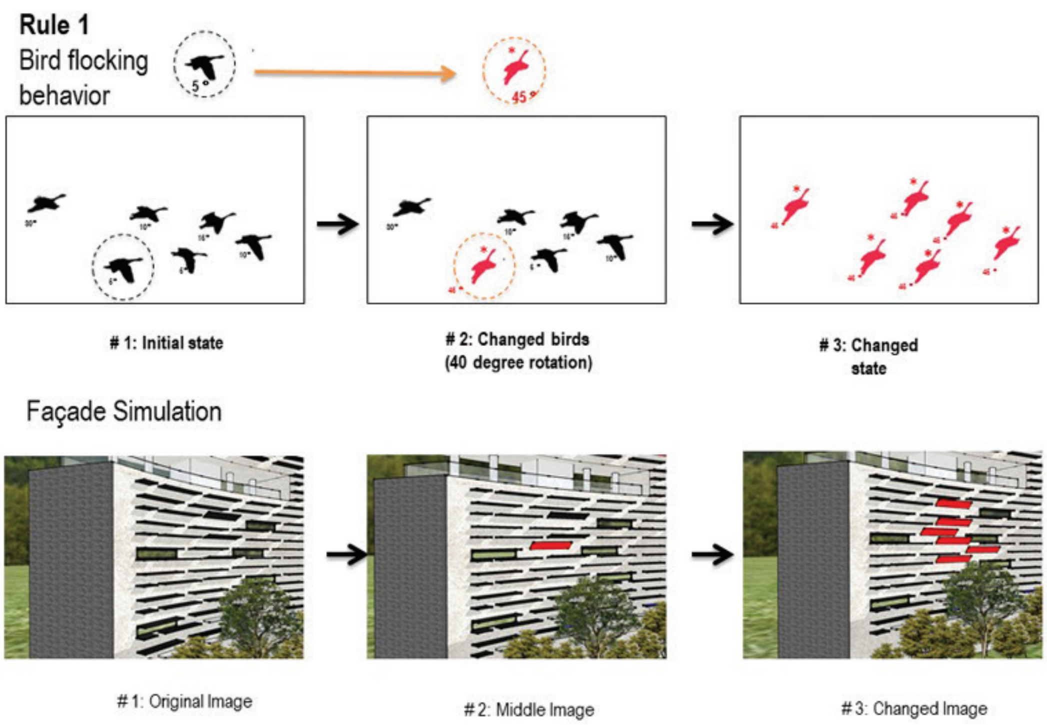


Figure 12. Façade simulation applied rule 1.

5.4. Discussion

In this study, we applied three biomimicry-inspired rules of behavior to a facade design. The method described here of applying the rules of bird behavior patterns to the case study building

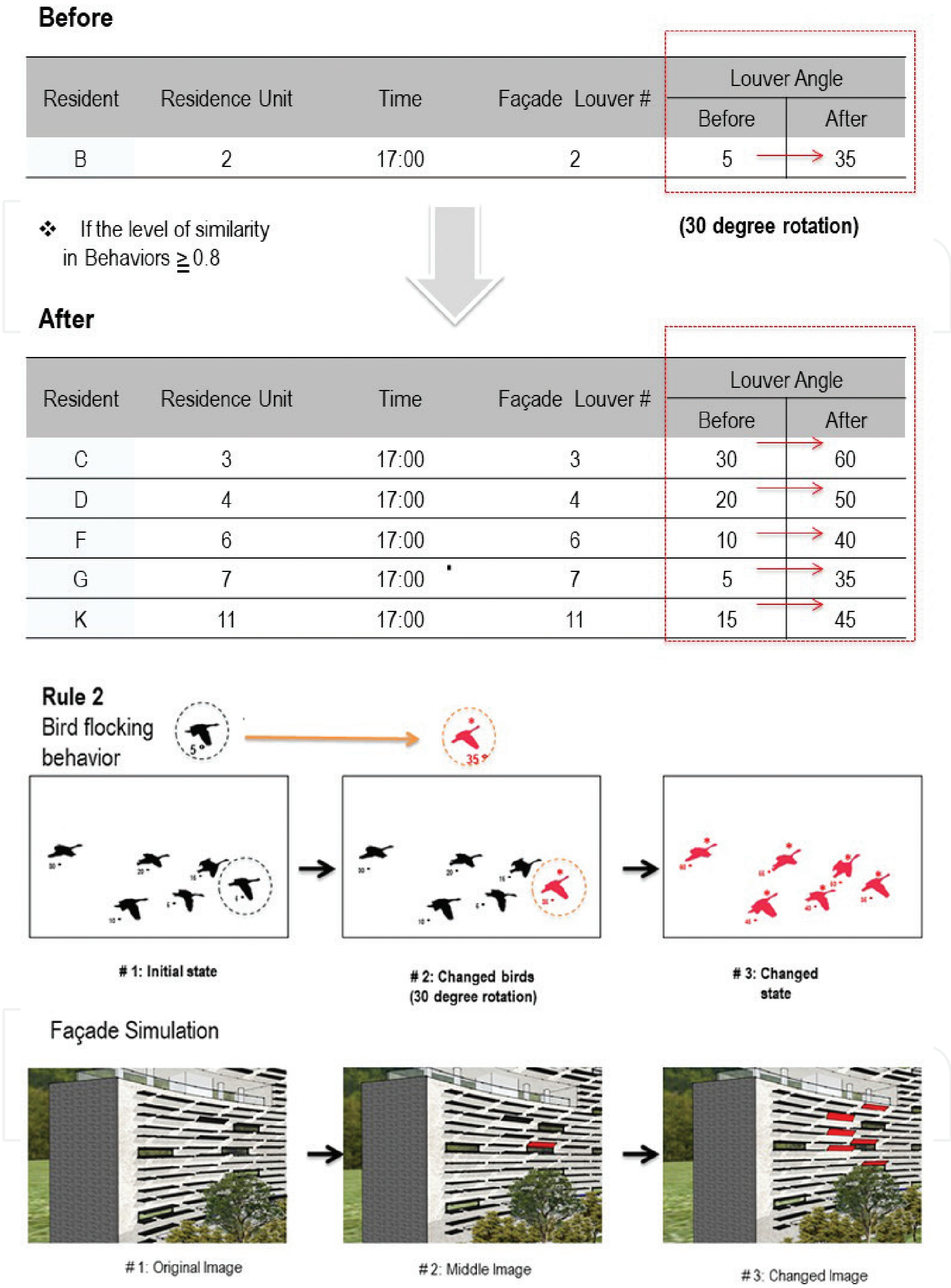


Figure 13. Façade simulation applied rule 2.

described here is surprisingly simple, indicating that it would be simple and straightforward to apply this method to the design of architectural facades. Significantly, the method also provides a starting point for one-to-one customized services based on lifestyle-driven rather than

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Before

Resident	Residence Unit	Time	Façade Louver #	Louver Angle	
				Before	After
A	1	18:00	1	20	80

❖ If the level of similarity in Behaviors =1.0

(Group 3)

User	Louver Angle	
	Before	After
A	20	80
D	10	35
H	5	45
J	30	60
(Group 3) Average		55

After

Resident	Residence Unit	Time	Façade Louver #	Louver Angle	
				Before	After
A	1	18:00	1	20	55
D	4	18:00	4	10	55
H	8	18:00	8	5	55
J	10	18:00	10	30	55

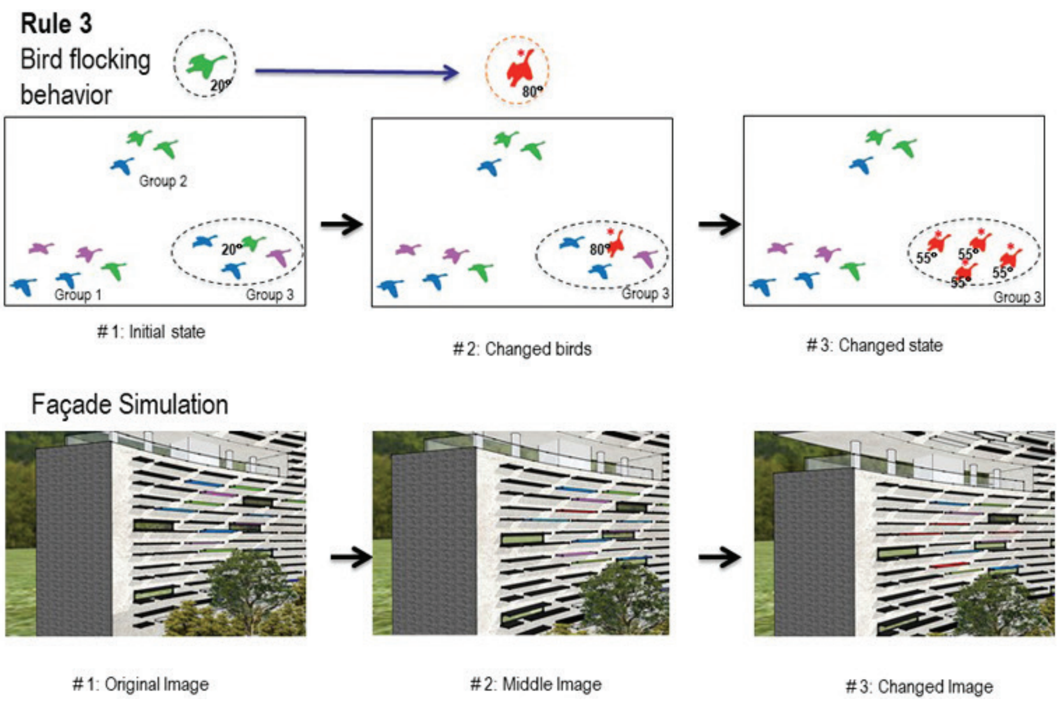

Figure 14. Façade simulation applied rule.

performance-driven controls. Performance-based controls can provide clear control baselines, but the problem is that the preference criteria for controls vary from resident to resident. One way to address this is through behavior-based control methods.

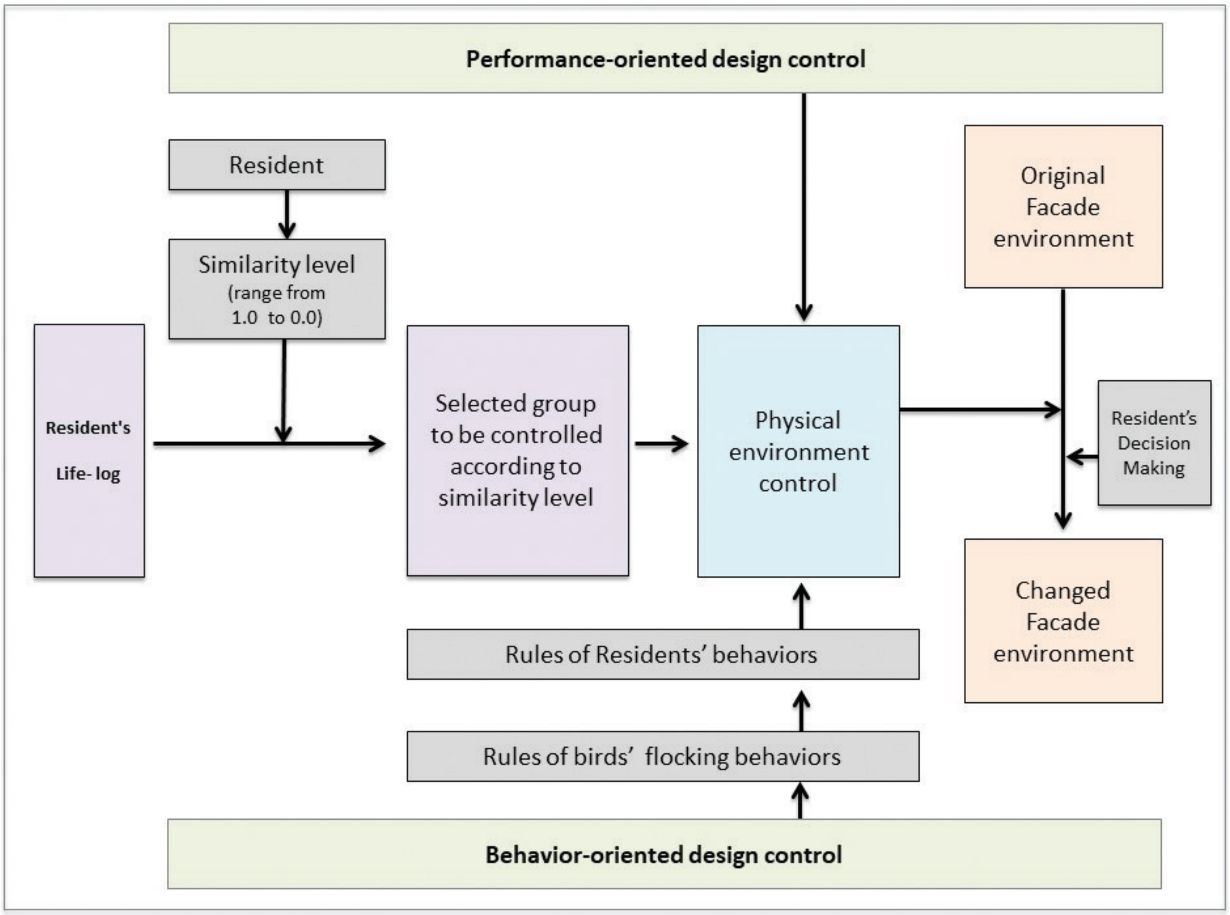

Figure 15. Hybrid control process of performance and behavior-based physical environment.

Above, we discussed the merits of biomimicry and also explained that biomimicry has a role in providing a source of design inspiration. The concept of biomimicry can take into account the form and function of any other natural organism. The present chapter focuses on the process of an adaptable façade design method for concept derivation, which still has practical limitations [9]. In the future research, more architectural sections and prototypes are needed to develop by adding more functional aspects. In other words, the development of intelligent façade louver controls requires a model that combines smart material and sensor technology rather than mechanical control. The ideal control process is a hybrid model that combines behavioral and performance bases, as shown in **Figure 15**.

6. Conclusion

6.1. Summary and contribution

This chapter focuses on adaptable architecture that responds to user behavior and the external environment, unlike previous studies on environmentally functional façades. In this regard, this chapter focuses on approaches to controlling façade functions based on user behavior and preference rather than a performance-based, functional control approach. The behavior-based method presented in this study provides an opportunity to increase the satisfaction of residents by providing each with individualized service. Of course, the behavior-based approach is not perfect. The ideal approach to façade control would be to integrate performance-based and behavior-based control methods more effectively.

The point of this chapter is not to mimic a bird's form but to apply principles of birds' behavior to an architectural façade. The contribution of this chapter is that it presents a façade louver control methodology based on an interpretation of birds' flight behavior from the perspective of facade louver control. In particular, this paper differs from the previous studies which has been focused on biological forms because it has viewed biomimicry in terms of biological processes and nature. Biomimetic design has great potential as a source of inspiration for innovative architectural design. A behavior-based approach, in particular, offers opportunities for users to increase their quality of life by meeting personalized needs.

6.2. Future research

In this study, a case study for the development of a façade design using biomimicry is presented. Although future research will propose an adaptable façade based on various façade types, this study limits itself to control of the façade louver angle. However, further research is needed to extend façade control to window opening and blind systems. Future research aimed at building a façade control system that considers the view of the interior from a user-centered rather than from an outside viewpoint is also needed.

Further research is also needed for further development of a hybrid façade that links performance and behavior. For instance, adaptable façades associated with ventilation, thermal insulation, and day lighting should be developed. Further studies on esthetic aspects of adaptable façades, including design algorithm patterns, composition, and design principles, should also be pursued. In addition, moving beyond planar façades, design methods for adaptable façades that fit curved forms must be developed. A study of adaptable façades that can be controlled by self-organism is also needed.

This chapter concludes that a good building should be able to respond flexibly to ever-changing environments. A bio-inspired adaptable façade is a solution with great potential for creating esthetically pleasing sustainable architecture with comfortable interior conditions.

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References

[1] Ball P. Follows your neighbour. In: Ball P, editor. Nature's Patterns. Oxford: Oxford University Press; 2009. pp. 124-159

[2] Beni G. From swarm intelligence to swarm robotics. In: SAB 2004 International Workshop on Swarm Robotics; July 17, 2005; Santa Monica. Berlin: Springer-Verlag; 2004. pp. 1-9

[3] Benyus JM. Biomimicry: Innovation Inspired by Nature. New York: Harper Collins Publishers; 2002

[4] Brownell B, Swackhamer M. Hypernatural: Architecture's New Relationship with Nature. New York: Princeton Architectural Press; 2015

[5] Caetano I, Leitão A. DrAFT: An algorithmic framework for facade design, generative design applications. Vol. 1. In: 34th CAADe; 2016; Oulu. pp. 465-474

[6] Capeluto G, Ochoa CE. Intelligent Envelopes for High-Performance Buildings: Design and Strategy. Switzerland: Springer; 2017. pp. 1-19

[7] Couzin ID, Krause J. Self-organization and collective behavior in vertebrates. Advances in the Study of Behavior. 2003;**32**:1-74

[8] Chen J, Huang S. Adaptive building facade optimization: An integrated green-BIM approach. In: 21st International Conference of the Association for Computer-Aided Architectural Design Research in Asia, CAADRIA; 2016; Hong Kong. pp. 259-268

[9] Fox M. Interactive Architecture: Adaptive World. New York: Princeton Architectural Press; 2016

[10] Fox M, Kemp M. Interactive Architecture. 1st ed. New York: Princeton Architectural press; 2009

[11] Gruber P. Biomimetics in Architecture: Architecture of Life and Buildings. Vienna: Ambra Verlag; 2010

[12] Harry S. Dynamic adaptive building envelopes: An innovative and state-of-the-art technology. Creative Space. 2016;**3**(2):167-183

[13] Helms M, Vattam SS, Goel AK. Biologically inspired design: Process and products. Design Studies. 2009;**30**:606-622

[14] Herzog T, Krippner R, Lang W. Facade Construct Manual. Basel: Boston, Birkhauser-Publishers for Architecture; 2004. pp. 36-47

[15] Kashani YA. Biomimetics and Architecture: An Exploration of Swarm Intelligence, Emergent Behaviour and Self-Organization. Saarbrucken: LAP Lambert Academic Publishing; 2012. pp. 57-70

[16] Kim E, Choi J. A case study on the environmental facade system using biomimicry. Proceedings of Conference of Architectural Institute of Korea. 2014;**34**(2):41-42

[17] Kolarevic B, Parlac V. Building Dynamics: Exploring Architecture of Change. London: Routledge; 2015

[18] Kotsopoulos SD, Casalegno F. Responsive architectures: Prototyping components and processes for the built environments of the late digital age, emerging experience in past, present and future of digital architecture. In: Proceedings of the 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia, CAADRIA; 2015; Hong Kong. pp. 335-344

[19] Lee H, Kim N. Biomimetic facade control inspired by bird flocking intelligence. In: Third International Conference of Biodigital Architecture & Genetics; 2017; Barcelona. pp. 38-49

[20] Lee H, Park S, Jung J. A study on developing a smart home service based on the behavior patterns of the elderly. Journal of the Architectural Institute of Korea Planning and Design. 2012;**28**(5):159-168

[21] Schmidt R, Austin S. Adaptable Architecture: Theory and Practice. London: Routledge; 2016

[22] Sjarifudin FU. Adaptive decorative building skin. In: 21st International Conference of the Association for Computer-Aided Architectural Design Research in Asia, CAADRIA; 2016; Hong Kong. pp. 425-434

[23] Pawlyn M. Biomimicry in Architecture. 2nd ed. Newcastle upon Tyne: Riba Publishing; 2016

[24] Pohl G, Nachtigall W. Biomimetics for Architecture & Design: Nature, Analogies, Technology. Cham: Springer; 2015

[25] Wu KY, Hao JH. Spark Wall: Control responsive environment by human behavior, emerging experience in past, present and future of digital architecture. In: Proceedings of the 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia, CAADRIA; Hong Kong. 2015

[26] Zeiny R. Biomimicry as a problem solving methodology in interior architecture. In: ASEAN Conference on Environment-Behaviour Studies; Bangkok. 2012. pp. 502-512

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