N. Gu, S. Watanabe, H. Erhan, M. Hank Haeusler, W. Huang, R. Sosa (eds.), *Rethinking Comprehensive Design: Speculative Counterculture, Proceedings of the 19th International Conference of the Association of Computer-Aided Architectural Design Research in Asia CAADRIA 2014*, 000–000. © 2014, The Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong

CONTROLLING KINETIC CLADDING COMPONENTS IN BUILDING FAÇADES: A CASE FOR AUTONOMOUS MOVEMENT

TATYANA PANKRATOV YEKUTIEL[1] and YASHA JACOB GROBMAN[2]
[1,2] *Faculty of Architecture and Town Planning, Technion – Israel Institute of Technology, Haifa, Israel*
[1] *tanyapankratov@gmail.com,* [2] *yasha@technion.ac.il*

Abstract. The movement of building façade cladding is usually used to control buildings' exposure to environmental conditions such as direct sunlight, noise and wind. Until recently, technology and cost constraints allowed for only limited types of façade cladding movement. One of the main restrictions stemmed from the limitations that architects face in designing and controlling movement scenarios in which each façade or cladding element moves autonomously. The introduction of parametric design tools for architectural design, combined with the advent of inexpensive sensor/actuator microcontrollers, made it possible to explore ways to overcome this limitation. Autonomous movement of building façade cladding elements has several potential benefits. One of the main feasible advantages of this type of movement is that it can deal with changing external and interior local conditions in different parts of the façade by individually controlled movement, by preceding reaction or flock behaviour. Thus, it can increase significantly the performance of the building façade.

This paper presents new results from an ongoing research study that is examining the potential of autonomous movement of façade cladding elements. It compares the environmental performance of centrally controlled kinetic façade elements and a prototypic façade made of autonomously controlled elements.

Keywords. Kinetic cladding components; responsiveness; interactive; decentralised control; Arduino.

1. Introduction

The proposed research examines the potential of developing an autonomous movement mechanism and control algorithm of building façade kinetic elements by employing a decentralised control approach. It is the second stage of an earlier study that reviewed the research on kinetic and interactive architecture (Fox, 2009; Kronenburg, 2007; Loonen, 2010; Moloney, 2011; Oosterhuis, 2002; Randl, 2008; Saggio, 2005; Zuk, 1970); defined types of autonomous movement strategies; compared the advantages of these strategies over those of traditional methods of centrally controlled movement; and developed design experiments with physical prototypes that examined the potential of the implementation of the suggested approach using state-of-the-practice technology (Grobman and Pankratov Yekutiel, 2013).

The current paper presents the results of the second stage of the research, which examined possible decentralised control and operation mechanisms and compared the efficiency of the two control methods in dealing with environmental conditions such as natural light distribution.

2. Controlled elements/mechanisms in building façades

The introduction of kinetic elements influencing the façade's performance can be achieved through two main approaches: the first influences the parameters of the openings of the façade itself, while the second influences the geometry of the façades or of an external cladding layer that is part of the façade. Over the last fifty years, numerous kinetic façade-cladding systems have been developed in accordance with each of these approaches. The control systems that actuate those kinetic façade mechanisms or systems can be differentiated into three main types, which also correspond to the evolution of these systems (detailed explanation of the types of control can be found in Grobman and Pankratov Yekutiel, 2013). The first type consists of elements that are actuated directly by a manual switch. The second type introduces an automatic reaction to information collected by sensors. The information from the sensors is used to actuate the kinetic cladding elements. This type, which makes up the majority of present-day kinetic façade cladding systems, relies on centralised control (CCFC), in which actuation is controlled through a central unit computer. The third type, which is the focus of this research, introduces the idea of autonomous or decentralised control over kinetic façade cladding (DCFC).

The idea of centralised control over kinetic façade elements is easy to understand. Decentralised control is more complex. It is based on the notion that each kinetic element in a building façade is activated and controlled by a single controller (a small, less costly and less powerful computer or microprocessor) and that these controllers are able to communicate with each other. Each independent element moves according to its local perception of the dynamic environment together with the interpretation of information that arrives from adjacent elements. Several recent projects could be seen as precedents of DCFC; examples include Media-TIC in Barcelona by Cloud 9 Architects (2010) and the project 'Shutters' designed by Marcelo Coelho. These projects mostly dealt with independent mechanical operation of the units, whereas the system under discussion here addresses the issues of control and graduation between autonomous movement based on direct response to environmental conditions and synchronised/monitored movement of the components.

3. Operating principles

The operating systems of kinetic cladding façades can be divided into three types: The first is traditional central control, similar to the systems in use today; the data is perceived by multiple sensors, then transferred to a single central processing device which compares perceived data according to a set algorithm and sends output orders to actuating devices – in this case, the actuation method will be the same for all the actuator units.

The second type consists of sensor-actuator devices, each of which is capable of autonomous data processing and actuation, as well as reciprocal information flow with the other sensor-actuator devices surrounding it. The data flow through an 'information hub' that enables a synchronised reaction while preserving the specificity in the reaction of each unit.

The third type is made up of multiple autonomous sensor-actuator units, each of which perceives and reacts to its immediate environment without direct input from the other units while still being influenced by them due to their impact on each unit's direct environment. This allows for greater redundancy within the system and the use of simpler and cheaper processors.

The following sections will focus on the implementation of the operating principles of the second and third types.

3.1. INFORMATION HUB – PRECEDING REACTION OR FLOCK BEHAVIOUR.

The actuation of elements before their sensor actually feels the change is based on information coming from the sensors of neighbouring façade cladding elements. The flock behaviour, or prediction, method operates through the following grouping principle (Figure 1):

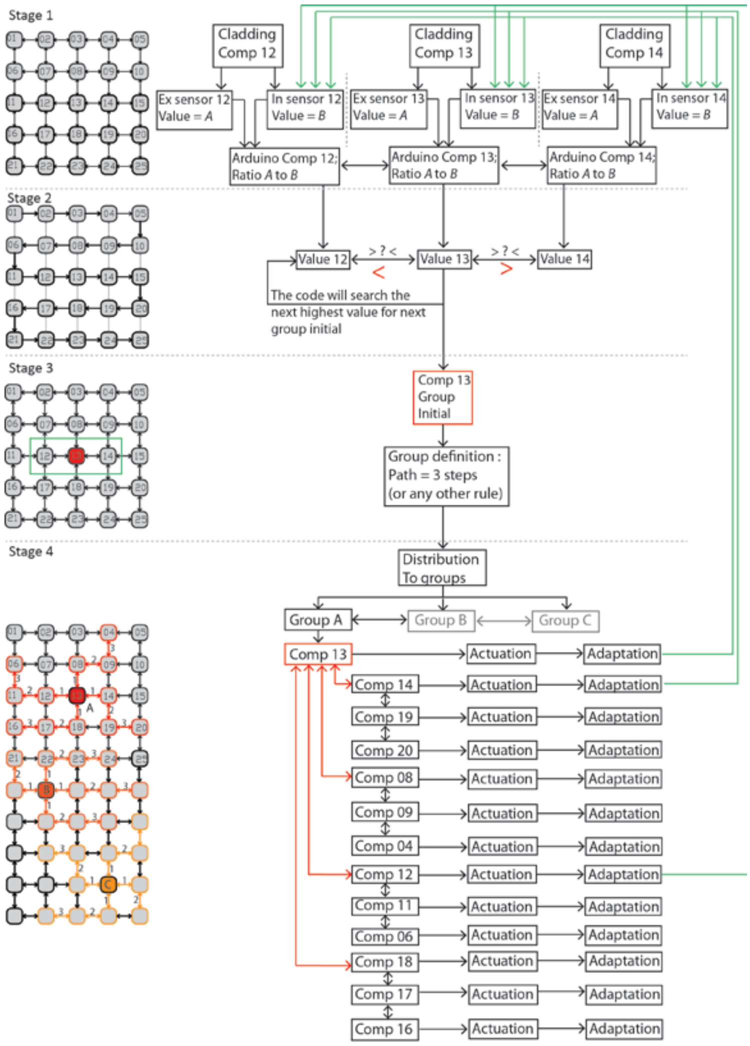


Figure 1. Preceding reaction or flock behaviour control diagram

- Stage 1: Multi-connection network – The building façade is divided into a grid according to the configuration of the cladding. Each cladding component is connected to two sensors: one exterior, which provides information about the exterior conditions; and one interior, which monitors the internal conditions. The data measured could include parameters such as temperature, light intensity (lux), wind speed, occupants' movement, etc. Each Arduino component is connected to four neighbouring components so that the evaluated data can be transferred from unit to unit in order to establish relations between the units. The first stage will include evaluation of the basic data from the sensors and establishment of the ratio between the exterior and the interior conditions of each unit.

- Stage 2: Data comparison – In this stage, the basic data received from the sensors are compared in order to define which of the units perceived the highest values received from the sensors. This identifies the focal points of the influence caused by the environmental conditions. This stage is necessary for the establishment of communication groups. In the following stage, these groups constitute the data distribution between the components. The group's initial point is determined by comparing the data received from the sensors. For example, when testing for lighting intensity, the code searches for and identifies the component that receives the highest value (lux), and this is defined as the initial component around which the group will be created. This scan is performed repeatedly until all of the system's components form groups.
- Stage 3: Group establishment – After identifying the focal points that are the initial components for group formation, the method of formation is determined. The grouping can be based upon various parameters such as area or route (that is, X components in radius Y from the initial component), or by the number of steps from the initial component. The steps method allows for higher spatial flexibility for the group's formation since it is not restricted by geometrical form.
- Stage 4: Information route – Each central component will have a reciprocal data flow through branches consisting of the other components within its group. Within each branch, the information between neighbouring components is processed and the processed data are then transferred to the central component. The groups' central components are interconnected and share information enabling a flow of information between all the system's units.

The information collected by each component is translated into actuation data, so that each component performs an individual adaptation, influenced by the information received from all the other components in the system. The degree to which each group of components is influenced by the system as a whole can be based on conditions that are suited to each scenario (based on the programmatic functionality of a given space). Therefore, a hierarchy could be established between the data received directly from the components' sensors and the data received from the neighbouring components.

The feedback loop established between the components is based on the physical adaptation of each unit as it responds to the collected environmental data and adapts to it. As a result, the measurement of the internal sensor changes and influences the ratio between the internal and external sensor, which sends new information through the information flow within the system.

This method could be highly advantageous in cases of multifunctional buildings that might require different kinds of envelope behaviour in different areas or function zones, for example, in conference rooms, banquet halls, libraries or offices. In such cases, the adaptation of the cladding components could be set within predetermined rules that adapt the components' range of motion to the specific requirements of the defined area.

The different areas would be interconnected through a central information pool in order to preserve the overall equilibrium of the system, so that if a certain amount of energy/electricity/wind flow is desired throughout the building, the system will be able to compensate one zone on behalf of another.

4. Design experiments

To examine the potential of the trajectories mentioned earlier, several design experiments were conducted. In these initial experiments, light was chosen as a performance criterion for the actuation of kinetic reaction. The first two experiments were conducted to examine the efficiency and suitability of the kinetic mechanisms and the possibility of activating decentralised control with Arduino.

The experiments relied on information from an investigation that mapped existing cladding methods and actuation mechanisms. Different types of mechanisms were analysed, including tensile, hydraulic, pantograph, rolling and sliding principles (Grobman and Pankratov Yekutiel, 2013).

4.1. PRELIMINARY DESIGN EXPERIMENT

The preliminary design experiments examined the feasibility of building operational physical models based on existing, state-of-the-practice technology such as Arduino hardware, and Rhino and Grasshopper software. Two mechanisms were examined: The first was based on a pantograph principle and the second was based on telescopic arches that were stabilised by a net of cables (for more details on these experiments, see Grobman and Pankratov Yekutiel, 2013).

4.2. DESIGN EXPERIMENT NO. 3: MULTIPLE COMPONENT PROTOTYPE.

The main purpose of this experiment was to compare the performance of DCFC vs. CCFC in controlling the interior light distribution within the model, as affected by various external conditions.

Constructed from whiteboard, the physical model was a scale model of a typical office space (3 by 3 by 5 meters, scale of 1:5) but the same principle can be applied to any scale or size. One of the model's surfaces was divided into nine kinetic units to represent the 'exterior' façade. The movement of the kinetic elements was based on a rolling mechanism and was actuated by servo motors. A sensor that perceives the external light was installed above each unit. Nine light sensors were placed on the interior side of the opposite surface (the 'interior façade') corresponding to each unit on the 'exterior façade' in order to measure the light distribution inside the model (Figure 2). The control method used was the second type of operation described in section 3, consisting of sensor-actuator devices (the flocking methods will be examined in future experiments).

The sensors were connected to an Arduino Microcontroller board, which performed a comparison between the external light measured and a pre-set value of the desired internal light distribution (in this case, 200 lux) and established the opening angle of each kinetic unit accordingly.

In CCFC operation, an average is derived from the values perceived in all the external sensors. This is compared to the desired value and then a unified opening angle of all the units is established and executed by the servo motors.

In DCFC operation, the data from each sensor are compared to the desired value and the opening angle is defined separately for each kinetic unit.

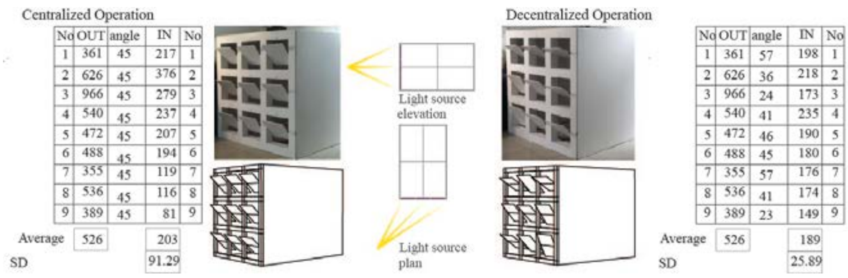
After the actuation process, the internal sensors perceive the values of light in each cell/room.

The two operation methods were compared in various scenarios based on different angles of illumination. It was also tested in a scenario that simulated a tree that shades parts of the building's exterior façade.

Figure 2. Construction of physical prototype.

5. Measurements and experiments

Measurement 1: Comparison of the light distribution. Light source frontal Y axis centralised to the façade, X axis tilted -45 degrees to the model façade (Figure 3)



Centralized Operation

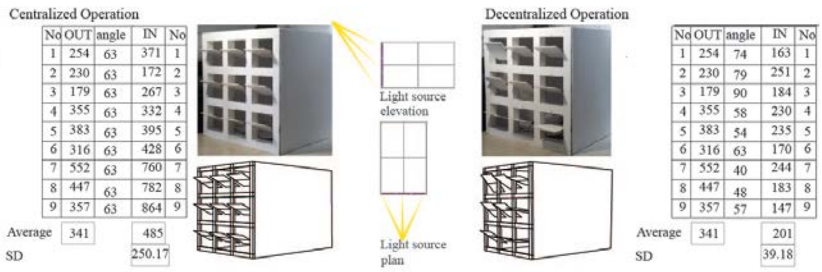
No	OUT	angle	IN	No
1	361	45	217	1
2	626	45	376	2
3	966	45	279	3
4	540	45	237	4
5	472	45	207	5
6	488	45	194	6
7	355	45	119	7
8	536	45	116	8
9	389	45	81	9
Average	526		203	
SD			91.29	

Decentralized Operation

No	OUT	angle	IN	No
1	361	57	198	1
2	626	36	218	2
3	966	24	173	3
4	540	41	235	4
5	472	46	190	5
6	488	45	180	6
7	355	57	176	7
8	536	41	174	8
9	389	23	149	9
Average	526		189	
SD			25.89	

Figure 3. Measurement 1.

Measurement 2: Comparison of the light distribution. Light source frontal Y axis tilted +45 degrees to the facade, X axis centralised to the model façade (Figure 4)



Centralized Operation

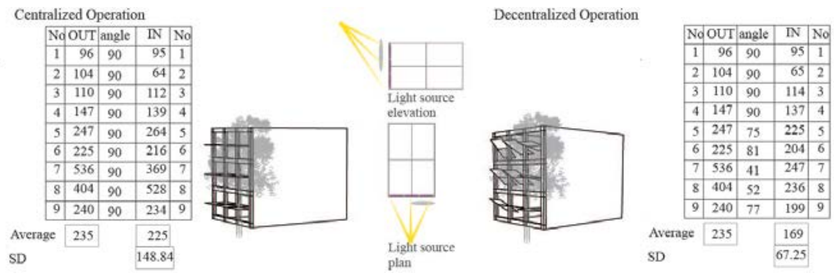
No	OUT	angle	IN	No
1	254	63	371	1
2	230	63	172	2
3	179	63	267	3
4	355	63	332	4
5	383	63	395	5
6	316	63	428	6
7	552	63	760	7
8	447	63	782	8
9	357	63	864	9
Average	341		485	
SD			250.17	

Decentralized Operation

No	OUT	angle	IN	No
1	254	74	163	1
2	230	79	251	2
3	179	90	184	3
4	355	58	230	4
5	383	54	235	5
6	316	63	170	6
7	552	40	244	7
8	447	48	183	8
9	357	57	147	9
Average	341		201	
SD			39.18	

Figure 4. Measurement 2.

Measurement 3: Comparison of the light distribution. Light source frontal Y axis tilted +45 degrees to the façade, X axis centralised to the model façade with shading element disturbance (Figure 5).



Centralized Operation

No	OUT	angle	IN	No
1	96	90	95	1
2	104	90	64	2
3	110	90	112	3
4	147	90	139	4
5	247	90	264	5
6	225	90	216	6
7	536	90	369	7
8	404	90	528	8
9	240	90	234	9
Average	235		225	
SD			148.84	

Decentralized Operation

No	OUT	angle	IN	No
1	96	90	95	1
2	104	90	65	2
3	110	90	114	3
4	147	90	137	4
5	247	75	225	5
6	225	81	204	6
7	536	41	247	7
8	404	52	236	8
9	240	77	199	9
Average	235		169	
SD			67.25	

Figure 5. Measurement 3.

5.1. RESULTS AND DISCUSSION

There are two important comparisons in the above measurements (Table 1). The first is the difference of the measured average from the desired set parameter. The second and the more important comparison is the variation between the values presided by the internal façade sensors. This variation is represented here by the standard deviation (SD). The smaller the SD, the more equally the light is distributed inside the model.

Table 1

	Average DCFC	Average CCFC	SD DCFC	SD CCFC
Measurement 1	203	189	91.29	25.89
Measurement 2	485	201	250.17	39.18
Measurement 3	225	169	148.84	67.25

Measurement 1: The results of this measurement show that, as expected, the average value read by the internal façade sensors in both cases is similar (CCFC – 203 lux vs. DCFC – 189 lux). However, the standard deviation values are significantly different (CCFC – 91.29 vs. DCFC – 25.89). This means that the light distribution inside the model was clearly more equal in the case of decentralised operation of the façade's kinetic shading elements.
Measurement 2: In this case, the differences were seen in the measurements of the average values (CCFC – 485 lux vs. DCFC – 201 lux). The standard deviation values also are significantly different (CCFC – 250.17 vs. DCFC – 39.18).
Measurement 3: This test introduced a shading element that cast shade on part of the external façade. The average value of the centralised operation was closer to the desired pre-set value of 200 centralised (CCFC – 225 lux vs. DCFC – 169 lux). However, the standard deviation values were again lower in the decentralised operation (CCFC – 148.84 vs. DCFC – 67.25). This might be because the shaded area could not be lit up to the desired value by natural light so the centrally operated system tried to compensate for it by opening the entire façade unit to its maximum, thus creating areas that were overlit as well as the shaded area which remained relatively dark. In the decentralised system, there was no attempt to compensate so the shaded areas remained dark, whereas the rest of the room received values closer to the desired value than those obtained in the centralised operation.

6. Conclusions and future research

The experiment we conducted examined the efficiency of the third type of decentralised system operation, which relates to an absolutely autonomous operation of the cladding components. The preliminary results imply that decentralised control over building façade cladding systems could deliver a better distribution of the natural light within a given space.

The next stage of this research will be to examine the second type of decentralised system operation, the information hub, which is expected to offer even better control of the building envelope and to allow a more flexible architectural design.

The methods that are being developed in this research may be applied and tested in the future also in relation to other environmental criteria such as ventilation, noise control and acoustic and visual exposure.

References

Fox M. and Kemp, M.: 2009, *Interactive architecture, 1st ed*., Princeton Architectural Press.

Grobman, Y.J. and Pankratov Yekutiel, T.: 2013, Autonomous movement of kinetic cladding components in building façades, *in* Chakrabarti, A., Prakash, R.V. (eds.), *ICoRD '13, Lecture Notes in Mechanical Engineering,* Springer India, 1051–1061.

Kronenburg, R.: 2007, *Flexible: Architecture that responds to change, 1st ed*., Laurence King Publishers.

Loonen, R.: 2010, *Climate adaptive building shells*, Faculty of Architecture, Building & Planning, Eindhoven University of Technology.

Moloney, J.: 2011, *Designing Kinetics for Architectural Facades: State Change, 1st ed*., Routledge.

Oosterhuis, K.: 2002, *Kas Oosterhuis: Programmable Architecture*, L'Arcaedizioni.

Randl, C.: 2008, *Revolving architecture: A history of buildings that rotate, swivel, and pivot, 1st ed.*, Princeton Architectural Press.

Saggio, A.: January 2005, Interactivity at the Centre of Avant Garde Architectural Research, *Architectural Design*, **75**(1), 23–29.

Zuk, W.: 1970, *Kinetic Architecture*, Van Nostrand Reinhold, New York.