Autonomous Movement of Kinetic Cladding Components in Building Facades

Yasha Jacob Grobman and Tatyana Pankratov Yekutiel

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Abstract Movement of building façade cladding is used to control buildings' exposure to environmental conditions such as direct sunlight, noise and wind. Until recently, technology and cost constraints allowed for limited instances of movement of facade cladding. One of the main restrictions had to do with 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 advent of inexpensive sensor/actuator microcontrollers, made it possible to explore ways to overcome this limitation. The paper presents an ongoing research that examines the potential of autonomous movement of façade cladding elements. It defines types of autonomous movement strategies and compares the advantages of these strategies over those of traditional methods of centrally controlled movement. Finally, it presents and discusses several case studies systems in which autonomous movement for building cladding elements is implemented.

Keywords Kinetic cladding components · Responsiveness · Interactive · Decentralized control · Arduino

Y. J. Grobman (✉) · T. P. Yekutiel
Architecture and Town Planning, Technion Isreali Institute of Technology, Haifa, Israel
e-mail: yasha@technion.ac.il

T. P. Yekutiel
e-mail: tanyapankratov@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_84, © Springer India 2013

1 Introduction

The notion of kinetic architecture can be traced back as far as the Roman Empire with legendary tales describing revolving rooms in Emperor Nero's palace [1]. Although the modern fascination with motion is associated with movements like Futurism in the early 20th century [2], research on kinetic architecture dates back to the 1960s [3]. From its earliest days, the research in this field encompassed a wide range of directions in various scales: plug-in cities by Archigram on an urban scale; the moving roof elements in Santiago Calatrava's Milwaukee Art Museum on a building scale; moving or folding walls in the Rietveld Schroder house or the moving office space in the OMA Bordeaux house on an interior design scale; moving structures as the Strandbeest by Theo Jansen or the Crate House by Alan Wexler on a furniture scale [4].

Starting from the early 1990s, when the immense implications of the information technology (IT) revolution in architectural design became evident, new types of computer-controlled movements in architectural design have emerged (mainly physical but also virtual). These new types were based on ideas such as interactive design and responsive environments [5–7].

One of the building industry's leading trends in both research and actual implementation is kinetic building facades, or more precisely, kinetic building cladding systems [8]. Indeed, the increasing focus on green architecture and especially on the environmental behavior of buildings has greatly increased the interest in high-performance facades. Until recently, technology and cost constraints allowed for only limited centrally controlled scenarios for movement of building facades or facade cladding. Centralized control over the facade elements limits the amount and type of movements they can perform to simple operations that are usually executed simultaneously by all the elements. The introduction of parametric design tools for architectural design, combined with advent of inexpensive sensor/actuator microcontrollers, makes it possible to examine different and more complex types of control over the building facade elements.

The following paper presents an ongoing research study that examines the potential of employing decentralized control of building facade kinetic elements. It begins with a brief discussion of the function of building facades and the types of kinetic movement of facade elements. It then looks at possible scenarios in which decentralized control could be employed. Finally, it presents and discusses two different case studies that examine a framework for decentralized control of cladding elements.

2 Controlled Elements/Mechanisms in Building Facades

Building facades have numerous distinct functions. Hutcheon [9] organized these functions into two groups with a total of 11 functional requirements. The first group consists of the items that relate to the facade as a barrier for the control of heat flow; air flow; water vapor flow; rain penetration; light, solar and other radiation; noise; and fire. The second group consists of overall requirements, such as providing strength and rigidity; being durable; being ecstatically pleasing; and being economical. Another aspect, which was not mentioned by Hutcheon and has become increasingly important, is visibility or visual exposure (both from inside outward and from outside inward) [10].

Introduction of kinetic elements influencing the facades performance may be done into main aspects; the first will influence the parameters of the openings of the facade itself. The second will influence the geometry of the facades or of an external cladding layer that is part of the facade. This research concentrates on the second group.

Numerous kinetic facade cladding systems have been developed in each of these aspects over the last 15 years. Loonen [11] presents in his thesis an overview of 100 different systems that control the performance of parameters from both groups. 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. The first type consists of elements that are actuated directly by a manual switch. In the second type, sensors are introduced. 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 centralized control, in which actuation is controlled through a central unit (computer).

The third type, which is the focus of this research, introduces the idea of decentralized control. The idea is based on the use of newly developed tools in parametric design, combined with sensor/actuator microcontrollers such as Arduino (an open-source single-board microcontroller, able to process signals passed by sensors to the microcontroller and translated through code into physical actions such as lighting or activating engines [12]). It refers to autonomous and direct actuation of kinetic facade elements by sensor/actuation units.

The following diagram describes the evolution of the types of control and the differences between them (Fig. 1).

3 Implications of Decentralized Control Over Building Elements

The idea of a centralized control over kinetic facade elements is easy to understand: It is meant to provide a single solution to a change in the basic conditions. For example, it is clear that once an environmental condition such as sunlight has changed, the control device must change the position of the cladding elements so that more or less light can penetrate the building.

Decentralized control is more complex. By definition, it’s meant to handle multiple conditions and generate various responses. It is based on local, cheap and

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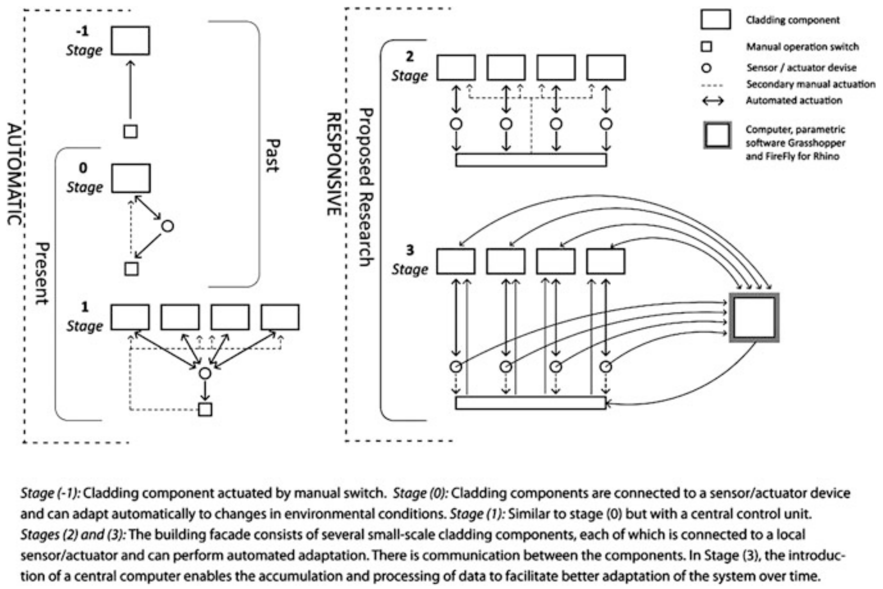

Fig. 1 Evolution of types of control over kinetic facade cladding elements

less powerful [than a central control computer (PC)] computers or microprocessors, which are connected to the kinetic elements.

The following advantages were identified to decentralized control in relation to traditional centralized control:

1. Efficiently—the possibility of insulated response to local environmental conditions emerging in a particular part of the façade. As opposed to traditional method where the adaptation can only be carried out by the whole facade
2. Redundancy—in multi connection system each component can substitute for its neighbor
3. Low cost—each component is relatively cheap and does not require high cost central operation system
4. Calculation time—the microprocessor located in each component will perform only the basic calculations and thus increase the efficiency of the system rather than performing the calculations of the data within the hole facade
5. Functional and compositional freedom.

The move form centralized control to decentralized control could be seen as three steps in terms of the relationships between the micro controllers and a central control unit. In the first level (centralized control) each cladding component is connected to a sensor devise and collects information about its immediate environmental conditions. The collected data from the entire facade is transferred to the main computer where the data processing takes place; as a result the facade will perform the necessary kinetic adaptation. The kinetic adaptation may be

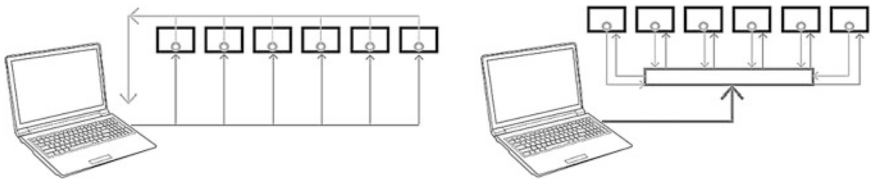

Fig. 2 Centralized control information flow (*left*). Decentralized control information flow through an "information hub" or a "bus systems" (*right*)

different for each cladding component but will be based on data processing in the main computer (see Fig. 2).

The second level preserves the data collecting principals of the previous level but disconnects the actuation process from the main computer and introduces an information hub or a "Bus system" for information navigation with in the facade. Each component will receive data from the environment and translate it to actuation. The information hub shares the information each unit has with all the units (Fig. 2).

The third level introduces the autonomous decentralized operation. Each component will receive data from the environmental conditions and data inputs from the neighboring components as well. The first evaluation will be done between the external and internal sensors of each unit, at the next stage the data from the neighboring component will be added as secondary input in order to preserve the systems equilibrium as whole. In this setting the components will influence each other and the kinetic adaptation of the facade will be performed by methods of flock behavior. The connection to the main computer in this case is not necessary and could serve as user interface for maintenance and occupants control device (Fig. 3).

Before developing a decentralized control mechanism for a cladding system, one must define scenarios in which this type of control could have potential either to handle situations that could not have been handled before or to introduce better results than those produced by the current method of centralized control. The following subsections presents trajectories that were identified as possessing this kind of potential.

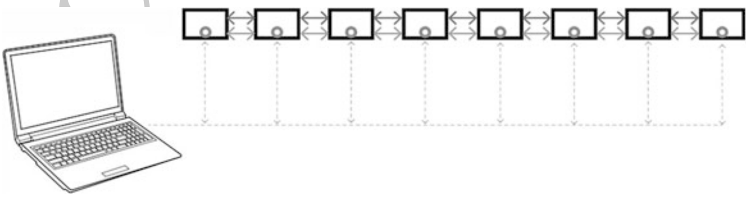

Fig. 3 Autonomous decentralized control information flow

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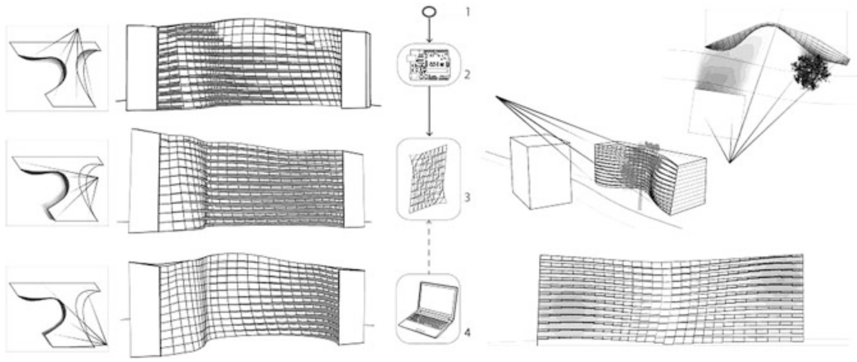

Fig. 4 Evolution of types of control over kinetic facade cladding elements

3.1 Handle Changing Local External Conditions

Partial shading by building, building elements or external elements—change the local position of kinetic shading elements according to the shade/reflection created by, inter alia, neighboring buildings, balconies and trees (see Fig. 4).

Visual exposure control—change the visual exposure of designated areas of a facade (see Fig. 5).

3.2 Handle Local Internal Changing Conditions

This possibility deals with internal changing conditions that require different facade settings, such as an increase in the number of people within a space that requires more natural ventilation, a change in the room's functions (see Fig. 6a, b).

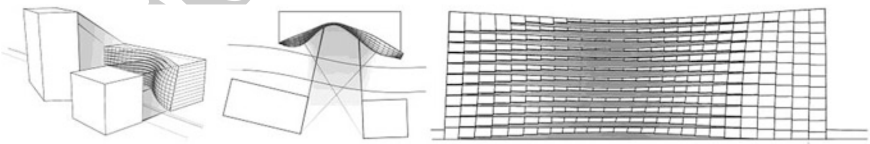

Fig. 5 The complexity of urban layout may cause undesirable privacy issues to building's occupants

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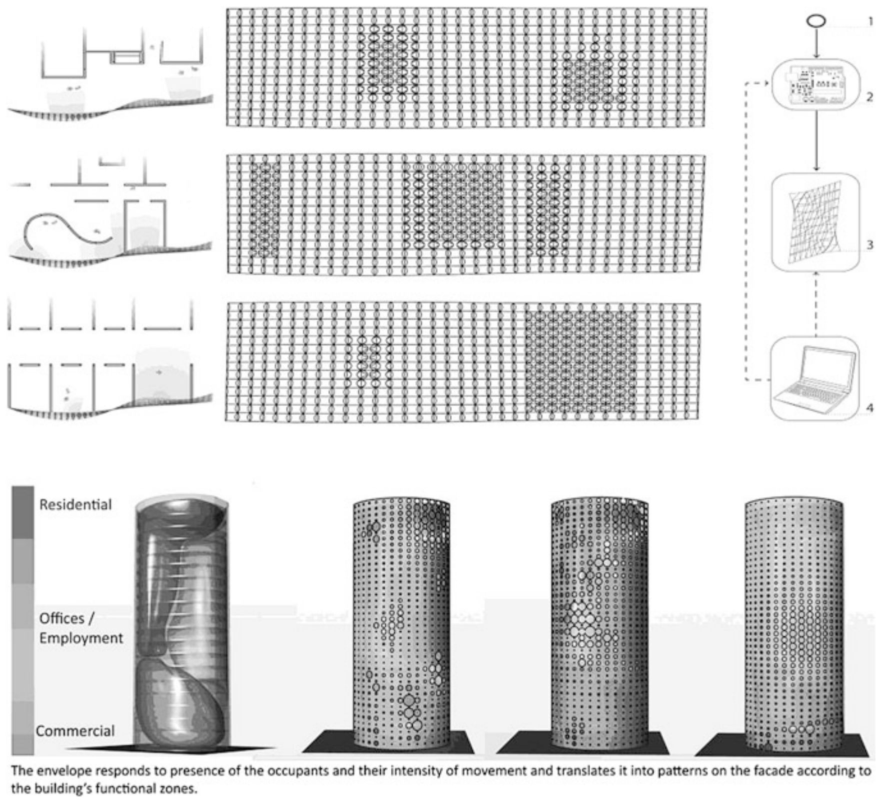

Fig. 6 **a** Programmatic flexibility. **b** Building's functional zones

3.3 Preceding Reaction or Flock Behavior

Actuating elements before their sensor feels the change based on information coming from the sensors of neighboring facade cladding elements (see Fig. 7).

4 Design Experiments

To examine the potential of the trajectories mentioned earlier, several design experiments were performed. In these initial experiments, light was chosen as a performance criterion for the actuation of the kinetic reaction The experiments' main aims, at this stage of the research, were to examine the efficiency and suitability of the kinetic mechanisms and the possibility of activating decentralized control with Arduino.

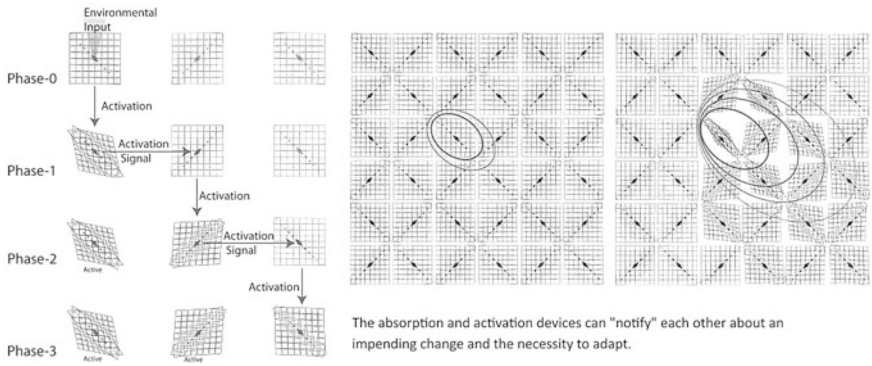

Fig. 7 Communication between the components

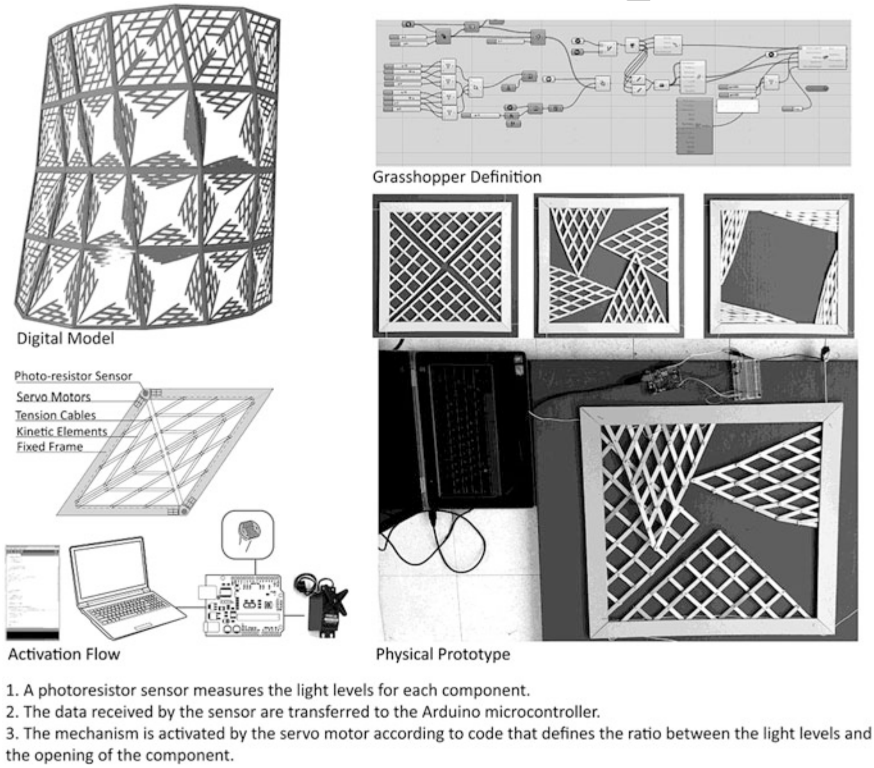

Fig. 8 Design experiment no. 1

4.1 Design Experiment No. 1: Cladding Component System Based on a Pantograph Principle

Based on a pantograph principal, the components' mechanism is able to fold and expand. The cladding components are divided into triangular elements connected to light-measuring sensors and servo motors, which operate the mechanism through a net of cables.

An algorithm (in Grasshopper for Rhino) connects between the components'geometry and the various parts of the kinetic mechanism. Each component can move both autonomously (activated by the sensor and controlled by the Arduino microprocessor) and via instruction from the main computer. A physical working example of this experiment was developed. The model is described in Fig. 8.

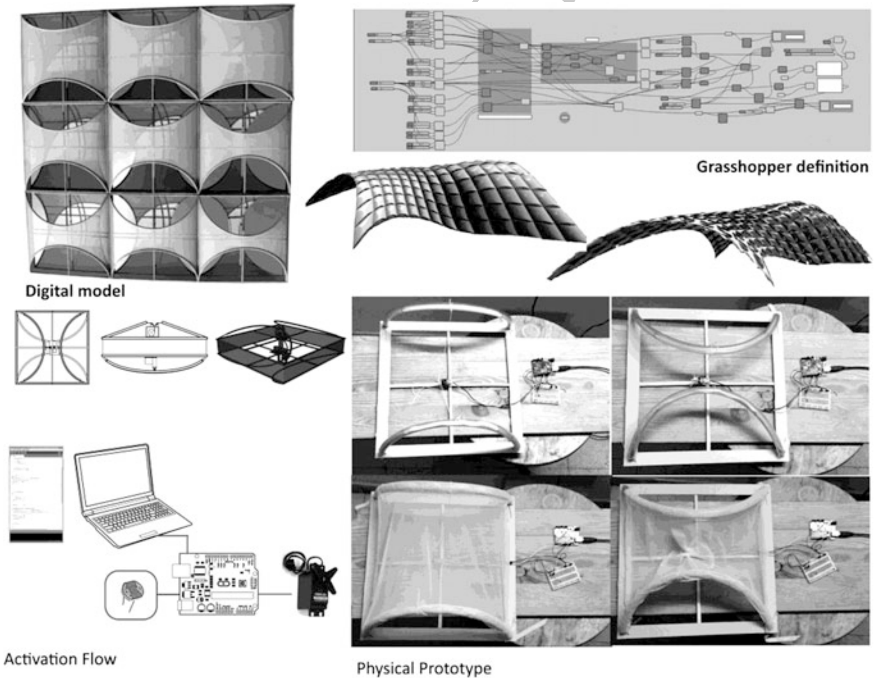

Fig. 9 Experiments no. 2

4.2 Design Experiment No. 2: Telescopic—Tension Components

The operating mechanism in this experiment combines two complementary principles. The main functional element consists of telescopic arches that are stabilized by a net of cables operated by servo motors. The main component has two perpendicular layers providing independent control over the different climatic parameters and allowing various degrees of shading and ventilation. The components' geometry is based on a rectangle and can be applied to facades that are based on quadrilateral geometry. The cladding movement is based on an algorithm (similar to the one in previous case study) and can vary in size and angles, making it suitable for application to complex geometry. A physical working model was developed for this experiment. The model is described in Fig. 9.

5 Conclusions and Future Research

Decentralized control over building facade cladding systems generates a new level of architectural complexity, one in which the designer cannot entirely control all of the design's architectural aspects [13] or to a certain extent needs to internalize how to allow the "human eye" to lose control over the design [14].

The design experiments and the preliminary research presented in this text are obviously only the initial steps of the research in this realm. Nevertheless, they seem to show both the plausibility and some unique possible capabilities of the proposed approach. The next stage of the research will concentrate on a comparative performance examination throw working prototype of various scenarios for decentralized control over kinetic cladding components in relation to traditional kinetic cladding systems.

References

1. Apollonio U (ed) (1973) Documents of 20th century art: futurist manifestos. Viking Press, New York, pp 19–24
2. Randl (2008) Revolving architecture: a history of buildings that rotate, swivel, and pivot, 1st edn. Princeton Architectural Press, New York
3. Zuk W (1970) Kinetic Architecture. Van Nostrand Reinhold, New York
4. Kronenburg R (2007) Flexible: architecture that responds to change, 1st edn. Laurence King Publishers, London
5. Kroner WM (1997) An intelligent and responsive architecture. Autom Constr 6(5–6):381–393
6. Fox M, Kemp M (2009) Interactive architecture, 1st edn. Princeton Architectural Press, New York
7. Oosterhuis K (2002) Kas oosterhuis: programmable architecture. L'Arcaedizioni, Milan

8. Moloney J (2011) Designing kinetics for architectural facades: state change, 1st edn. Routledge, Londan
9. Hutcheon N (1963) CBD-48 Requirements for exterior walls—IRC—NRC-CNRC. Can Build Dig 48
10. Shach-Pinsly D, Fisher-Gewirtzman D, Burt M (2011) Visual exposure and visual openness: an integrated approach and comparative evaluation. J Urban Des 16(2):233–256
11. Loonen R (2010) Climate adaptive building shells. Faculty of Architecture, Building and Planning. Eindhoven Univ Technol
12. Banzi M (2012) "Arduino tinkering," decoded conference. Available http://vimeo.com/24489835. Accessed 31 Mar 2012
13. Saggio A (2005) Interactivity at the centre of avant-garde architectural research. Architect Des 75(1):23–29 AQ2
14. Eisenman P (1992) Visions unfolding: architecture in the age of electronic media. Domus 734:17–21

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