USING PHYSICAL TESTING TO DESIGN AND EVALUATE THE ACCLIMATISATION OF KINETIC FAÇADES FOR DAYLIGHT AND THERMAL HEAT PERFORMANCE

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ABSTRACT

Successfully simulating building performance is a challenging task that requires the art of selecting the right type of virtual experiments with the right models and tools (Beaman and Bader 2010). Recent Computer-Aided Design (CAD) and Engineering tools allow architects and engineers to simulate different aspects of building performance such as thermal heat and lighting (Fernandez, Rubio, and Gonzalez 2013). This process includes evaluating the dynamic behaviors of kinetic façade systems. Although façades have historically been static systems, they are nevertheless designed to respond to many different scenarios. Often, façades need to perform contradictory functions such as allowing solar heat and light to enter the interior space as much as possible whilst regulating the glare and heat at certain periods. In evaluating the active mechanism and responsive elements of kinetic façade systems, it is necessary to simulate the performance and kinetic behaviors using physical models. This paper presents a new way to design kinetic façade through evaluating their performance.
ACCLIMATED KINETIC FAÇADE

Architectural design has always involved a culture of simulation and experiments. In the fifteenth century, Filippo Brunelleschi invented perspective drawings to simulate the visual perception of space. While in the eighteenth century France, Pierre Patte graphically mapped the propagation of sound in buildings (Loukissas 2012). However, in the nineteenth century Catalan architect Antoni Gaudi adopted a method called graphic statics to draw structural forces. It is evident, that for many centuries, geometry was the medium of simulation. By the twentieth century, numerical methods overtook graphical means in all these domains: lighting, acoustics and structures (Loukissas 2012).

Acclimated kinetic façade are designed to improve the quality of environmental of indoors spaces in buildings through active techniques. Although acclimated kinetic façade are not a newly discovered concept, it has not been widely applied to date. This research on acclimated kinetic façade focuses on shading devices or active brise-soleil that is responsive to changing environmental conditions.

Kinetic façade systems have received considerable attention for its concept. However, proposals on how kinetic façade should be designed and analysed to ensure its functionality and performance are still a developing area of research. While the proliferation of sensors and instrumentation technology, enable kinetic façade to be evaluated differently, the use of digital simulations and physical models to predict the performance of kinetic façade often produces different results.

In designing kinetic façade with multiple parameters, the use of design simulation to visualise achievable construction is complicated by the kinetic requirements (Moloney 2007). The degree and speed of translations and rotations in the physical world are constrained by both the geometry of the components and the mechanics of the kinetic systems.

Historically, practitioners have developed a variety of tools and techniques for sharing the idea and even the experience of buildings before they are built. In their simplest form, design simulations can be in the form of personal thought experiments and mental images (Loukissas 2012). Effective simulation tools for dynamic design or kinetic façade need to be conducted in the early design phase. This will help the designers to make predictions about the performance of the kinetic systems and assists bordering the knowledge to better inform the decision-making process.

In designing kinetic façade that deal with large-scale transformation of human environments: plan, sections, models, diagrams and other possible design medium; physical simulations are part of the evolving tool-kit that practitioners use to establish a site in which design can be tested before construction. The physical simulations exist between conception and construction, as well as between professional groups. However physical simulation can vary among groups such as through the tools used for exploration, verification, reflection or simply communication.

This paper will describe an attempt to perform physical simulation for evaluating the daylight and thermal heat performance of a kinetic façade in the early design phase. Furthermore, it will describe what can be gained from physical simulations as well as identifying the challenges that arise from adopting this type of investigation.

WHY PHYSICAL SIMULATIONS?

Why do kinetic façade need to use physical simulations to evaluate the environmental performance? Is physical simulation is just another name for physical testing? The short answer is no and they are not similar. While all physical simulation involves physical testing, the key difference is that physical simulation attempts to replicate real-worlds process on a laboratory scale in a way that the data can be used to solve real world problems (Groat and Groat 2013). For example, it is fairly easy to heat the façade’s surface to nominally uniform temperatures in a furnace, and then measure the deformation at a given temperature. This is a physical test and when performed properly, it should yield reproducible results representative of real boundary conditions.

However, if the architect’s goal is to understand the mechanism, microstructure and material behavior on the kinetic façade system, then more information is required. For example, anyone who has ever observed steel being rolled, will notice that the edges of the surface are darker than the middle of the surface, and the corners, where the edges meet, is darker still. That is because the edges and corners of the steel surface cool faster than its main body. As a result, the surface is not at a uniform temperature; instead, there are thermal gradients between warmer and cooler portions of the surface. This is an example of the steel being used as a frame or surface for the kinetic façade system.

The folding motion may be affected by this kind of phenomenon. Thermal gradients are present in every heating and cooling process and are part of almost every metal fabrication process. Research has clearly shown that thermal gradients affect ductil-
ity and workability of material especially in application to kinetic façade systems ("Dynamic Systems for Materials Research - What Is Physical Simulation?" 2014). Therefore, the architects will have to physically simulate these thermal gradients (and other factors as well) in order to gather meaningful information in the laboratory that can later be applied successfully to the design of kinetic façades.

Frequently, physical simulations must be performed in a series of steps. For example, one test to simulate the opening and closing behavior, another to replicate part of the edge, another to replicate a portion further in. The data can then be linked together to form an accurate predictive model that can be used to set the operating parameters for design of kinetic façade.

METHODODOLOGY

In this paper, the experiments are set up and investigated in two different strategies. The first part of investigation is aimed to explore the designing of kinetic façade prototypes. The second is to understand and to replicate the real world boundary conditions as much as possible. In this experiment, the time to setup the simulation is considered during the early stage. In this stage, effective decision-making is crucial, as it will affect the design and performance of the kinetic façade.

The first strategy is to define the location of the testing. The environmental conditions are defined and the simulations are for these specific conditions. In this investigation, the location proposed was in Melbourne, Australia. Further elaborations of the environmental condition are detailed in the physical simulation setup. The prototypes are designed and improved a couple of times based on the feedback obtained from the simulations.

EXPERIMENT SETUP: TESTING UNDER REAL BOUNDARY CONDITIONS

Physical models are design tools commonly used in the architectural creative process and reflect most of the aspects of daylight design (Figure 1). From schematic design to architectural project presentation, they play an important role in the decision-making process throughout the different development stages of a project. Architects also use scale models to evaluate the lighting environment within buildings (Thanachareonkit, Scartezzini, and Andersen 2005). Scale models are among the primary design tools used for daylight systems before their integration into a real building (Chauvel et al. 1985). Virtual models have recently become a universal design tool for architects and environmental researchers (Scartezzini et al. 1994c; International Energy Agency 1999); many validations of daylighting simulation programs have been carried out (Thanachareonkit, Scartezzini, and Andersen 2005). Daylighting researchers usually require detailed scale and virtual models for the assessment of daylight performance.

Prior to the prototyping and fabrication of the kinetic façades, the prototypes have been tested through digital model simulation using integrated software. This software includes Grasshopper, Ecotect and Galapagos, in order to configure the appropriate geometry and pattern for the kinetic façade that can effectively control the daylight during the day throughout the year (Sharaidin, Burry, and Salim 2012). The results from the simulations are further tested and evaluated using physical models.

Daylight, glare and visual transparency are the main parameters that are considered in this simulation (Figure 2). The triangulated parameters are negotiated between daylight and the façades transparency in response to daylight and thermal heat performance. The integration of computational tools and techniques such as parametric design, real-time simulation with environmental information mapping, using sensing and actuating systems with inbuilt control systems helps to evaluate the kinetic façade performance. Manufacturing physical models has created a strong background in order to understand kinetic façade design. Further explorations from this simulation are explored using physical models behavior.

PHYSICAL PROTOTYPE

A scale model was carefully constructed during the course of this study in order to simulate the daylight environment and properties of the test module. The model was constructed using mdf boards, polypropylene as the main surface, and nuts and bolts to join the components together. The façade’s elements were fixed using screws and glue. To avoid parasitic light, the joints were sealed with black tape. The surfaces for the façade were perforated in order to introduce transparency.

The façades are designed to create a concave and convex surface when closed. This strategy might help to trap heat under winter conditions. The color of the surface is tested using white and black, however in this simulation reflective black surfaces of polypropylene are used which can reflect heat and absorb heat at the same time. This strategy may be beneficial during winter and summer conditions.
The façades are adjustable and tested in three different states. The behavior of the opening and closing of the façade is based on the sliding motion. Several types of motions have been tested in previous experiments. Based on the observations and experiences of the writer in previous experiments (Sharadin, Burry, and Salim 2012), sliding motion has been selected to be tested further, due to the simplicity of the system. This performs well with the intended mechanism of the façade.

DAYLIGHT SIMULATION SETUP
The setup of the experiment includes five halogen lamps with 500W electrical power in a planar arrangement. For special application, the lamp can be rotated at different angles. These particular experiments are conducted for two different states involving a seventy-five degree angle in summer, and twenty-nine degree angle in winter. Different angles are setup one at a time to measure the effect of the kinetic façade in each case. The halogen lamps are positioned at 1.5 meters from the façade and the experimental setup includes five halogen lamps with 500W electrical power in a planar arrangement. For special application, the lamp can be rotated at different angles. These particular experiments are conducted for two different states involving a seventy-five degree angle in summer, and twenty-nine degree angle in winter. Different angles are setup one at a time to measure the effect of the kinetic façade in each case. 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The daylight and kinetic performance of the façade is clearly shown during the physical simulation of the kinetic façade system. By comparison, the mechanical problems are hardly visible in the early design stage in digital simulations. Hence, highlighting the importance of conducting a physical experiment in order to understand, evaluate the environmental performance, and develop the design of the kinetic façade. During this simulation, problems with friction of the mechanism are being identified that suggested improvements of the façade's design. Additionally, improving the mechanism of the system might also affect the environmental performance of the façade's system.

THERMAL HEAT SIMULATION SETUP

A simulation model is a virtual image of real physical phenomena and the simplification of reality is an inherent feature of models. In other words, a building has to be simplified in a suitable way in order to obtain a simulation model. For example, in the case of a large building with many similar rooms, a representation can be made via the selection of a small number of rooms. An examination regarding the potential overheating of a large building requires analysis of the internal and external heat gains of the different rooms in order to identify those that are potentially critical. These are selected for modeling and appropriate boundary conditions are defined. In this simulation, the boundary conditions are simplified in order to understand how the heat behaves in this specific area and surface.

Similar investigations are conducted in the thermal heat simulation. This experiment is part of the experimentation setup during the Thermal Reticulation cluster workshop in Smart Geometry 2013 (Burry et al. 2013). The cluster investigated heat transfer phenomena from one point to another on the building façade. The simulation is conducted to inform the designers of the performance of kinetic façade design in the early design stage.

The experimental environment for thermal heat simulation was reduced to 300mm x 300mm x 400mm box. This strategy also helped to reduce the complexity of the simulation setup and the number of pieces of equipment involved. The setup applied two different strategies. The first box is integrated with infrared imaging cameras located at the back of the box and in front of the box. This setup was to observe how heat transfers from one surface to another. A second box was set up using twenty-seven thermal sensors (as shown in Figure 5) located as a grid inside the box to visualise how the heat transfers into the space and how well the façade perform in regulating the thermal behavior of the space (Figure 5).
Setup for thermal heat simulation using twenty seven heat sensors and two thermal imaging camera conducted in smart geometry 2013, London (Burry et al. 2013).

The sample façade systems installed on the first box were analysed and evaluated based on how the heat was transferred across the surface into the interior space. This simulation is conducted using two thermal heat infrared cameras to see how the heat transfers from one surface to another. In this simulation, folded perforated kinetic façades are tested to see how well the façade performs in protecting the space from the artificial heat (Figure 6). A halogen lamp is used as a heat source for this simulation. The halogen lamp is positioned at a ninety-degree angle to get a uniform distribution of heat on the surface. The halogen lamp was turned on for fifteen minutes in every simulation. The images from the thermal camera were captured every 200 seconds to see the heat behavior changes on the surface of the façade. The images were recorded from in front (Figure 7) and inside the box (Figure 8).
Early observations demonstrate that the edge of the surface of the façade is heated up very quickly and the folded façade is not, therefore creating a uniform surface heat response. In the second simulation, the folded kinetic façade was tested to analyse its effectiveness in responding to the external heat and protect the space. Three states of the façade conditions were tested in this simulation (Figure 9). In this simulation, two moveable façades were installed as adjustable louvers to create a closing and opening behavior. As this simulation is an early attempt to simulate kinetic façade performance using heat sensors, the interactive system are not integrated with the façade behavior and the output from the sensors. There will be further investigations of the interactive systems.

The behaviors of the façade toward the thermal heat are visualised through Matlab software (Figure 10). The setup of physical testing was conducted during the workshop of smart geometry 2013 (Burry et al. 2013). The diagram (Figure 10) represents three different states of kinetic façades opening: fully open, semi-open and closed. The circular point represents the heat condition when the sensor detects the present of heat and changing the sizes. The larger the circle around the point (sensors), the higher the temperature being detected. These observations indicate the performance of the kinetic façades in response to various heat conditions. This setup was used repetitively to improve the performance of the façades. The flux of the data from the twenty-seven sensors, which were located in a grid, were observed and monitored through this visualisation (Burry et al. 2013).
During early observations, we can see the convection of hot air was transferred towards the back of the box very quickly. After the façades were fully opened, the façade was then quickly closed to measure how long the façade can store heat. These exercises are effective to visualise the façade performance and enables many design and test iterations in a short period of time to improve the façade’s performance.

The simulation setup can be improved in terms of accuracy, as some additional parameters can be taken into further consideration. For example, the temperatures inside and after the simulation can be measured and setup as a constant mode. Cooler spray can be used to lower the temperature inside the box in order to get the optimum result. In these experiments, the surrounding temperature outside the box might be effecting the measurement of the simulation. Conducting this simulation in thermal chamber will be more effective in maintaining a constant external boundary conditions and produce more accurate results.

CONCLUSION

In conclusion, physical simulation is a significant method to evaluate the performance of kinetic façades in the early design phase. The integration of physical testing in the simulation process can assist designer’s to better understand the performance of kinetic façades while complementing the digital simulation process. The outputs from the physical simulation in the early design stage are very intuitive for designers to understand the façade behavior and performance in response to the daylight conditions. The attempts to conduct physical simulation were successful in terms of evaluating the façade performance in the early design phase, as the physical simulation could highlight potential design issues, which may not be visible otherwise. However, in terms of accuracy and technical setup, this simulation can be improved by considering certain aspects in detail, such as the surrounding temperature, material properties used for the façade, and the insulation of the box and thermal sensor sensitivity. Conducting the physical simulation for the kinetic façade provides a more informed understanding on the performance and behavior of kinetic façade design. Physical testing can become increasingly robust and accurate when combined with digital simulation, therefore presenting the opportunity to investigate different kinds of behavior that are critical for the kinetic façades performance.

ACKNOWLEDGEMENTS

Part of this research work was conducted under the cluster with Thermal Reticulation team in Smart Geometry, 2013.

REFERENCES


IMAGE CREDITS


Figures 2-10. Image credits to Kamil Sharaidin (2014).

KAMIL SHARAIDIN is a PhD candidate at Spatial Information Architecture Laboratory (SIAL), RMIT University. His current research is investigating the evaluation of kinetic façades for environmental condition to improve building performance in architectural practice. He is investigating how the evaluation and analysis of kinetic façades in early design can help designers in making effective decisions in the early design stage. He also tutors at RMIT University.