Design Considerations for Adopting Kinetic Facades in Building Practice

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Abstract. Interactive architecture plays an increasingly important role in today's building practice. This includes design and implementation of kinetic facades. However, in the age of digital architecture, design and construction of kinetic facade has been under-explored and not well practically implemented. Hence, new design approach to integrate kinetic facade and architecture is needed for physical and content integration, instead of the traditional design approach. The ultimate objective of this study is to formulate a suitable design method to integrate kinesis with a building. Furthermore, this research aims to establish effective tectonics for kinetic facades through the exploration of different perspectives of practitioners involved directly with kinetic facades.

Keywords. Kinetic facades; building practice; design consideration; early design stages; practitioner.

INTRODUCTION
For the past few decades, there is increasing interest among architects and engineers in kinetic facades that adapt to the changing climatic conditions and building occupant needs. Kinetic facades are generally applied on high-rise buildings envelope. In recent practices, architects and engineers are strategically designing and installing kinetic facades not only for their aesthetic values but also to improve building energy performance. According to the designers of the TIC building in Barcelona and Al Bahr in Dubai, installation of kinetic façades employed multiple design strategies such as for energy performance, daylighting control and aesthetic. The high integration of these strategies for kinetic facades will increase durability and suitability of the facades with the current building demands, which targets for energy efficiency and thermal comfort level. Despite the popularity of kinetic facades in regulating buildings energy, architects have limited tools available to simulate the behaviour and performance of kinetic facades prior to construction. The energy efficiency of kinetic facades is rarely measured and evaluated until they are installed and become fully operational (Maloney, 2006). Difficulties occur in predicting the outcome of kinetic facades at the early design stage, especially with the combination of two or more design strategies for example for aesthetic or thermal control. Previously, traditional façade designs were evaluated based on basic usage of simulation tools, primarily for peak load estimates and thermal comfort. The performance of kinetic facades must be analysed using a range of diverse environmental conditions for better de-
sign outcome. The available tools may not be able to measure the energy load of façades embedded with moving mechanics, electronics and computers while running the calculations. Then, how can we evaluate the actual building energy performance of kinetic façades in today’s building practice? In previous investigation, the small-scale prototypes were developed in order to understand the behaviour and complexity dealing with kinetic façades. However, the researchers were aware that the results of the previous experiments are not representing an actual performance of the kinetic façades. Therefore, further investigations are extended into building practise which deal closely to kinetic façade to understand how the practitioner design and construct the kinetic façades. Surveys and interviews with five practitioners that working closely with kinetic façades design are conducted to gauge on what are the main considerations to create and develop effective design of kinetic façades to improve energy performance.

This paper examines design and implementation of kinetic façades in real-world practice from the early design stage up to the installation stage. In this paper, the authors will present the findings from the interviews and surveys. Results from the interviews will be used to analyse and identify key elements in constructing kinetic façades of the future. The key elements will be analysed and compared with the narratives of today’s successful and unsuccessful implementation of kinetic façades to improve building performance. This paper investigates the lessons learnt from the current practice in order to create effective kinetic façades for traditional curtain wall. This will serve as knowledge and references in designing kinetic façades from the initial design stage, which include design sketches, digital simulation and physical model experimentation, to the installation stage. The paper will also evaluate the effective methods in designing kinetic façades and propose a design framework for the designers to guide kinetic façade design, which is aimed for improving building performance.

**DESIGNING KINETIC FACADES FOR PERFORMANCE**

With this new architecture interest of designer and practitioner in kinetic façades, a new design problem is being confronted. The interviews were conducted in investigating the effective design of kinetic façade. How new approach to architectural design can be created when objects are conventionally static and responsive adaptability is typically unexplored? How kinetic façades design product from the early design stage can be effectively designed and generated? More specifically, how do architects or designers visualize, imagine, and design the interaction and kinesis of kinetic façades for suitable integration with buildings? And how the metamorphosis of kinetic façades is constructed through time and space?

While the practitioners have numerous techniques for improving the appearance of architectural forms, they are still lacking in design methods and considerations to create interaction and kinesis for model on feasible architectural façades in building practice. Due to rapid technology growth in building constructions, some architect have been trying to look for suitable design solutions to satisfy new variable conditions of kinetic façades. The challenge is shifting the design objective towards producing the whole system instead of a single object. A kinetic façade therefore has to be designed as integrated system with other architectural components.

Contemporary approaches to kinetic performance base design are fundamentally different from conventional CAD simulation processes. Traditional simulation tools depend on the ability to simulate and evaluate design performance as it has been defined at an appropriate and desired level of solution. Current technology generally are not capable of integrating design analysis which directly be informed by performance base simulations resulting in the simulations are not flexible enough to evaluate performance of kinetic façade behaviour. This study begins with investigating the interactive process toward s optimisation of kinetic façades performance whereby the façade profile and surface are modified
according to kinetic performance towards daylight.

The investigation will explore different states of kinetic facade to build design parameters such as interaction, display technology, and content that being practised by designers of 3 different buildings. Different design tools that were used for interaction between dynamic surfaces, may supply effective solution for complex behavior that are independent between the elements in kinetic facades.

Therefore, the ultimate purpose of this research is to explore this new and uncharted territory, by formulating a suitable design method for kinetic facades from the practitioner’s perspective. Moreover, this research contributes to providing the frameworks for designers in designing and aiding researchers in developing design tools for kinetic facades.

**INTERVIEW RESULT**

Interviews and surveys are conducted to investigate on what are considerations in constructing an effective kinetic facade. The main question asked is how do they design and predicted the performance of kinetic facades at early design stage using the available tools? What are the main considerations in designing effective kinetic facades?

[Figure1] shows various considerations of kinetic facades. These results are based on interviews and surveys conducted on engineers and architects of Al-Bahr in Abu Dhabi, TIC building in Barcelona and RMIT design hub in Melbourne. One of the important elements discussed during the interviews was the design support tool used at the early design stages. Most of them admitted that it was really hard
to predict the interaction between content, interactions and display kinetic facades at the early design stages. It is a common practice to evaluate the design using digital tools, yet the accuracy and result of the simulation was usually far from the actual performance. This is due to lack of proper tools and methods to evaluate and produce the interactivity of kinetic facades in real time data. Early findings from the interviews showed that digital tools, such as Energy Plus, Dynamic, DIVA, eQuest and Ecotect, are mostly used to simulate energy performance at the early design stages though they were aware the simulation results did not represent the real energy performance of actual building. Hence, assumptions were made using their experience and knowledge in order to predict and evaluate actual energy performance and its behaviour. Subsequently, improvements are made to meet the design intention and requirements. The process is extended for improvement by experimenting with physical prototypes, which are embedded with mechanics and electronics.

The process of evaluating and decision-making at the early design stages is essential to ensure kinetic facades are performing successfully. At this stage, kinetic façades may also expose to the risk of design misinterpretation the facades mechanism, materials and function may be compromised, and lead to inefficient building envelope. Hence, analysing the close results and data toward actual installation for designing kinetic façades at this stage is very crucial as it will affect the performance and the efficiency of kinetic facades in tackling certain problems.

The comparison in Figure 1 further explains on the most important factors considered by the engineers and architects in designing kinetic facades. From the comparison, structure, surface, material and understanding the way and the means of every elements of effective kinetic facades are the most significant considerations at the early design stage. Besides, the Figure shows that early design decision involved design system, materials, energy performance, construction method and consultant experience in determining the effective design which portrayed that there are still lacking in the tools used to evaluate the integration of these strategies in constructing kinetic facades. This outcome will be further explored in some of the experiments.

**EARLY DESIGN DECISIONS**

Design and evaluation of environmental and design strategies are becoming complex. This includes designing kinetic facades for energy performance. According to kinetic facades designer, in practice, such complexity arises from the rapid advance in technology, changing perception and demands of building owner, operators and tenants as well as the increasing importance of the building as a facilitator of human control, productivity and information interchange. One the challenge in the design process is to understand the interaction between various aspects of building performance and their implications for complex kinetic facades control systems. The over reliance in mechanical system to achieve the required levels of efficiency has also obscured the inherent performance implications of other critical kinetic facades design decisions at the early design stages. As a result, the decision on mechanical system and controls is frequently not integrated into kinetic facades design at the early design process and thought. In most practice, designing always begin with testing the preliminary design using the digital simulation tools. Then, the results from this simulation are further tested with small physical model and prototypes. However, due to complexity of different strategies, the kinetic façade performance cannot be evaluated in real time as the simulation tools to evaluate different strategies embedded within kinetic facades are limited.

For example, there was certain percentage of lighting condition that architects would like to achieve in the case of building Al-Bahr in Abu Dhabi. The architects used Ecotect to evaluate the heat gain from the solar radiation, which emphasises energy performance of the facades. However, as the early design evaluation was done through estimation, assumption, anticipation and prediction from the digi-
tal tools, the evaluations were not made integrated with the kinetic motion and behaviour in real time, resulting in non-performance after installation.

From the perspective of the architects, digital simulation tools can be quite accurate at times, however they are only good based on assumption and input at the beginning of early design evaluations. However, nature applications of the facades in building industry are more complex. Special cases like malfunctioning of component embedded with kinetic facades might happen when engineers/architects fail to anticipate and predict future problems which influenced decisions at the early design stages. Hence, there is a need to test the facades in actual scale on site as well in order to know the real performance of the kinetic facades. This is because one cannot rely on digital simulation only due to different variables requires by the architects. There must be a tool or method to verify the performance of the kinetic façade at the beginning for actual performance of an actual prototype on site. This is important in order to make decision to suite the design objective of installing kinetic facades. As in the case of Al-Bahr, the architects predicted that the result of digital simulation had to be increased 40 per cent toward the actual building performance based on their experience and lesson learnt. However, after further evaluation on site prototype, this percentage had to be reduced as the kinetic facades installed performed beyond the intention. In this scenario, accurate design simulation and prediction at the early design stage is crucial as this affect cost and performance of kinetic facades.

One of the evaluation approaches is looking on performance base design as a process of evaluation. Contemporary approaches to kinetic performance base design are fundamentally different from conventional CAD simulation processes. Traditional simulation tools depend on the ability to simulate and evaluate design performance as it has been defined at an appropriate and desired level of solution which do not suit with different integration design analysis which directly be informed by performance base simulations. Therefore, current simulations are not flexible to evaluate performance of kinetic façade behaviour. Some of this process of evaluation will be presented and further explained in this paper.

PROPOSED FRAMEWORKS FOR KINETIC FAÇADE DESIGN

One of the important processes of adopting kinetic facades is to understand what the facades can do and it significance to make it kinetic. This approach should be explored and studied through small physical model. This is important to understand not only on how does it behaves in responding to environment yet also to identify whether the idea and concept work efficiently as it involve different level of complexity. This integration of dynamic skin, structure and actuator through early small physical model give understanding to the design and problems arise at the beginning of design development. The paper suggests pre-evaluation and exploration with physical models due to inability of digital simulation to expose similar issues and problems dealing with kinetic facades. In this evaluation, few factors in designing kinetic facades such as modular system, decentralise and local system, flexible surface and structure and lightweight structure can be well understood.

Through this process, further evaluation of kinetic concept is translated to model using the parametric tools to evaluate on performance and impact of the concept and behaviour of facades in respond to real environment. This task can be evaluated through different integration of form finding software, parametric models and environmental analysis tools. This evaluation is important to provide idea to designers on the performance of the facades.

Small-scale models and actual human scale prototype have different processes of evaluation. This is due to the level of complexity are totally different between working with small-scale model and hu-
man scale models. On human scale prototype, more issues and problems are exposed in realising the kinetic behaviours. The main issue is problems dealing with mechanical behaviour and overall system to work effectively. This process may change some of the design elements in making them working appropriately.

The final stage of this process is to evaluate on the performance of this human scale model on responding to actual environment. This evaluation is important before the design can be proceed to the next stage of development. Evaluation will be conducted using sensor and actuator for data gathering to understand the performance of these prototypes. Some of the processes are presented in this paper as whole development of this research area.

**DYNAMIC BEHAVIOUR**

For kinetic facades, the major factors in producing effective design are mechanising and kinetic solutions. Good understanding of kinematic, movement simulation, reliability and durability are the keys to successful implementation of kinetic facades in buildings. These elements are agreed by most of the architects and engineers when dealing with kinetic facades. Similarly, selection of behaviour and right actuator or motors of kinetic facades and what the devices can do and perform are vital as the understanding will influence the intended performance of the facades. Selection of joints, materials; stain steel, fabric for kinetic design requires good understanding and knowledge in this field to make it successful. Usually, architects do not have this information and understanding on the element of this component, which lead to inaccuracy of prediction in kinetic facades. The evaluation at the early design stages will be an advantage to the designer if the physical simulation and digital simulation can be integrated in real time. This will give good understanding on how every component in kinetic design work. Moreover, the respond from the interviews also stated that, it is important to consider on how to do effective simulation through computerization of the kinetic facades. In designing kinetic façade, the designer should be able to evaluate the process of designing kinetic facade at bigger picture to predict what are the design problems and difficulties that might obstruct the performance of kinetic facades. An effective kinetic façade is always associated with well prediction of cost or available technology. It may not necessarily the architect task to ensure the effectiveness, yet others who involved closely with the architects should be able to share the knowledge and experiences.

**DYNAMIC MATERIALS**

Kinetic facades can be fully integrated by considering the kinetic element as part of architectural design. These kinetic façades are characterized as distribution, continuity and modularity by way of form (McCullough, 2005). With this categorization, architects should design and develop new architectural material with kinetics from the early design stage. The understanding of material and behaviour is significant in ensuring effective design. However, architects are generally inexperienced in designing kinetic material and behaviour, as they are more knowledgeable in inventing static aesthetic patterns. Based on the response from the interviews, most of the engineers agreed that without any knowledge of basic kinetic mechanisms, it is not easy for them to create aesthetic kinetic material, since they have not been trained in the necessary principles of movement. The evaluation at the early design stage is also crucial. For example, the dynamic material such as ETFE always has different results and outcomes when compared with different scale and form. Thus, architects needs to extend their scope of expertise and understanding when creating kinetic facades. Otherwise, the role of architects and engineers will be unclear and overlapping when working with kinetic façade systems. The integration of evaluations between different variables are clearly important at the early design stages to create better communication between architects and engineers.
PERFORMANCE BASE DESIGN

In conventional façade design models, evaluations provide feedback for repetitive design modifications. However, future directions for façade performance-based design can provide digital model that couple with different performance strategies on façade generation principles. In the context of digital tools, generative processes controlled by analytical and numeric findings that can automatically modified the model. Performance-based façade design is defined as the ability to directly manipulate the geometric properties of digital model on the basis of performance analysis to optimize performance. Instead of analysing the performance of a design, and modifying them accordingly, it may be possible to directly inform, generate and modify the design model using performance-based simulations tools.

In this case, works of kinetic facades that related with environmental performance simulations are adapted in parallel with modelling and parametric design to find optimum performance.

Many available façade designs associated with digital architecture reflect new consideration of performance-based design. Kinetic facades design is one of the examples on how this method is adapted in evaluating the facades performance. Some of the examples of recent project that had incorporated this simulation method are Aedas, Headquater in Abu Dhabi (2012) and the TIC building in Barcelona.

One of the fundamental ingredients in realising the advancement of kinetic façade system in these buildings is the existence of parametric modelling systems. Integrating geometry in parametric design enabled the establishment of façade schema to be flexible by creating dependency on geometric model element to control the transformation behaviour whilst maintaining the topological characteristic. This study will begin by investigating the interactive
process towards optimising kinetic facades performance. In this study façade profile and surface are modified according to kinetic performance towards daylight.

**SIMULATION AS A GENERATIVE DESIGN TOOL FOR KINETIC FAÇADE CLOSURE**

In this paper, simulation tools in digital environments are tested, evaluated and modified for physical prototypes in virtual environments. This enables rapid design feedback and support design modification processes (Figure 3). This process is based on human centric, design oriented approach in which architects/engineers will evaluate the simulation results and modify the design accordingly. The aim of the design experiment presented was to test the outcome from the interviews on how the design could be generated as an integral part of simulation evaluation. This includes identifying different alteration in respond to real time feedback from the simulation tools. Some pattern and form of kinetic facades are generated for further evaluation process as shown in Figure 4.

**IMPLEMENTATION**

Designers usually seek to create interaction when working with kinetic facades. Hence, they compose different scenarios according to the degree of user engagement and environments. This can be decided by a passive or active system for the kinetic facades. From this, the designer can select suitable input devices for their design solution. In implementing kinetic facades, the data from the selected input device can be remotely or locally collected depending on the location of input devices. Parameters in “interaction” have both a functional goal and aesthetic goal: intelligence and visualization. The data is controlled by their degree of intelligence: linear, single loop and multi-loop. The multi-loop system as a learning system can suggest new possibilities to establish a meaningful dialogue between user and environment. This behaviour is important to be implemented in early design decision.

Furthermore, visualizing data with motion properties such as sped and controlling electronic and mechanical movements represents abstract and concrete directions. The primary parameter in “display” is “physicality”, which refers to the degree of physicality in the composition of the kinetic facades. This concerns on whether architects use electronic components or mechanical components for their design. The mechanical components have properties such as linear rotational, sliding, retractable, elastic and radial motion for their kinesis, while electronic components have properties such as colour and light for their motion. Theses component have parameters such as granularity, which refer to their size, and continuity, which means they are continuously arranged for their shape and form. According to the respondents from the interview, this information and understanding should be made viable to the designer of kinetic facades as early as possible in design stage.

**CONCLUSION AND FUTURE WORK**

A common goal of kinetic facades in building practice is to integrate effective design, information technology and architecture at the same time. It is impossible for the designer and architect to ignore the design components mechanical behaviour, material and motions of kinetic facades as part of architectural design. The simplicity and the intelligent behavioural system application is the key to successful and effective kinetic facades design. Making the right decision and choosing the right techniques is significant in developing kinetic façades that serve the design objective. Understanding the basic principles of kinetic design and material will help to create effective kinetic facades. Therefore, designers need to consider architectural design elements in parallel with kinetic and motion, beyond simple adding electronic or mechanical devices to their design. Designing such systems is not inventing, but appreciating and marshalling the existing technology and extrapolating them to suit architectural vision. To a great extent, the success of creating intelligent kinetic systems in architecture will be
predicated upon the real-world test-bed. Application must consider the capability for such systems to yield real world benefits. Actual construction and operation will allow designers to develop realistic consideration of human and environmental conditions, and to overcome simplified assumptions on effective kinetic façade system. The outcome of these interviews will be further explored in digital and physical prototypes. Evaluations in one to one scale prototype will be compared with digital simulation to verify the respond gained from these surveys and interviews.

REFERENCES