Integration of Digital Simulation Tools With Parametric Designs to Evaluate Kinetic Façades for Daylight Performance

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Abstract. *This research presents a solution for evaluation of kinetic façades system performance via experiences and lessons learnt from experiments. We bridge between architects and engineers to address limitations associated with incorporating performance criteria in the design of kinetic façades by integrating different simulation tools. The experiments focus on optimization of the daylight performance through the design and motion of kinetic façades using various integrated software. The research is developed using real time data feedback processed through various digital tools from three domains: (1) Architectural design, (2) day-lighting performance and (3) parametric design computation. From the evaluations, the paper demonstrates the analysis of kinetic motion for daylight optimization at the early design stage and suggests possible configurations for daylight performance.*
Keywords. *Kinetic façades; digital simulations; design considerations; early design stage.*

BACKGROUND

Successful simulation of building performance is a challenging task and has been phrased as the art of performing the right type of virtual experiment with the right model and tool (Augenbroe, 2010). Recent computer-aided design and engineering (CAD) tools allow architects and engineers to simulate many different aspects of building performance such as energy and lighting (Leighton, 2010). This process includes evaluation of kinetic façades system, which involve dynamic behaviour. Although façades have historically been static systems, they are nevertheless designed to respond to many different scenarios. Often, façades are needed to perform functions that are contradictory to each other in order to control the indoor environment. For instance, they are used to allow solar heat to enter as much as possible, whilst keeping out the glare and heat at certain periods of time, protecting the building and allowing the building occupant to have a visual connection with the outside environment. They balance different functions throughout the life of the building.

By actuating the façades and making them more dynamically responsive to the environment, they can now better adapt to the different conditions and improve occupant comfort by providing a higher level of building performance. Dynamic actuation reduces the compromises needed in the design of the trade-off process to balance daylight in the space. Hence, one of the minor scopes of this research is to explore the evaluation of this idea using computer simulation and empirical testing of selected kinetic motions that can be adapted for

Figure 1
Traditional simulation method (left) and dynamic performance method.

environmental benefits. These can be compared to each other and recommendations can be proposed from the outcomes.

DESIGN PROBLEM

The problem with existing environmental simulation tools is that they were designed for static building elements. For example, material properties such as thermal conductivity, solar factors or daylight transmission are assumed as a constant in these tools, not a variable. Traditional simulation tools are based on static design, primarily suggesting solutions for peak load estimates. However, in evaluating dynamic building performance, kinetic systems must be analysed under a range of diverse conditions for proper system sizing. (Selkowitz, 2003). Figure 1 shows the differences between traditional façade design and kinetic façade design. The evaluation process for kinetic façades has integrated a few variables, which are simulated together in real-time.

The most promising tools for the simulation at present is called Control Virtual Test Bed, an open source software platform that integrates several building energy and control tools such as *Energy plus, TRNSYS, ESP-r, Radiance, Modelica, Fluent, MATLAB, Eco-Tect* and others. Some of the environmental tools are tested and presented in this paper.

It remains of paramount importance to develop adequate building performance simulation tools as there is a great demand for effective tools and instruments that can be used in the design process of kinetic façades (Loonel, 2010). Some evaluations and observations will be recorded in this paper. The simulation process will allow us to choose the right design among several options; to understand how kinetic façade systems work in relation to the whole building; to explore design possibilities and variations; to identify constraints; to build consensus with other specialists; and to predict the final performance in the early design stage (Fernandaz, 2012). These computational simulation tools are still largely unexplored. This is one of the reasons why responsive building envelopes are not yet a mainstream concept in the building industry.

SIMULATION OBJECTIVE

Simulation projects usually originate from the queries about real world systems evaluation, which in this case is kinetic façade concept design. This is to give some ideas on the performance of kinetic façades in responding to the environment. In this process, before the performance of these objects can be predicted, the systems first need to be translated into conceptual models. A conceptual model is defined as “a non-software specific description of a computer simulation model, describing the objective, inputs, output, content, assumptions and simplification of the model” (Robinson, 2008). Modelling and simulation by definition implies ‘approximation’, introduced in the abstraction process by means of assumptions. Assumptions are ways of incorporating uncertainties and beliefs about the real world into the model (Robinson, 2008). In this way, it deals with randomness and unknowns about the system, conditioning these trials to obtain reliable outcomes. It should be noted here that it is not a model itself, but the model of the model’s results should be close to reality (Leighton, 2000). For this reason conceptual kinetic façades models are presented in critical evaluation with the right level of detail relationships to predict actual behaviour with sufficient accuracy for the early design stage. This result suggests a possible design process for kinetic façades.

However, designers are often unable to leverage simulation tools during the design process due to the difficulties of setting up. Effective simulation tools must be set up to complete a design cycle involving accurate analysis by integrating different variables and running in real time. One of the issues is difficulties in evaluating different variables together in real time interactions. This is important due to the fact that (i) unexpected events can take place, (ii) decisions have to be made in real-time, and (iii) future conditions are highly uncertain which make the control process even more complex. This requires thoughtful control strategies, which take all the interrelated aspects above into account. When one succeeds, it perhaps leads to an elegant conceptual idea for both energy and occupant comfort that the designer can use at the early design stage.

Kinetic façades are inherently complex systems, consisting of interrelated components that are working across various physical domains. All components have to deal with trade-offs and resolve conflictive performance objectives in real-time. For these reasons, traditional design methods are likely deemed inappropriate and it will no longer be effective to rely on past experiences or rules of thumb. In order to obtain adequate kinetic façades design, all the functional requirements need to be considered and satisfied simultaneously. As the requirements are strongly interrelated and sometimes even conflicting, this is not always a simple task (Rivard et al., 1995).

Moreover, another advantage of conducting this simulation is that the software tools create virtual building models which can be used to predict building performance for the following purposes: choose correctly, understand why, explore possibilities, diagnose problems, identify constraints, develop understanding, build consensus, etc (Sokolowski and Banks, 2009).

This paper presents an algorithmic and parametric design process developed in *Rhino/Grasshopper, Galapagos* as form finding tools and *Ecotect* as a daylighting simulation tool. These tools are selected based on the possibilities for integrating them together to run at the same time to get real time feedback. The main objective of the process and algorithm is to evaluate the performance of kinetic façades in integrating different motions and to compose a series of kinetic louvers that actuate in response to dynamic daylighting. Within the framework of this study, Grasshopper as a parametric computational tool allows the integration into a single process of Rhino/Grasshoper as the design space modeller, *Ecotect*, as the dynamic day-lighting tool, and *Galapagos* as the solver. The parametric tool extracts designed geometry from the modelling space and sends the inputs into the Ecotect component to be tested for luminous distribution and daylight penetration depth inside a space. In this process, Galapagos is given a few different variables, for example, maximum size and pattern of geometry. These variables will undergo a process of interrogating fitness where the trade-off between these two variables will be calculated in a loop process in finding an optimal solution. This allows the designer to run numerous iterations during the design stage and select the best possible based on pre-determined criteria.

ENVIRONMENTAL CONDITION AS FIRST LEVEL DESIGN ASSUMPTION

The research presents a methodology and develops tools that focus on performance-based design integration to address designs, simulations and motions of kinetic façades and analysis of the impact on daylight performance to produce intelligent configurations. The research situates itself in the field of kinetic façades and adds to existing solutions a validation of the performance of kinetic façades systems with interdependent louvers of varying tilt angle, with different configurations. It provides a digital evaluation of kinetic façades' response to dynamic lighting conditions. Within the scope of this framework, Grasshopper, Rhino, Galapagos and Ecotect are linked and programmed into one integrated process, facilitating design options to get real time feedback. The paper will conclude with a description of the extensibility of the tools, the future incorporation of physical system interaction and complexity in combination with the digital. The main objective of this study is to investigate:

1. what the effective way of using digital simulations for kinetic façades is as an early predictor of the performance of the façades.

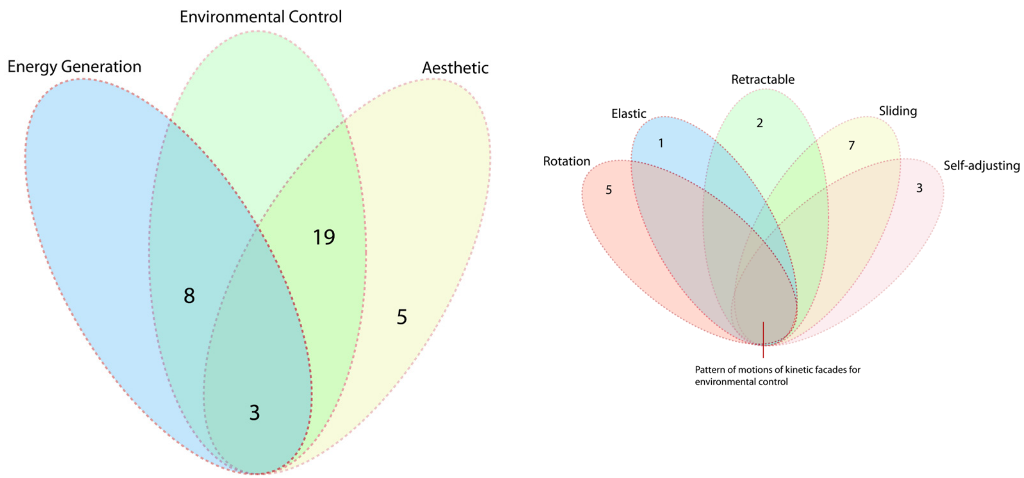

Figure 2
Function of existing kinetic motions (left) and type of existing of kinetic motions: the numbers indicate the numbers of case studies in each category.

2. What the available options and possibilities to improve the performance of kinetic façade designs are using digital simulations at the early design stage.

This study focuses on the climatic and geographical conditions in Melbourne, Australia located at 37.8075°S 144.9700°E, with a monthly av. max. temperature of 26.7 degree Celsius in the hottest month and monthly av. min. temperature of 5.7°C the lowest. The critical surface of north- west façades of the building will be evaluated in this paper. This side of the building is critical due to direct solar radiation which has max. angle of altitude of 75° in summer and 29°at winter solstice. In this paper, numbers of kinetic motions that have potential for environmental control have been identified and tested in this simulation process. Within the design component presented here, three different development stages can be defined, of which the first has already been finalized. The first stage implied a study of the state of the art in kinetic façade design and further definition of the design problem. It involved a wide literature review and analysis of various kinetic façade motions, placing emphasis on solutions of a local nature that respond to local climatic conditions. This process is further developed into case studies which are conducted to identify different kinetic façades patterns or motions which were adapted in the existing buildings around the world specifically in respond to the environmental control. Figure 2 represents existing kinetic façades' function and kinetic

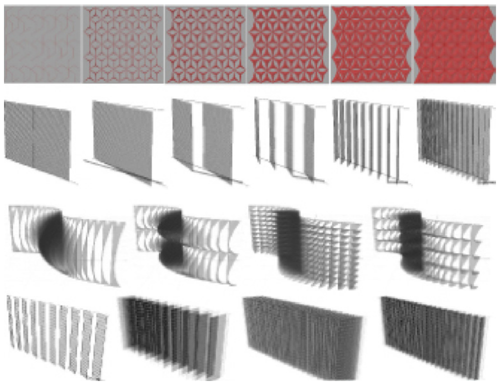

Figure 3
Parametric model of different type of motions.

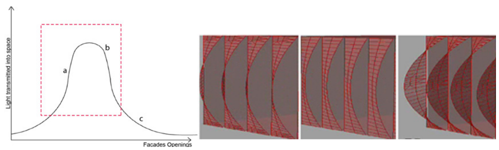

Figure 4
Problem that can be avoided using this simulation in the early design stage: a =, b =, c =

façades' motions in existing buildings for environmental control.

Four out of five kinetic motions are identified for this study: rotation, elastic, retractable, self-adjusting and sliding as show in Figure 2.

The kinetic motion selections are based on the pattern of geometry, kinetic surface behaviour, and the size of the surface. These elements are important to consider in order to obtain accurate results in this analysis to avoid a phenomenon shown in Figure 4. The oversize surface when it is retracted to open and close will overshadow another opening and prevent solar radiation from penetrating the space. The red section in Figure 4 suggests the possibility of optimal size openings for this type of motion. Further evaluation of kinetic motion will be presented using this process.

SIMULATION STRATEGY

The simulation investigates the possibilities of integrating different variables into designing the kinetic system. Evaluating the kinetic geometry and surface in this research is important as they play a vital role in kinetic façade systems' operation. These parameters will affect the behaviour of the kinetics and determine how they respond to daylight during the simulation. In this simulation, appropriate candidate tools met four requirements: 1) kinetic features are present in the conceptual model, 2) the desired performance outcome is at an appropriate level of detail, 3) the way adaptive behaviour is controlled is …, and 4) supports physical kinetic interactions.

The variables are simulated in real time using Melbourne weather data for part of the year. The simulation processes were developed by design-

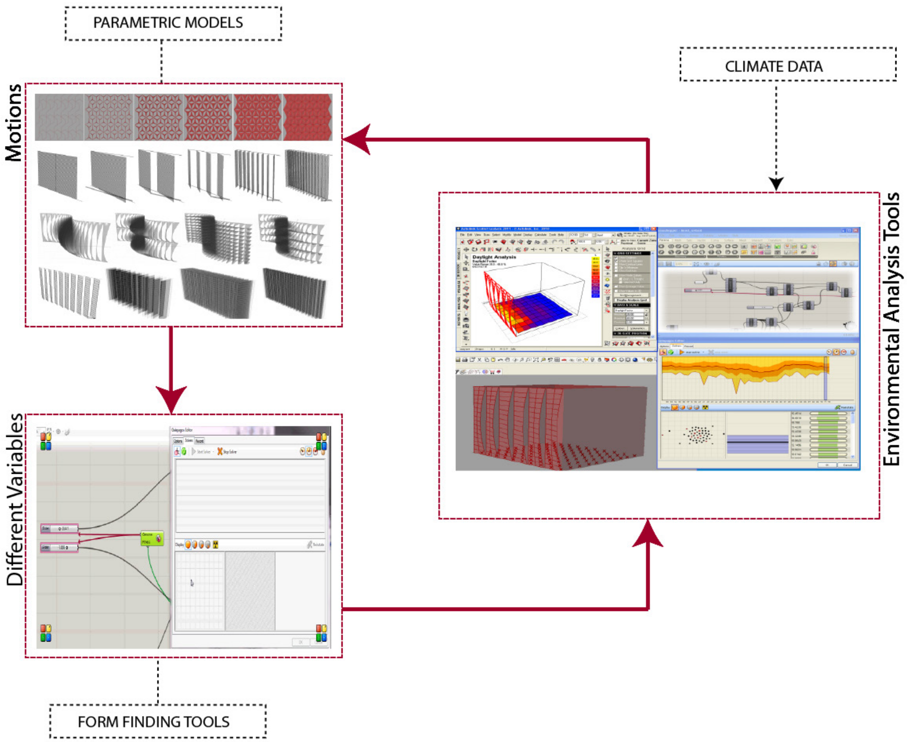

Figure 5
Simulation process.

ing the façade motions which were embedded with 5000mm x 5000mmmm x 3500mm cubic spaces. The real time weather data of Melbourne solar radiation from 21 June to 21 December 2011 were integrated with *Ecotect*. *Galapagos*, integrated with *Ecotect* and *Grasshopper* and used in this simulation to identify the optimal opening and closing patterns of kinetic façades for this period. This design tool adds possible solutions to the current performance-based technology by making a particular contribution to the field of integrated energy performance in the early design phase. The outcome includes finding the best possible skin configuration for better daylighting performance throughout the year.

Based on previous studies, this research further defined the variables field for five types of kinetic motion where patterns of motion and movements were influenced by the geometrical configurations. The design parameters were integrated into three groups i.e. first group responding to general conditions, second group to the structure and surface and third group to defining the potential behaviour of kinetic façades.

Through these simulations, the optimal pattern, size of surface and form of kinetic façades were also identified. Figure 5 explains the process of these simulations to find the optimal configuration of kinetic façades.

The variables were represented by sliders with set minimum and maximum values depending on designers' requirements. The proposed design tool is extensible; it is open to accepting additional parameters and variables, which makes it more complex but with better performance assessment.

The main objective of using *Galapagos* in this study as an algorithmic process is to evaluate the performance of an intelligent façade, which is composed of a series of kinetic louvers that are actuated in response to dynamic daylighting, and incorporates occupants' preferences. It creates an evolutionary generic loop that populates generations of possible solutions with random individuals based on the predefined criteria. The system couples similar possible solutions together and then finds a best '*fit*' solution, which may end up being a locally optimal solution in some cases. *Galapagos* is used in this study to find the best possible tilt angles of the louvers' configuration for certain times of the day. However, *Galapagos* is run using a pre-defined set of parameters, leaving only the calculation for this tool. A genetic algorithm has been incorporated into the definition to enable a search for the best skin configuration at specific dates and times or under different sky conditions. The genetic algorithm works by finding an optimal - although not necessarily the best - solution under certain parameters and conditions. These parameters could range from users desired illumination levels, to externally reflected daylighting components. Changes in any of these parameters trigger the system to run and find an optimal configuration for the skin to maintain the desired luminous environment. It creates an evolutionary loop that populates generations of possible solutions with random individuals based on the previously defined criteria

Through the entire process, the material assigned for the external louvers is high reflectance (90%) in this set up. The parametric tool extracts the designed geometry from the modelling space and inputs it into the *Ecotect* component to be tested for illumination performance, luminous distribution, and daylight penetration depth inside an office space. This allows the designer to run numerous iterations during the design process at early stage and select the best possible one based on pre-defined criteria.

In this simulation, there is some behaviour that is not eligible, for example, evaluation of hybrid motion. This would be possible with a more complex simulation configuration. This motion can be classified as combination of two totally different types of motions, for instance, *elastic* and *sliding*, which creates the need for a more integrated simulation process. In this case, the model behaviour is being simplified and requires more rigorous assumptions or less detailed analysis to ensure that it does not violate the utility of the simulation process. The capabilities of the simulation tool for better solutions for more complex cases may be developed in near future. However as this is a cost and time intensive process, the effort to accommodate complex combined motions might not be justifiable in the routine design development stages.

DESIGN GENERATION AND APPLICATION

As a parametric design tool, *Grasshopper* allows the creation of a kinetic system that can respond to multiple inputs (variables) and outputs through genetic algorithm (*Galapogos*). However, in this context of application, intelligence is represented by variables, mathematical functions and benchmarks. This means that the intelligence system is limited, but flexible enough for the system to implement certain desired tasks for better daylighting performance. As *Ecotect* is a *Rhino/ Grasshopper* plugin, it can easily be integrated into the intelligent part of parametric model definition.

From these simulations, numbers of parameters were identified which can be classified into definitions, variables and design categories. The motion and changing position of the surface defined the positioning and pattern relative to the external environment, resulting in higher or lower levels of solar radiation in the space. For instance, the surface pattern was identified for a retractable kinetic motion, which was flat, singly curved or doubly curved as shown in Figure 5.

The designs were analysed in terms of their performance as a climatic barrier. The evaluations have been realised in different types of motions and the highest performing models have been compared and selected with respect to the best environmental outcomes. After a comparative analysis of 23 possible geometries and patterns of kinetic motion, five models representing different kinetic motions were selected. Self-adjusting and elastic motions are suggested for more dynamic material behaviour with integrated dynamic structure. Both motions in Figure 5 show possible geometry that is effective for particular places and micro level behaviours by integrating with dynamic materials. The suggestion of the geometry and surface can be represented by a value in the simulation, which involves size and dynamic behaviour. For these two motions' configuration, it is important to understand the potential materials that can be associated with self-adjusting and elastic behaviour in order to select the right material in *Ecotect*. The suggested configurations as shown in Figure 6 may perhaps give an understanding to the designer of what kinds of geometry can be considered in designing kinetic façades using these types of kinetic motion.

Another three types of kinetic motions, with the potential to be developed into macro scale behaviour, are rotation, retractable and sliding. These motions are categorised in different possible ge-

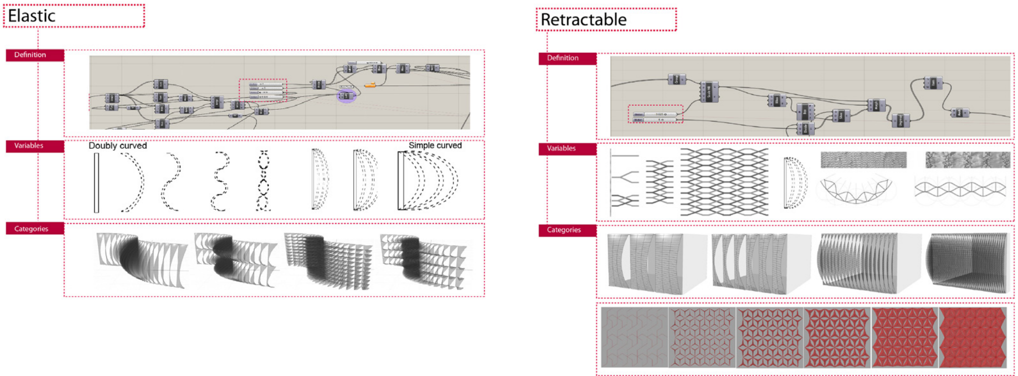

Figure 6
Two type of kinetic motion configuration for dynamic material application.

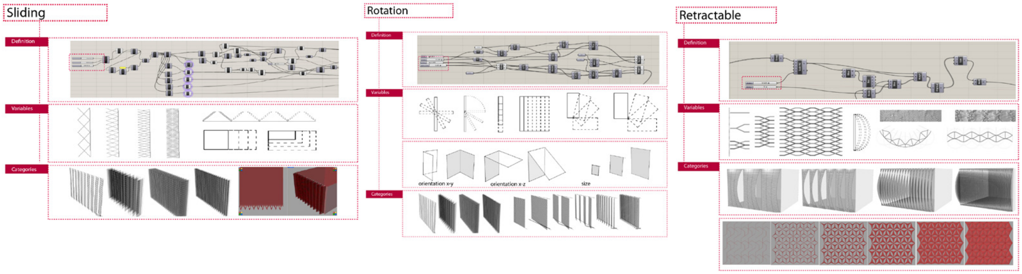

Figure 7
Types of motion: rotation, retractable and sliding suggested for kinetic configurations.

ometries in response to daylight conditions and presented in different configurations. The alteration definition is flexible to add different variables, which are represented in sliders. The alteration of the variable will make changes and suggest different configurations of particular motions. For these three types of motion shown in Figure 7, two or more possible variables are integrated in the evaluation. However, different possibilities due to environmental factors, such as wind, can also be integrated, adopting a similar process. These factors may affect the categories of configuration of kinetic pattern. In this particular study, it is suggested to the designer to further evaluate kinetic motions in realising kinetic façades for effective daylight control for the early design stage.

Parametric models are being used to fine tune for the best geometrical attributes to design for a particular case. Further evaluation will be conducted using physical models to know better the possibilities of these motions working as intended.

CONCLUSION

The paper focuses on the integration of parametric design definitions and environmental software, which can assist in the development of kinetic facades' design. The process involved different kinds of constraints, parameters and strategies, which created different options and variables to assist designers to make effective decisions at the early design stage. This is significant as creating digital simulation with different variables simultaneously in real time will surely help to identify and solve the crucial issues at the beginning of the design stages. Moreover, in evaluating kinetic façades in this study, there is already a result that can guide designers towards informed solutions of a problem studied in a wide research context. In addition, the study demonstrated a methodology, which is clearly understood as part of so many other similar examples. It can assist the new construction of kinetic façades to be more efficient in term of digitally driven evaluation

As the ultimate objective is to realise kinetic façades for environmental control, the needs of effective simulation tools are necessary at the early design stage. One of the challenges of an effective simulation tool is not only the ability to evaluate accurately but to speed up and simplify the process used by the tool for such dynamic design evaluation. This is crucial and will affect overall performance of the kinetic façades and design. Further evaluation using physical model analysis will be conducted on selected kinetic motions from this study. This evaluation will be compared and analysed in the context of kinetic performance for environmental control.

REFERENCES

Fernandez, I, 2012, 'Designing with Responsive Building Envelopes: Beyond passive and active: integrating adaptive elements in building envelopes'. *VI International Congress on Architectural Envelopes June 20, 21, 22, 2012*, Donostia-San Sebastián, Spain.

Knaack, U et al, 2008, *The Future Envelope*, IOS Press, Amsterdam.

Leighton, M and Bader, S, 2010, 'Responsive shading - Intelligent façade systems', *Proceedings of the 30th annual*

conference of the Association of Computer Aided Design.
Leighton, M and Bader, S 2010, 'Responsive shading - Intelligent façade systems', *Proceedings of the 30th annual conference of the Association of Computer Aided Design in Architecture ACADIA*, New York,. pp. 263-269.
Oxman, R, 2008, 'Performance-based Design: Current Practices and Research Issues', *International Journal Of Architectural Computing*, Number 01, Volume 06, 2008, pp. 01-17.
Selkowitz,S, 2003. 'Advanced Interactive Façades – Critical Elements for Future Green Buildings?' Presented at *GreenBuild, the annual USGBC International Conference and Expo*, November 2003. LBNL-53876.
Schnabel, MA, 2007, 'Parametric Designing in Architecture', *CAADFutures'07*, 237-250. Springer.
Woodbury, R 2010, *Elements of Parametric Design*, Routledge, New York.