AFFORDABLE, PERFORMATIVE, AND RESPONSIVE

Designing affordable responsive architectural prototypes through physical and digital modelling

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Abstract. The significance of this research lies in the investigation of agglomerating issues of affordability in responsive architecture to achieve long term performative and cost-saving benefits. Conventionally, performance analysis of responsive design is evaluated using simulation of digital model. The inaccuracy of most building performance simulation leads to a huge prediction error in the actual building performance, which yields miscalculation in the building operational cost. This paper proposes a novel method for delivering a cost benefit analysis for responsive design. Two different strategies are explored in parallel. Firstly, hands-on approach through fabrication of physical models which directly associated to digital models, whereby the fabrication and operational costs of the physical prototypes are measured and monitored. Secondly, qualitative approach through cost benefit analysis of real world building projects which employ responsive architectural components.

Keywords. Responsive design; affordability; performative design; low-tech.

1. Background

Recently, there is an increasing interest in designing responsive architecture to meet aesthetics and performative design goals. Creating envelopes and objects that can physically reconfigure themselves to changing needs is one of the attempts to improve building performance (Fox, 2007). However, the issue on affordability has always becomes a major hindrance in translating this idea
into built projects as new technology and mechanical system involve high cost. This is supported by Haque who believed that the complexity, logistic and costs have prevented their prototype research (2007).

On the hand, responsive architecture often does not require very sophisticated equipment to develop a truly interesting project, for instance, by adapting relatively simple technology, utilising available materials and mechanical system. Therefore, the solution lies in what is called ‘open sources architecture’, combining reusability and low tech. Hence, in implementing responsive architecture, it is suggested that new media artist and architect practise precision and accuracy that scientist do in order to explore the poetries of interaction (Haque, 2007).

Looking into a wider context at the implementation stage, the successful of responsive architecture lies in fulfilling the environmental criteria and cost constraints. In highlighting this dilemma, the need for researches and practical solutions for an affordable technique should be developed and explored to address today’s challenges in generating efficient building (Fox, 2007).

Hence, this project scrutinizes the issues of affordability in designing responsive design performance, by utilising parametric design and prototype model strategies. In obtaining accurate data for energy usage and performance, parallel explorations of digital modelling and hands-on physical prototyping are implemented using affordable electronic devices such as Arduino processing boards. The physical model obtains input from the environment whilst the digital model responds to the input. Subsequently, this data is evaluated using cost benefit analysis and repeated for the other models. Based on this approach, series of responsive models are fabricated by integrating low-tech mechanical system and low-cost materials. Cost evaluations are conducted on the energy usage, low tech application, materials and design performance from the output of both models to identify the optimum behaviour and to be extended for experiment towards actual buildings.

2. Design problems

Though existing building simulation software can be used to study building performance, costs and energy consumption, yet they are limited to static building with no responsive elements. Previous studies have shown that digital simulation outcome at design stage do not contribute to enhance building performance after been occupied. This is due to inaccuracy of data from digital simulation experiments at early design stages (Leaman, 2006). Alternatively, physical prototypes simulation is suggested to overcome the above problem. Though the prototypes may represent the movement in responsive buildings, for instance, tracking the sun movement, yet they cannot be associated with
the energy consumption and building performance.

Therefore, the combination of these two simulations would be useful in responsive design constructions study, where the challenges and limitations to create affordable and performative responsive design are the pillars of this research. Realising the lack of study and in the absence of integrated digital and physical modelling has been the key motivation in exploring this kind of experiments to produce affordable responsive architecture.

It is worth to mention that the issue of costs has always be the key issue in any responsive or kinetic architecture. Yet, novelty of the subject and insufficiency of evidences have provided no concrete answers on the affordability of responsive design (Angeliki, 2010). Usually, market demand shows that products will be at higher costs at the beginning of market released, but may drop at very low rates when become vastly available to the public (Angeliki, 2010). However, in relation to building performance and efficiency, this principle may not apply in analysing the responsive design cost, as it involves long term building cycle costs i.e. energy and maintenance costs. For that reason, this paper will experiment on how affordable responsive architecture can be evaluated and analysed before being build. The integration between digital and physical data is important to produce affordable responsive designs which are parallel to the actual building performance.

3. The design process

This design process involved data evaluation from digital and physical models. Figure 1 shows the experimental process of evaluating both digital and physical prototypes from the existing responsive building elements, focusing on the affordability of responsive design. Since this process involved hand-on experiment, preliminary problems of responsive design were analysed and identified for further evaluation and improvement through various solutions.

Designing prototypes are basically a thinking activity. The proposed prototype models – in this case building design process – is a kind of framework which is in accordance with the nature of thinking activities with no sequential process. Hence, the development on the solution to a design problem is a responsive search process, driven by insight and creative leaps within the framework of affordable responsive architecture. The framework is meant to support the exploration and clarification of the problem as well as to extend the solution for affordable responsive architecture by various means such as, development of scenarios and strategic values in developing an innovative approach towards the design process of responsive building. The creation of a building (conception, design and development) is a process of crystallisation from all directions, starting from a conceptual centre outwards.
Through this process, based on Figure 2, the first stage looked into the application of mechanical system, followed by how the system can be replaced by sensor and actuator whilst the last stage considered the integration of low tech material and method for energy reduction with better performance.

3.1 STAGE 1: DESIGNING AND EXPERIMENTING THE MODEL MANUALLY

The first stage in responsive prototype model construction looked on how the responsive model operated and responded to specific environmental condition.

The model was first constructed using digital modelling (Rhino and Grasshopper) where problems and issues were identified in relation to
responsive mechanism. Then, the 3D modelling was physically constructed using available materials with very simple method. Cost and time for constructing the model were evaluated throughout the process.

3.2 STAGE 2: PROTOTYPING WITH PERFORMANCE AND MECHANICAL BEHAVIOUR

In the next stage, Arduino boards, motor, sensor, actuator and computational system were integrated into the prototype model to experiment the technologies applied in responsive model and to improve the prototype performance. The process of adapting this low tech application were re-evaluate and re-design to get the possible optimum performance and considering its application to the real building situation.

3.3 STAGE 3: EXPERIMENTING WITH OTHER SMART MATERIAL AND ENERGY

The third stage looked into replacing the technical and computer application with low tech and smart materials. The objective of this process is to find an alternative solution for the model to operate in accordance with the same intention and performance of the mechanical system. This process may provide affordable installation, operational and energy costs used by the model. This idea and process can be projected to the actual building to evaluate the outcome and performance of the responsive facade before applying it to the real building design.

In the past, most of the responsive system involved very high tech mechanical system. Hence, it is time to look for different approaches in operating responsive design through integration of smart and low-tech materials (Fox, 2007). Since the process of constructing responsive prototypes deal with cost and prototypes performance, the solution should be explored in the context of smart material and low tech application which are suitable for responsive facade design. The materials such as Smart memory alloy, ETFE and Paraffin wax can be adopted into responsive design façade to replace the mechanical system in producing affordable and effective responsive design. This material are quite expensive in the market at the moment however, as this materials slowly adapted to the building construction the material will be affordable.
4. Design and Development of Responsive Prototypes

4.1 PROTOTYPE MODEL 01

The model was constructed by considering possible behaviours of kinetic facades and envelops which applied mechanical system. The behaviours were tested using manual mechanical system and problems were identified and resolved by simplifying the mechanical system work on the prototype model. Based on Figure 3, Prototype 1 used two panels to move thirty panels in different positions; up and down which create different form and behaviours. The panel relies on different position of planes which are located in different degrees. These panels can be adjusted and reconfigured to avoid cost increase in redesigning the responsive facade. This panel can be adapted into real building as re-adjustable shading devices.

4.2 PROTOTYPE 2

The responsive prototype model in Figure 4 was developed based on available materials using straws, bamboo sticks, mdf boards and rubber band while the model behaviour was develop based on open and closed panel. The flexibility of each panel depends on the opening degree in every square panel. The model can be operated by using rotation at the back of the prototypes.
At the first stage, the prototypes were developed and tested using manual system to determine whether the prototype behaviour is responding properly and effectively. The main design goal of the prototype was to achieve high efficiency and low operational cost in real-world buildings.

4.3 PROTOTYPE 3

The prototype in Figure 5 and 6 were constructed using paper and stapled clips. Based on simple behaviour of the façade system, Arduino board and light sensor were used for the opening and closing. For instance, Arduino and light sensor in Figure 6 can be programmed and adjusted to suit user requirement or the intended behaviour. The main issue of developing this model is low energy supplied to make the prototypes more responsive and effective.
5. Preliminary outcome

Considering the possibilities, limitations and nature of the problem, the first approach is to create a responsive prototype for responsive facade which is in parallel to the affordability and building performance. Since the sustainability issues are essential to the building performance, the preliminary investigation of responsive prototypes model shows that the mechanical system and the application of right material are very crucial in developing responsive facade design.

Table 1 demonstrated that simple construction may produce more efficient and effective responsive models with lower installation cost and minimum assembly time. The model creation takes longer time since it involves designing around the actual problems of responsive architecture design. The workability of prototype was experimented digitally in Rhino and Grasshopper before physical construction. The physical installation of responsive affordable prototype deals with similar type of real construction of responsive design. This may provide a real idea on how the affordability and performance of responsive architecture can be realised. From the data collection and analysis, it is suggested that the integration of digital and physical models offer a quick turnaround in order to test, manufacture and market our idea as well as produce good quality of responsive prototypes from computed generated data in relation to hours, instead of week. Besides, prototyping our design idea can be tested and refined quickly and economically resulting in tremendous reduction in development time costs and enhancement in the final result.

In comparison to the complexity and behaviour between Prototype 1 and 3, the construction of Prototype 1 was more complex than Prototype 3 as the behaviours of responsive elements were almost similar. As the cost of Prototype 3 was lesser than Prototype 1, the experiments showed that in order to create affordable responsive architecture, the early design stage should be simple and practical. From the time and cost point of view, results will vary according to the size, complexity and geometric definition of each prototype. It is difficult to estimate and analyse the accurate model creation method as there are too many iterations associated to modelling prototypes i.e. designing a parametric model, exercising parameters, prototyping material, defining parts and different technologies required in the process. Therefore, the results presented in this paper are best suited for scaled prototype models whereby similar parts are constructed using similar modelling parameters.

This will lead to an affordable responsive prototype whereby this estimation can be projected to the actual responsive building design at the early installation stage for an affordable responsive design.
Besides, Fox highlighted that as most of the smart system has been explored in engineering, aerospace and agriculture area, the time has come for the application of smart material and low-tech technology in architecture, specifically to the responsive design facade to create solution for the building performance and affordability issues (2007).

6. Conclusion and future work

In designing responsive prototypes model, there are a few requirements that should be considered:

- Satisfied technical criteria of designing responsive design
- It is impossible to reach one best solution
- Always considering double loop learning and adaptation
- Creativity and experiment will play an important role in innovation approach.

The proposed responsive prototypical model may to a certain extent are idealistic and risky but at the same time provide solutions to all initially set challenges—such as facilitate the development of responsive architecture, complex interactive environments with the prototypes, as well as the issue of affordability and building efficiency for integrated design and prototyping in dynamic architectural systems.

It is acknowledged that the lack of standards and no predefined method for simulation of responsive prototypes models may (and arguably, should) lead to larger inconsistencies among different future implementations developed under the experimentation of responsive architecture. However, to date, most of the experimental projects in the domain of responsive design do not conform to any common models. Thus, providing a framework without any substantial constraint to freedom of creative exploration seems to be the only solution to allow further development of experimental responsive models, while providing a platform for interoperability and reuse of components, sub-models and plug-ins across projects when desired. To further facilitate this experiment, the exploration of affordable responsive model should be tested as one to one scale model integrated with integration with digital model and

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apply towards the actual building facades. This method of experiment is one of the effective ways to identify and to analyse the affordability and performance of responsive design facade. The exploration and adaptation of smart material and low-tech system are significance in ensuring the responsive design facade working effectively and efficiently at the same time affordable.

References


