Thermal performance of patterned facades

Studies on effects of patterns on the thermal performance of facades

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Skin is the primary shield between our body and its surroundings. It protects the body from the harmful environmental effects like dehydration and radiation from intense sunlight. Likewise, the outer layer, or skin of a building has the same function of protecting its inhabitants against the external elements. This research is a part of a larger investigation into geometrical patterning and layering of facades as an effective intervention between the outdoor space and the indoor environment to regulate the conditions for occupant thermal comfort. This paper reports on exploration of an approach for measurement, evaluation and feedback in the design workflow through a mixed digital -physical simulation platform (MDPS) based on the objectives of the larger study. For this purpose, it introduces a new way of analyzing thermal performance of double skin facades by using temperature sensors, Arduino, post visualization with MATLAB and digital energy simulation. The main aspects of this proposed workflow is the design of a thermal performance feedback loop as an integral part of the process of geometrical patterning design for façade.

Keywords: *Patterned facades, Thermal performance, Surface temperature, Data visualization, mixed digital physical simulation*

INTRODUCTION

Skin is the primary shield between our body and its surroundings. It protects the body from the harmful environmental effects like intense sunlight and radiation. Likewise, the outer layer, the skin, of a building has the same function of protecting its inhabitants against external elements.

In harsh environments, like hot and arid climates, building skins play an important role in moderating the harsh conditions. Facades can be designed with traditional features and elements that draw on a climate- and culturally specific vernacular for example, *Mashrabiyas*.These elements control the daylight and air flow while cooling the air passing through them (Fathy 1986). In hot arid climates the moderating function of facades, including their geometrical characteristics and features, impact on inhabitant comfort, reducing direct exposure to the harsh external atmospheric conditions. Geometrical façade characteristics contribute to the moderation role of the facade, by preventing heat gain through the surfaces in part through self-shading. How can designers emulate these effects effectually in early design in order to develop genuinely climate responsive screens and barriers to reduce over heating in buildings?

This research is going through a proposed platform based on capability of investigation into geometrical patterning of facades as an effective intervention between the outdoor space and the indoor environment to reduce surface temperature, incident solar radiation and transmitted heat through the surfaces. Design strategies and effective approaches to measurement, evaluation and feedback in the design workflow are combined in the proposed platform. Initially such strategies target rapid feedback to inform early design, enrich the design process, for getting dynamic feedback, and bring it back to the design stage for manipulating the skin forms.For this proposed design loop both physical and digital simulation are integrated in the thermal performance feedback.

SKIN THERMAL PERFORMANCE: BACKGROUND, OBJECTIVES AND MOTIVATION

Studies in bioscience show that shapes and patterns of *Barrel cactuses*, including opening patterns, spines, and ribs, affect their thermal energy exchanges (Lewis and Nobel 1977;Nobel 1978).

These studies show how features of the cacti as examples of desert plants help them moderate the difficult conditions of hot and arid zones. Lewis and Noble (1977) observed that the surface temperature of the cactus' stems increased rapidly during the summer days when their spines and ribs are removed .They concluded that the ribs and spines are effective features in changing the cactus skin's thermal performance and characteristics, through shading the exterior surface from solar irrigation (figure 1).

Studies in engineering and architecture demonstrate that layers of vegetation on walls and double skin facades can change the thermal performance of the surfaces in convection, conduction and surface temperature (Eumorfopoulou & Kontoleon 2009; Hensen, Bartak, & Drkal 2002; Susorova, Angulo, Bahrami, & Stephens 2013).

Wong et al (2012) in their studies, by comparing eight different types of greenery wall, concluded that thermal performance of the greenery wall depends on various factors such as the shading areas.

These results point to potential strategies for reducing buildings' surface temperature and consequently improving the thermal performance of the building skin by adding different layers to the facades or protecting them through self-shading techniques. Self shading techniques in our research refer to the ways that parts of surface could protect other parts from the direct sunlight like a cactus' ribs. These layers could be vegetation layers as natural elements or layers of materials and construction elements such as double skin facades. Both of these layering strate-

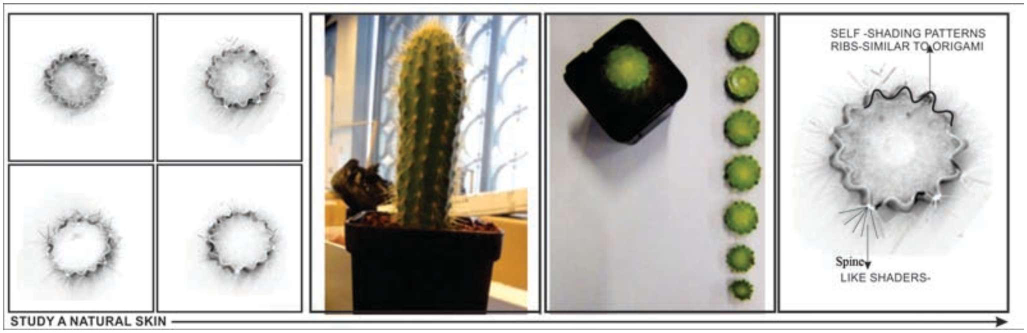


Figure 1
Horizontal sections of a cacti show the ribs and spines, effective features in changing the cactus skin's thermal performance.

gies can be applied to increase human comfort and decrease energy consumption in the buildings; however, vertical greenery systems have limited potential application in dry climates when water and vegetation are scarce. This leads to the question: What kinds of geometrical patterns and systems could perform similarly and have analogous effects on thermal behavior of the buildings' elements to improve the climate modifying function of the building for inhabitants in hot arid conditions? To answer this question, about the effects of geometries on the protective function of the façade and designing for it in the early stage of design, finding a good methodology for assessment and evaluation of the designed geometries is critical. Having a simulation platform that mixes physical and digital simulation is one criterion for a solution .

THERMAL PERFORMANCE EVALUATION AND ASSESSMENT

It would be impossible for architects and designers to go through the optimization of geometries for improving thermal performance, without considering proper tools for assessment and evaluation. Meanwhile the selection of the right tools depends on the aims and objectives of studies.To select the right tools, it is essential to define the aims and objectives of the studies and the assessment criteria. In this research, following the mentioned literature, we have considered four main parameters affecting thermal

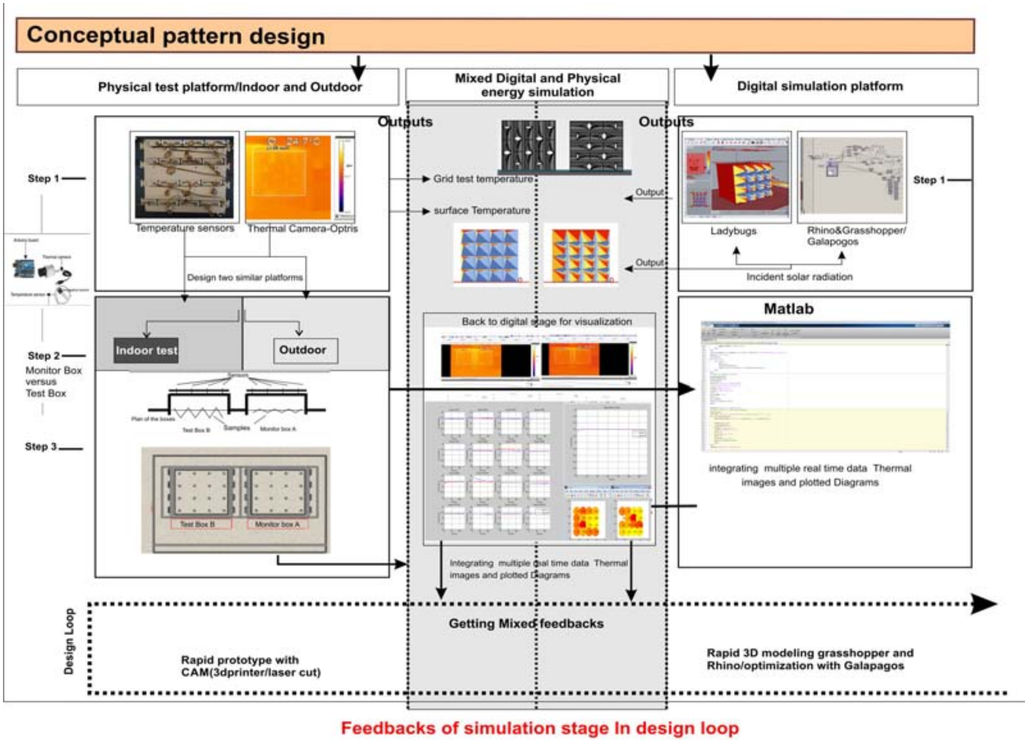


Figure 2
Proposed framework for driving the forms base on drawn feedbacks from the mix digital- physical simulation platform(MDPS).

performance of the façades as below:

a) Incident solar radiation
b) Pattern surface temperature
c) Temperature behind the surfaces
d) Area of self-shading

Time is considered as a critical factor in selecting the proper tools as in the early stage of design designers need to make decisions in a limited time. These are derived from the background research and lead to the detailed design of a mixed digital -physical simulation platform as below.

MIXED DIGITAL -PHYSICAL SIMULATION PLATFORM

According to the background studies, we proposed a mixed digital-physical simulation platform (MDPS) based on two main stages: a) data collection b) data visualization and analysis including a series of physical and digital simulation ,data collection and visualizations (Figure 2).

The output from the conceptual design process enters as an input to the MDPS platform for the thermal performance evaluation and assessment by considering the defined criteria to form the next generation of the patterned screen based on the feedbacks. The analyzing output data from this mixed digital - physical platform are:

- Colored images based on incident solar radiation (ladybugs+Grasshopper)
- Thermal images for surface temperature (thermal camera images)
- Plotted charts of temperature of individual sensors including 16 individual diagrams for the Test Box and Monitor Box (Arduino+temperature sensors+Matlab) and a chart for mean temperature of Box A and Box B.
- Colored images based on transmitted heat through the surfaces (Arduino+temperature sensors+Matlab)
- Shadow movies and images, illustrating self-shading areas(Autodesk Vasari+Ladybugs)

Data fusion plays an important role in the post processing as we have various types of extracted data in the performance loop stage. Therefore, we decided to use Matlab as the post processing visualization tool, which can be used to extract knowledge from the data for the future studies.

DATA COLLECTION

The data collection from the MDPS platform involves analyzing in the digital energy simulation software. Advanced computational methods offer various tools for design exploration, evaluation and assessment during the early stage of design. Based on our studies' objective,Vasari and different plugins of grasshopper like Ladybugs, Diva and Geco exist as good tools for energy simulation .They are very user-friendly tools and their combination with other plugins like Galapagos in grasshopper offers the opportunity of undertaking complex optimization. However, they are for the two criteria only: incident solar radiation on the patterned surface and self-shading areas.

Getting accurate results based on the surface temperature and temperature behind the surfaces involves fluid flows dynamics into the simulation platform, offered by computational fluid dynamics (CFD) software packages. However, the simulation process with CFD is very time-consuming for the early design stage, especially when the aim is optimizing different generations of the forms to have a comprehensive overview, and considering the dynamics of heat phenomena within the study domains. Consequently, the physical analogue simulation has been considered as an alternative solution.

Many practitioners use physical simulation as a tool for thermal analysis.For instance, Wong et al (2012) used a physical set up and field measurement to study the effects of greenery layers on reducing the radiation on the surfaces.Two similar labs have been constructed in a one-to-one scale set up named *"thermal lab"*, in the Department of Architecture of Texas, Austin, where students and researchers can

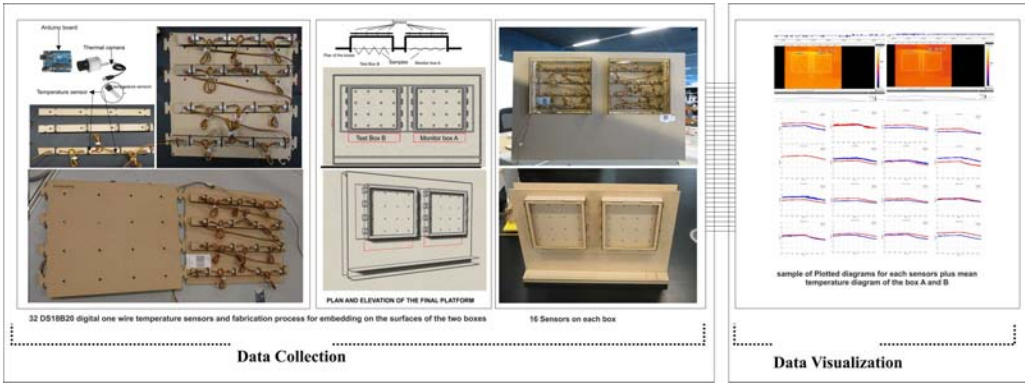


Figure 3
The designed physical platform.

test their designed geometries by attaching them to the glass walls of the lab [1].However,it has the limitation of the study being narrowed to only one location and orientation(South façade in Texas). Another example is *"Thermal Reticulation cluster of Smart Geometry 2013"* in which the series of sensors and thermal camera were used for capturing the heat movement inside of a box. In this case they used digital simulation packages beside the analogue test platform (Burry et al 2013).

With physical Simulation tools it is possible to test and evaluate different configurations while increasing the environmental perceptions by creating more tangible platforms. Moreover, through experiencing the physical models of designed motifs that are tested in the platform we could study their aesthetics in physical space including dynamic aspects of shadows as hidden secondary geometries. Hence, a physical platform was designed.

PHYSICAL PLATFORM

Two similar boxes are designed, one to be used as a control during experimentation and the other as the test domain out of 90*60cm MDF panels, representing the wall of an existing building that designed screens are attached to them externally. The designed screens are applied as a second protective building skin and the impact on the permanent protected inner surface is measured. This measurement gives feedbacks about heat transmission by the patterned screens to consider the effects of first screens on the second facade.

The key novel contribution of this platform is using two identical rigs for evaluating the designed screen pattern, in which certain design iterations are evaluated against different design generations. The 'control box', named "Box A", is designed to monitor the effects of changing temperatures though a previous generation of the façade. The second alternative of designed façade geometry could be applied externally to the second box, which is named "Box B or Test box". There are 32 digital one wire temperature sensors (DS18B20) which are embedded in the 3mm MDF test box and monitor box (16 sensors on each box) to measure the amount of heat that is transmitted through the patterned surface.

The data collection in this stage involves data gathering by temperature sensors and a thermal camera. The sensor arrays can measure the temperatures of the grid on the second wall through connecting to an Arduino board.The thermal camera, which provides thermal images of the different design surfaces, is mounted in front of the domains to capture the thermal images of the external surfaces.These images show the mean temperature of each domain (including Monitor and Test Box)(Figure 3).

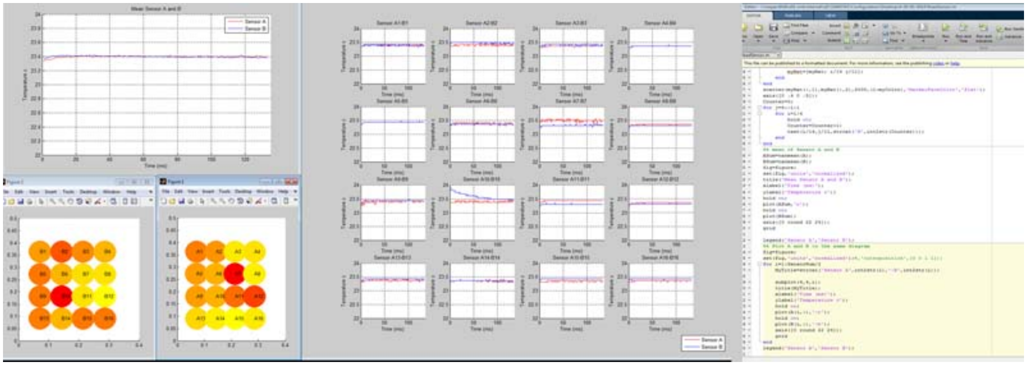


Figure 4
Sample of data visualization of temperature sensors with MATLAB.

The extracted data from the sensor measurements will be visualized using MATLAB, which enables researchers to gain insight into the extracted data .This stage enables the researcher to get feedback on their designed models visually and give them the opportunity of comparing the extracted data for detailed assessment processes. Moreover, MATLAB is used for mapping the temperature sensors as they are addressed randomly by the Arduino board. A sample of the visualization is illustrated in Figure 4 in which sensor B10 and A7 were tested.

ADVANTAGES OF THE PHYSICAL PLATFORM

Having a portable laboratory gives the opportunity of doing the test both indoors and outdoors. Although the indoor test could be repeatable by controlling the domain conditions in the laboratory, these two platforms would be helpful for outdoor tests according to dynamic atmospheric conditions and enables the users to compare thermal analysis of two designed screens at the same time in similar conditions. Moreover having two similar test boxes in the platform makes it possible to go through the optimization process by comparing two similar geometries that differ just by changing one parameter, for instance porosity or 3D pattern shapes.

The other contribution of this platform is having a plan for a design process and bringing the feedback to the design stage, which is beneficial to make better-informed design decisions.Moreover, it is capable of visualizing both Surface temperature and the gradient mean temperature behind the screen.

The size of this platform is adjustable, which allows users to make the various scale models for testing and do tests even in the real site location. Furthermore, by using Arduino, it is possible to add different kinds of sensors like light and humidity sensors, to explore other natural phenomena that may have an influence on the thermal performance of facades under simulated conditions. It depends on the aims of the studies.However getting very precise and accurate results needs the engagement of other sciences with the platforms.

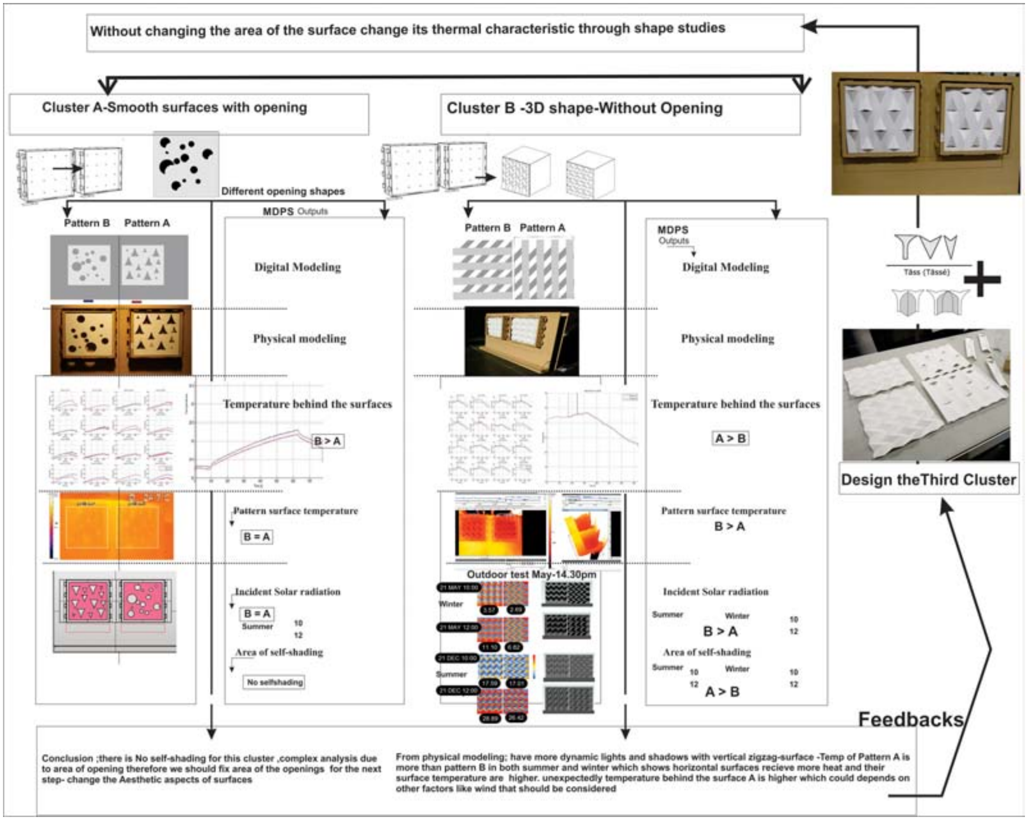
CASE STUDY

A series of prototypes has been implemented out of white polypropylene sheets to illustrate the potential and limitations of the MDPS platform for early stage of façade design.

Reflecting on a series of prototyping techniques like layering and casting, we used origami folding as a good technique for this stage of the studies, offering potential of rapid prototyping without needs of additional material like glue. Consequently, this method offers homogeneous surfaces for the heat studies

The design started with ideas of having two clus-

Figure 5
First and second clusters of patterns were studied in the mixed digital - physical platform.



ters of patterns for a scenario of designing a second screen for the north façade of a building in Melbourne :

a) Smooth surfaces with opening

b) Patterned or 3D shape surfaces without openings (Figure 5)

For the first cluster, 'smooth surfaces with openings', several smooth patterns with different shapes and size of openings were studied. The results of this stage were too complicated to inform the next generation of the design. Therefore, it was concluded that for minimizing this complexity we should have same area of opening for the next generation of studies. Reflecting on the second cluster of studies, it was concluded that one origami shape is capable of generating at least two different patterns with different thermal characteristics (figure 5).

The result from the second cluster in the physical platform led to the question: how could we have variation of forms with different thermal characteristics just by rotating the screens? This question informed the next generation of forms designed to provide variation out of one shape. Through this exploration, it was possible to play with one module to vary the screen outcomes by rotating. Therefore, the next generations of forms were designed by combination

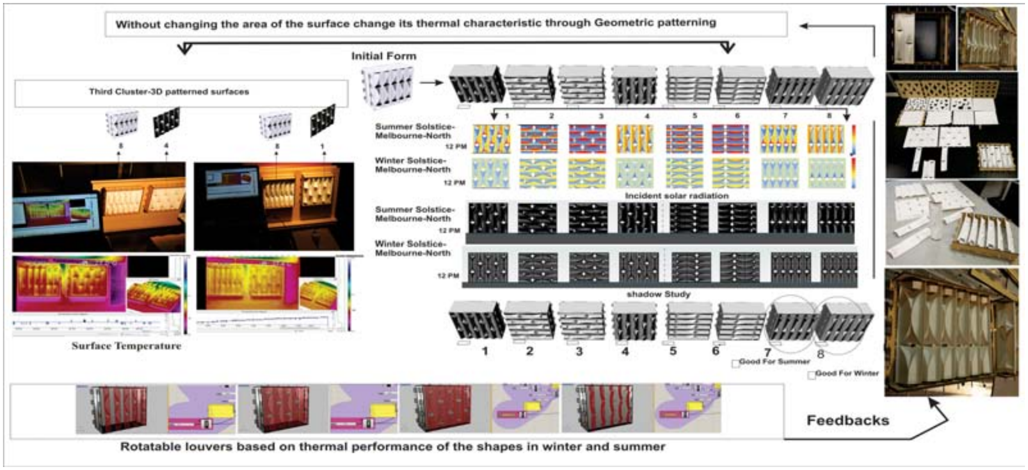


Figure 6
Shows eight different shapes that were generated out of the initial module in the third cluster.

of both opening and patterning for façade composition.

Eight different shapes were generated out of one studied module through rotation and flipping the module (Figure 6).The patterns evaluated and analyzed in terms of the defined criteria including self-shading , temperature behind the surfaces , surface temperature and incident solar radiation. The results are summarized in figure 6. The results of studies in the mix digital and physical simulation platform showed the capability of having one module with different thermal characteristics. By testing the designed patterns in the MDPS platform the third generation were designed based on this capability of controlling more heat in the hottest days and blocking less heat during winter time(Figure 7) .

The final outcome was a screen consisting of horizantal louvers capable of rotating 180 degree for changing the shape based on the season. The studies showed that one side is good for winter as it receives more heat while the other side would be better for summer because it could block more solar radiation and provide more selfshading areas.

CONCLUSION AND FUTURE WORK

This paper reports on exploration of an approach for measurement, evaluation and feedback in the design workflow through a mixed digital -physical simulation platform (MDPS) based on objectives of the study. For this purpose, it introduces a new way of analyzing thermal performance of double skin facades by using temperature sensors, Arduino control system, post visualization with MATLAB and energy simulation with grasshopper plugins and Vasari. The main aspects of this proposed workflow, in which both physical and digital simulation are integrated, is the design of a thermal performance feedback loop as an integral part of the design process to facilitate driving forms based on better understanding of geometrical patterning thermal performance. This leads to the design of a physical platform to provide qualitative and quantitative information. From the research that has been carried out, it is possible to conclude that having such a mixed Digital-Physical simulation platform enriches the feedback loop during the form finding process. Each of them covered different aspects of the studies based on their capacities. Although there are some limitations and disadvantages for both physical and digital simulations,

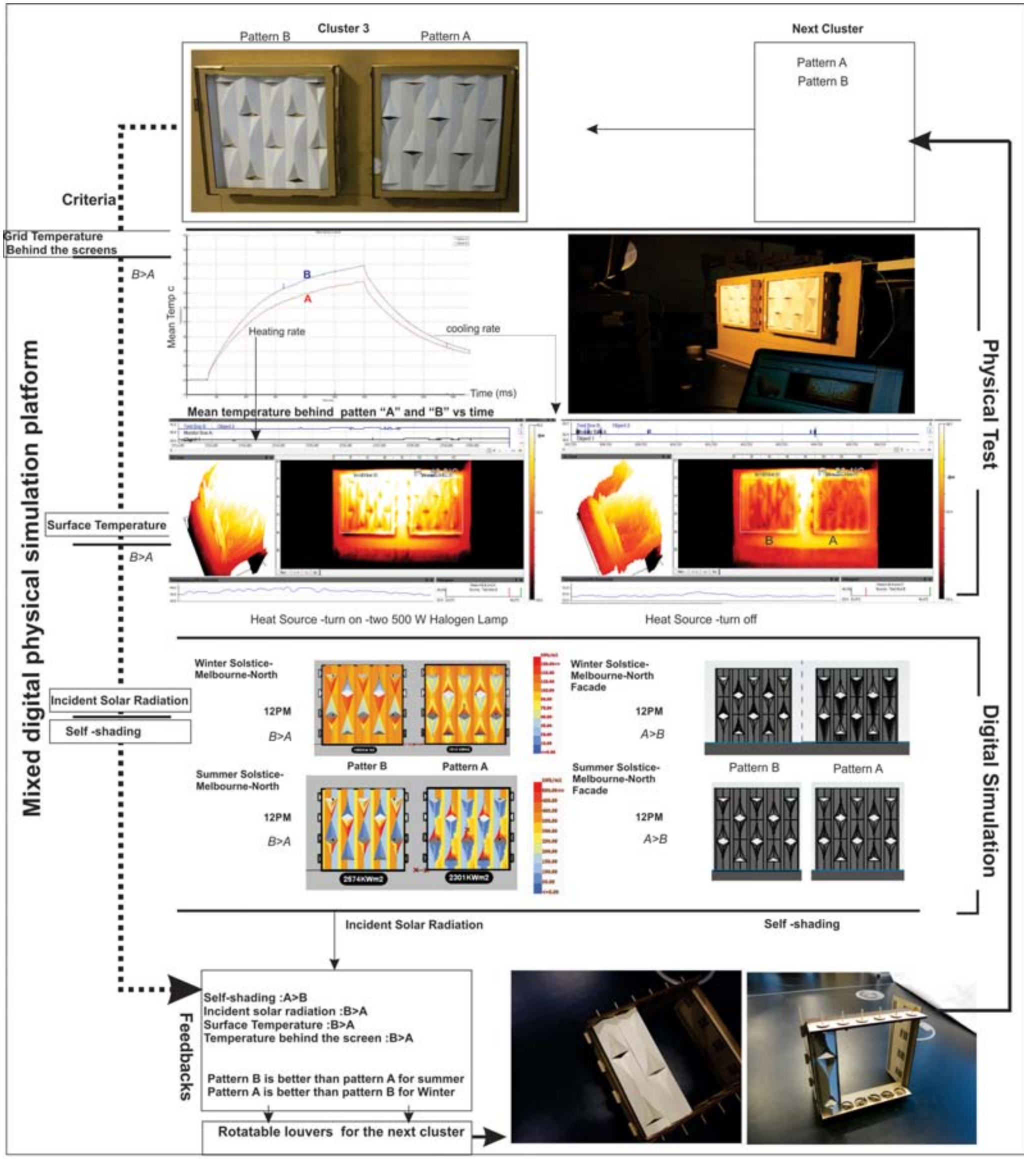


Figure 7
Two samples from the third cluster with more details.

by considering both of them in the early stages, we could get comprehensive results. Such a platform is user friendly for investigators and they can get rapid feedback on their designed surfaces just by attaching their sample models to the existing platform, that may lead to an increased ability of understanding the thermal performance of the design modules while applying user-friendly digital software in parallel .Having physical exploration with real time domain beside digital simulations improved our understanding of heat as a dynamic phenomenon. All of these efforts are for exposing environmental parameters to the design process of the early stage.

For the case study series, the designed surfaces were simulated to study their thermal performance, with the aim of optimizing and refining patterns to minimize the mean surface temperatures, incident solar radiation and the temperature behind the surfaces during hot summers of Melbourne.

Future work will involve using additional sensors and developing the platform for more accurate tests and results, including outdoor and indoor tests.

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