Hybrid Environmental-Media Facade

Full-Scale Prototype Panel Fabrication

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This paper reports the design, fabrication and evaluation strategies of full-scale aluminium panel prototypes developed for a kinetic hybrid facade system. The concept of a hybrid facade system was proposed as a solution to maximise the value of kinetic intelligent building systems by repurposing the animation sunscreening as a low-resolution media display. The overarching research project investigates the potential, feasibility and real-life applications of a hybrid facade that integrates the: environmental, media and individual micro-control functions in one compound system that operates through autonomous wirelessly controlled hexagonal rotating panels. The study explores new ways of communication and connectivity in architectural and urban context, utilising and fusing together a wide range of technologies including: artificial intelligence, robotics, wireless control technologies, calibration of physical and digital simulations, development of fully autonomous self-organised and powered units and the use of additive digital manufacturing. This article reports the third research stage of the hybrid facade project development - the manufacture of full scale panel prototypes.

Keywords: *kinetic facade, digital fabrication, full-scale prototype, intelligent building systems, hybrid facade*

PROJECT BACKGROUND

This paper describes the design, fabrication and evaluation of full-scale aluminium panel prototypes developed for a kinetic hybrid facade system. The study itself is the third stage of a larger ongoing research project that investigates the potential, feasibility and real-life applications of a hybrid facade that integrates the: environmental, media and individual micro-control functions in one compound system that operates through autonomous wirelessly controlled rotating panels.

The hybrid facade project directly relates to the agenda of the conference - interrogating the application of architectural systems in the age of the 4th Industrial Revolution (4IR). It does so through the exploration of new ways of 'communication and connectivity' (Marr, 2016) in architectural and urban context, utilising and fusing together a wide range of technologies including: artificial intelligence, robotics, wireless control technologies, calibration of physical and digital simulations, development of fully autonomous self-organised and powered units (facade panels) and the use of additive digital manufacturing (Weforum, 2016).

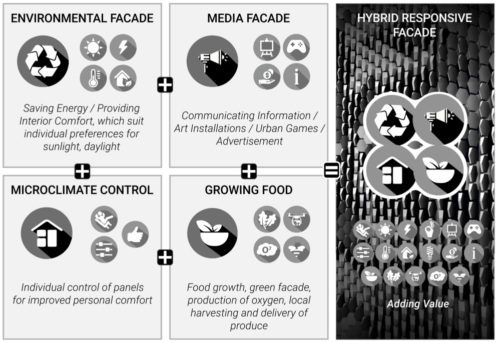


Figure 1
Hybrid Environmental-Media Facade Concept: Adding Value

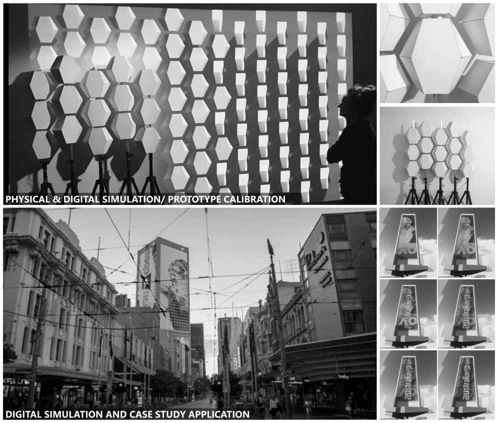


Figure 2
Second Research Stage: Proof of Concept / Simulation and Calibration

The concept of a hybrid environmental-media facade was conceived as a solution to maximise the value of kinetic intelligent building systems by repurposing the animation sunscreening as a low-resolution [panel=pixel] media screen (Moloney et. al. 2018). The initial research stage involved extensive literature reviews, development of conceptual framework and generative experimentations exploring the composition, shape and animation of kinetic facades in architecture (Moloney, 2011). The second, proof-of-concept research stage, moved from theory to the development of first physical prototypes and included: fabrication and evaluation of a scaled physical facade prototype, calibrated to a real-time simulation; and an economic feasibility study of hybrid facades in architecture.

The findings of the second research stage demonstrated that the proposed highly customisable hybrid approach offered a realistic and economically feasible opportunity for truly smart building facade systems, responsive to a variety of issues including: environmental (sun screening, energy saving), cultural (interactive, advertisement, urban media facade) and individual occupancy (micro-control) agendas. For more detailed information, encompassing the in-depth literature reviews, rationale and feasibility findings of the on-going Hybrid Environmental-Media Facade project please refer to our recent publication in Architectural Engineering and design Management journal (Moloney et. al. 2018).

This article reports the third research stage of the hybrid facade project development - the manufacture of full scale panel prototypes.

FULL-SCALE PROTOTYPING

This article details the design, fabrication and evaluation methodology of twenty five full-scale autonomous wirelessly controlled hybrid facade panels manufactured from aluminium. The tilted three dimensional hexagonal shape of the panels was informed by previously conducted experimental studies (Moloney, 2011); the choice of material - aluminium - being informed by two factors: firstly, the outcomes of the economic feasibility and life cycle analysis study carried out during the second research stage (Moloney et. al. 2018); and secondly, the practicalities of the project as a prototype build using the available resource and skill base. The current (third) research stage evaluates and compares three test groups, that refer to three distinct panel design options that were jet-cut from aluminium sheets of

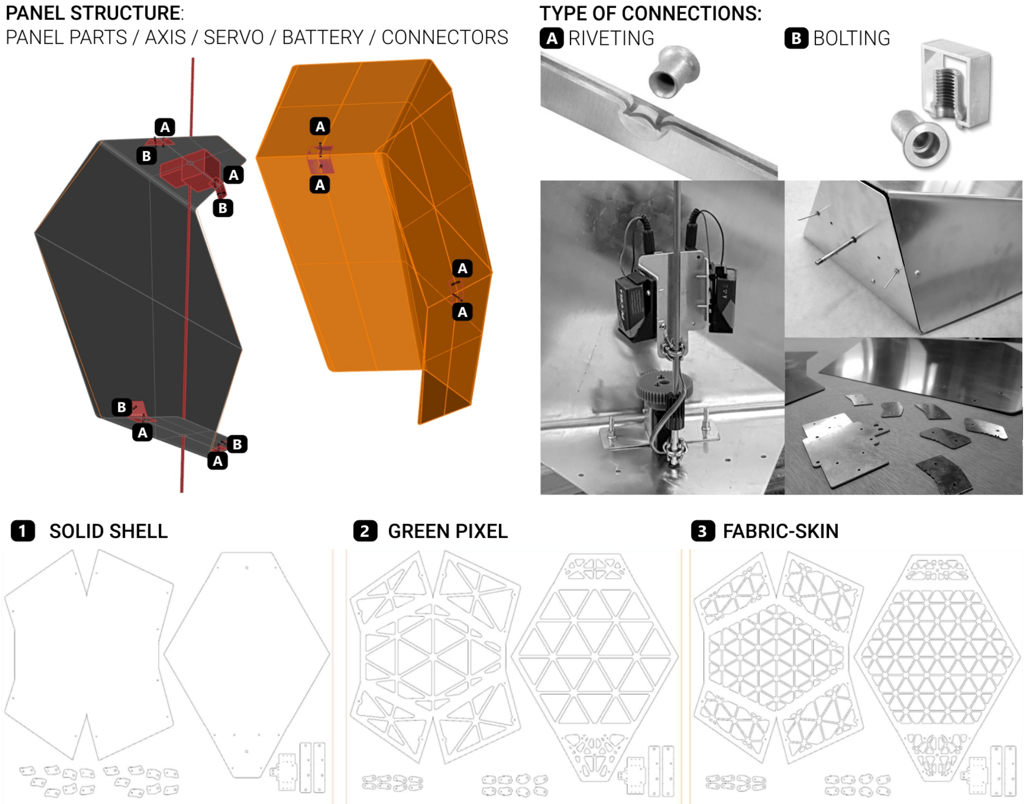


Figure 3
Third Research Stage: Panel structure / Jet cutting aluminum sheets

various thicknesses [1.0 - 1.6 mm]. All panels (test groups) had identical three dimensional hexagonal shape, however the three test groups had different structural cut patterns.

The panels were designed to be fully autonomous, easily managed and/or replaced without disrupting the rest of the facade system. The outer- shell panel designs were composed of two main parts: a) detachable front -cover; and b) base back-cover, that was attached to the rotating servo. The servo-to-panel rotation was transferred using two gears: the first, a 50 tooth nylon spur gear, was attached to the servo and the second, a 15 tooth carbon steel gear, was attached to the rotation axis - in this case a 6mm stainless steel metal rod shaft. The metal rod and its steel gear had a fixed position and were not moving, the larger diameter nylon gear was attached to the servo that transferred its rotation to the gear and thus rotated the gear and itself around the axis. The panel back-cover was in its turn attached to the servo which, as a result, rotated the panel.

The full-scale prototyping study was split into three 'panel design' test groups: 1) Solid Shell, 2) Green Pixel, 3) Fabric-Skin; with eight panels per group. Each of the test groups was further split into

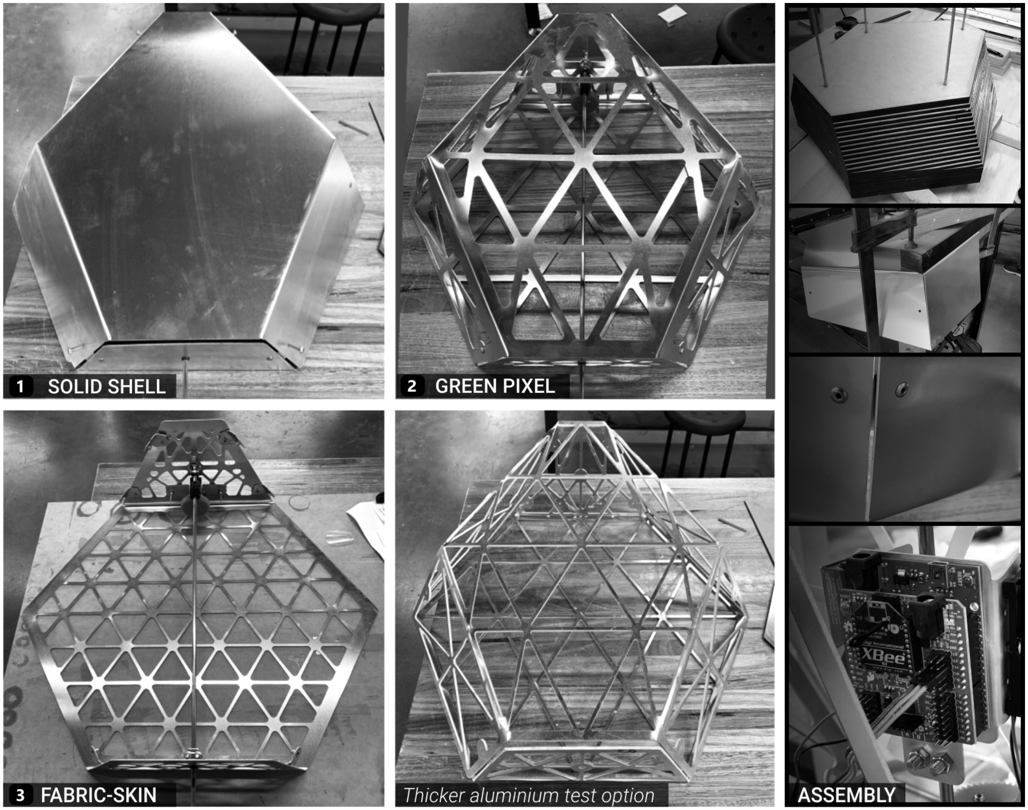


Figure 4
The structure. Panel Test Groups: Solid shell / Green Pixel / Fabric skin / 3mm Test Option. Panel Assembly Progression

three sub-categories that referred to the three different thicknesses of aluminium sheets from which they were cut, i.e.: 1.0mm, 1.2mm and 1.6mm. This was done to determine the optimal (weight vs structural performance) thickness of aluminium sheets. To test the feasibility of manufacturing the panels using a thicker grade of aluminium one panel was cut out of a 3mm aluminium sheet. The design (cut-out pattern) of this panel's frame structure was altered to be half as wide (5mm as opposed to 10mm) as previous frames, in order to minimise the use of material, and hence lower the overall weight.

The three panel test groups refer to the alternative structural design (and some extra functions) strategies which are outlined below:

- The **Solid Shell** panel design: This is a fully enclosed solid aluminium shell. As a design option it references the initial panel design adopted directly from the outcomes of the first and the second research stages (Moloney, 2011), (Moloney et. al. 2018).
- The **Green Pixel** panel design: This refers to a large (150mm) triangular grid frame with embedded water tubes for irrigation and plants growing purposes. This panel serves as the an analogue 'pixel' to host the edible plants

and vegetations with different colours, enabling the panel to perform various functions simultaneously, e.g.: shading device, media pixel and green wall. This design strategy brings together various subsets from the general fields of vertical garden and media facade to achieve a hybrid environmental-media facade. (Gehring and Kruger, 2012) , (Schoch, 2006).

- The **Fabric-Skin** panel design: This is a composite material strategy for panel designs that uses aluminium structure with a smaller (75 mm) triangular grid frame that is afterwards draped with a flexible water resistant textile (fabric skin). This design strategy is inspired through the speculative form-changing surfaces of BMW's GINA Light Visionary Model that challenge the new possibilities to be applied in the design of architectural skins. (Bangle, 2000). The perforated aluminium frame structure thus serves as the 'skeleton', enabling flexible water resistant and lightweight textile to serve as an exceptionally light outer 'skin'. Depending upon the characteristics of the host building, climate conditions and urban context, different types of the outer skins could be applied and updated constantly varying such properties as level of water and wind resistance, durability, texture, transparency, translucency and colour.

FULL SCALE FABRICATION / PIPELINE AND ASSEMBLY

The fabrication pipeline could be split into six consecutive steps:

1. panels designed as three dimensional components using Grasshopper(2019) and Rhino3D (2019);
2. the structural outer-shell surfaces and fixings 'unrolled' as two dimensional (2D) vector outlines;
3. the 120mm x 2400mm aluminium sheets were jet-cut using the unrolled 2D outlines;
4. the cut-out elements were bent to form using the three dimensional panel moulds (manufactured from glue laminated 6mm MDF sheet, CNC cut using the initial Rhino 3D file); The glued mould then sculpted by hand to the required specifications;
5. bent elements were assembled together using: a) permanent aluminium rivets and b) rivet nuts + bolts, that allowed each panel to be easily opened when necessary;
6. finally, the core rotation axis, two (nylon and metal) gears, servos, batteries and controllers were installed inside each panel.

Construction of the panels was, as with any prototype build, an exercise in practical experimentation. The very first panel, a 'solid shell' panel as described in the previous section and shown in image 1 above, was bent by hand and eye into the desired shape. The panel was then fully assembled including all gearing, shaft and motor drive. During this process it was discovered that the nylon gear needed to be accurately counterbored to take the bolts used to mount it to the drive motor. This was a proof of concept creation designed to ascertain that the gear ratios selected were indeed optimal, and that the geometry for rotation around the centre shaft was correct. Likewise it proved that the motor and associated electronics worked to specification.

In concluding this phase it became obvious that a faster folding technique needed to be devised if the number of panels to be generated could be output within an acceptable time frame. The decision to fabricate an MDF mold was taken, and although this in itself took a significant portion of the available time, it radically sped up the folding of the remaining outer shells and backing components, even though this was still done by hand panel beating techniques. Included in the production of this mold were two small molds for the folding of the brackets used to couple the front and back panels together.

Once all the panels and coupling components were appropriately folded a rapid assembly process

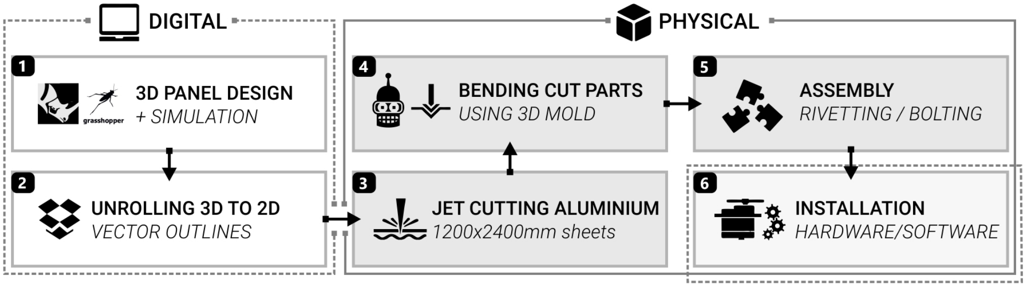


Figure 5
Panel Fabrication Pipeline

followed based upon the knowledge gained from the first solid panel. This was undertaken using a 'production line' approach whereby multiple components were drilled, bent, and assembled in sets.

The final step in making a fully functional façade was to assemble a suite of panels in a stable frame. Aside from providing a visual proof of concept, it allowed for testing of rotation in unison, and later, air tunnel testing where laminar flows could be used to determine key engineering elements such as required shear and extraction stresses for support and mounting design. It was determined that the panels would be mounted vertically in two sets of three and one of two. Aluminium square hollow section was used to create three 'U' shaped stands where were coupled by a single sheet of 6mm Perspex. This allowed for the panels to be transported to exhibition spaces whilst providing a genuine example of its variable light transmission properties.

The creation of the panel set showed the limitations of the main axis rods, which, though adequate as a prototype, would require more support or be upgraded in a real world application. Likewise, the testing of the motor drives under the computer program gave light to inadequacy of the motor mounting when stressed by accidentally applied rapid movement; as against the slow movements for which it was initially designed. Wind tunnel testing may also show that this mounting may not withstand firm wind pressures, allowing the panels to jump teeth on the main drive gear.

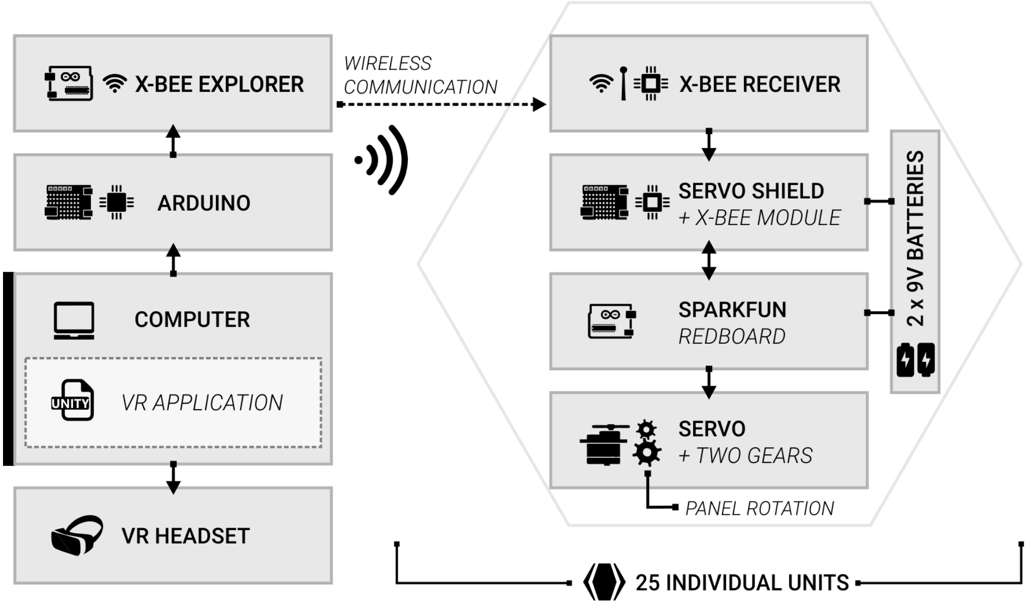
KINETIC SYSTEM CONTROLS / SOFTWARE AND HARDWARE

The kinetic control system is consisted of 15 rotating panels arranged on a 3x5 hexagonal grid unit; each unit is controlled by an individual kinect module, which wirelessly communicates with a VR application on the laptop. Fig.6 illustrates the design of this kinetic control system. The design and development details of the kinect module (hardware) and the VR application (software) are presented in this section.

Each individual panel is controlled by a separate kinect source, which consists of: (1) a vertical rotation axis (6mm metal rod) that was to be attached to an existing facade; (2) a SparkFun Redboard which can be programmed to give "commands" to attached device; (3) a wireless motor driver shield board attached to the Redboard, with an XBee module; (4) an XBee receiver attached to the wireless motor driver; (5) a powerful standard-size servo with metal gears (Power HD High-Torque Servo 1501MG) attached to the wireless motor driver. Such components are connected by wires and are placed inside the detachable outer aluminium shell (as illustrated on the right of Fig.6).

At the current stage, two rechargeable 9V batteries are connected to the Redboard and the wireless servo shield as power supplies; in the future, the panels are expected to be powered by a small-scale solar panel, solar charger and batteries. By doing so, the kinect control system will be sustainably driven by renewable energy; there will be no need for bat-

Figure 6
Kinetic Control System: Hardware and Software



tery changing and thus reduce both the costs and the maintenance.

All facade panels are controlled by an VR application installed on an external computer communicating wirelessly through an Arduino and an XBee Explorer. The XBee Explorer is attached to an Arduino board, which is connected to the laptop that runs the VR application (as shown on the left of Fig.6). The VR application sends signals to the computer port to which the Arduino board is attached; simultaneously the Arduino board passes the signals to the remote panels through the XBee components. Upon picking up the signals, the wireless servo shield will drive the servo rotating to the same angles to the virtual panels in the VR application.

The application that controls the physical panel was developed with the game engine Unity3d, with a third party plugin named Uduino. The Uduino script can automatically discover ports that are connected to Arduino boards, read and write to pins of the Arduino boards. Pins can be defined as either digital or analog; for the application described in this paper, the pins are defined as "digital servo output", so that the desired angles of the panels will be sent out from the pins in the form of numbers. On the panel side, the physical servo needs to be connected to the same pin ID to be able to receive the expected values. For example, a servo that connects to pin 13 on the wireless servo driver will only be receiving values sent out from pin 13 on the Arduino board. If there are two or more servos connected to pin 13 of separate servo drivers, all of them will receive the same value and thus rotate to the same angle.

GREEN PIXEL AND FABRIC-SKIN PANEL STRATEGIES / RATIONALE AND APPLICATION

In general, a conventional responsive facade system focuses on the adaptive shading, climatic control and media purposes, few intend to explore the additional hybrid functions for an integrated environmental-media architectural skin. As briefly mentioned in the previous section, these integrated functions of the hybrid environmental-media facade (HEMF) will be further discussed in this section that include the rationale and potential application of the proposed Green Pixel and Fabric-Skin panels. The outcome of the full scale prototype panel fabrication is a promising demonstration that enables the implementation of these applications to achieve a hybrid responsive facade with multiple, editable and changeable functions.

Green Pixel Panel

Research on green facades is not new in the fields of architecture and built environment, however this approach could be further extended to include alternative design implications beyond planting and vegetation. For instance, the vast vertical surface areas of the existing walls and facades of high-rise buildings in crowded, highly populated cities not only provide an opportunity to design and implement green facades; architectural features such as media facades have also been created on building walls and facades for purposes of commerce, advertisement, communication, art installation and social interaction (Dalsgaard and Halskov 2010, Fortin et al. 2014). In the context of contemporary cities, media facades normally take the form of LED displays or projection systems embedded into the surface of a facade. But what if media facades were conceived as a series of vertically arranged edible plants?

PixelGreen - a hybrid green media wall - demonstrates each plant could serve as an individual 'pixel', allowing a range of content and use scenarios to be considered. Due to the life cycle of the edible plants, the content of this analogue media facade could be updated at timely intervals through each harvest (Khoo and Wee 2019). The proposed Green Pixel panel could achieve this design strategy and application to bring together the green and media content to form an integrated green media facade. The edible plant will be hosted in each Green Pixel panel. These plants can be controlled and maintained by the water based hydroponic system and the programmed unmanned aerial vehicle (UAV).

Fabric-Skin Panel

Besides the typical materials such as aluminium and steel, the 'skin' surface of the panels could be replaced by the soft materials such as ethylene tetrafluoroethylene (ETFE) and kevlar to fulfill and respond the various purposes and performances. Indeed, soft materials have been implemented on building facade or surface since 1960s. The famous climatic skin of the Biosphere at the Montreal Expo of 1967, designed by Buckminster Fuller, sets the first precedent for this type of soft architectural skin approach. It is considered a pioneering use of soft materials (fabrics) in the design of the shutters on its geodesic dome steel structure, and its acrylic cell envelope (Bonnemaison 2008).

Since 1960s, material technology advancement has providing a vast opportunity to apply soft material on building facade with multiple functions and performances. These soft materials are able to perform colour, physical, temperature, shape change and energy harvesting such as photovoltaic cells are available today that make them attractive to architects, both from visual and a practical point of view (Konarzewska 2017). Soft building materials are becoming more feasible to be applied as building elements, especially for facade and building envelope.

The overall perforated structure of the Fabric-Skin panel serves as the flexible 'platform' to accommodate various soft materials with different purposes and situations. For instance, the outer soft skin of the Fabric-Skin panel is changeable to respond to the different needs to achieve the transparency and translucency of the overall facade appearance. In addition, phosphorescent material and photovoltaic cells can be integrated into the soft fabric skin to achieve a self-sustained energy supply for the passive and active lighting system.

Figure 7
Hybrid Kinetic Facade System - Full Scale Prototype

DISCUSSION

Current accessibility and affordability of advanced digital fabrication technologies allow architects and designers to develop and evaluate the full-scale architectural components and prototypes directly with minimum inputs from specialised fabricators and manufacturers. The outcomes presented in this paper illustrate a successful methodology and step-by-step development approach for the real-life application of a hybrid media facade, doing so with a lean fabrication process, minimal cost and time.

Indicative to the overall trends of the Fourth Industrial Revolution (4IR) this research project progresses through the use of an iterative prototyping approach utilising a diverse spectrum of technologies; simultaneously tapping into and fusing together the digital (computation / simulation / calibration / intelligent and interactive wireless control systems / 'live' weather, urban environment and individual preference input) and the physical (full-scale aluminium panel fabrication / autonomous kinetic units / composite material solutions that uses metal, fabric and vegetation / and physical engineering testing) (Weforum, 2016).

But more importantly, the hybrid facade system adopts self organization and support, and the actualization characteristics of the 4IR (Lee at al., 2018): re-imaging the ways that architecture could communicate and connect with people and environment on the individual occupancy, building, urban context, and broader global levels. In so doing, responding to the ever shifting variables of weather, news, social networks, advertising trends and the like.

FURTHER WORK

This article reports the design and fabrication aspects of full-scale panel prototypes. Further work will include evaluation of each design strategy through Integral Life Cycle Sustainability Assessment, engineering analysis and qualitative assessment by end users.

- Integral Life Cycle Sustainability Assessment (LCSA) - carried out by an external international collaboration group. The objective of this proposed study would be to use the project as a case study to develop and test a comprehensive approach for an integral theory applied to LCSA using the four quadrant assessment. This would evaluate the hybrid facade performance within qualitative and quantitative, individual and collective agendas; with quadrants represented as: Systems, Behaviours, Experiences, and Culture.
- Engineering Analysis looking into: fatigue, structural strength, durability, wind and water resistance will be delegated to a team of engineers and material scientists working at Deakin University. It is planned to use eighteen out of twenty five fabricated panels for the engineering performance evaluation. It is to be noted that testing need not be destructive as the prototypes inform sufficiently of their basic structural limitations. The main tests will be low pressure wind modelling, from which future mounting systems, and panel responses to lateral and thermal differential pressures scaled up through computer modelling of this real to world data: This data then informing future prototype generation with the intent of on structure (building) testing.
- The qualitative assessment of three panel design strategies using Virtual and/or Augmented Reality is planned to be undertaken

by the MiND Lab (2019) development and research group in collaboration with the University of Sydney. The objective of this 'pre-occupancy' study will be to engage with the multi-sensory feedback from the observers afforded by the immersive VR environment, and thus evaluate various characteristics of each of three panel design strategies applied within different architectural contexts

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