

Case Studies – Adaptive Facade Network

Laura Aelenei
Daniel Aelenei
Rosa Romano
Enrico Sergio Mazzucchelli
Marcin Brzezicki
Jose Miguel Rico-Martinez

Case Studies

Adaptive Facade Network

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Editors

Laura Aelenei, Daniel Aelenei, Rosa Romano, Enrico Sergio Mazzucchelli, Marcin Brzezicki, Jose Miguel Rico-Martinez

Layout and Co-Editing

Ashal Tyurkay, Uta Pottgiesser

Design

Sirene Ontwerpers, Rotterdam

Cover Image

Marcin Brzezicki, Wroclaw

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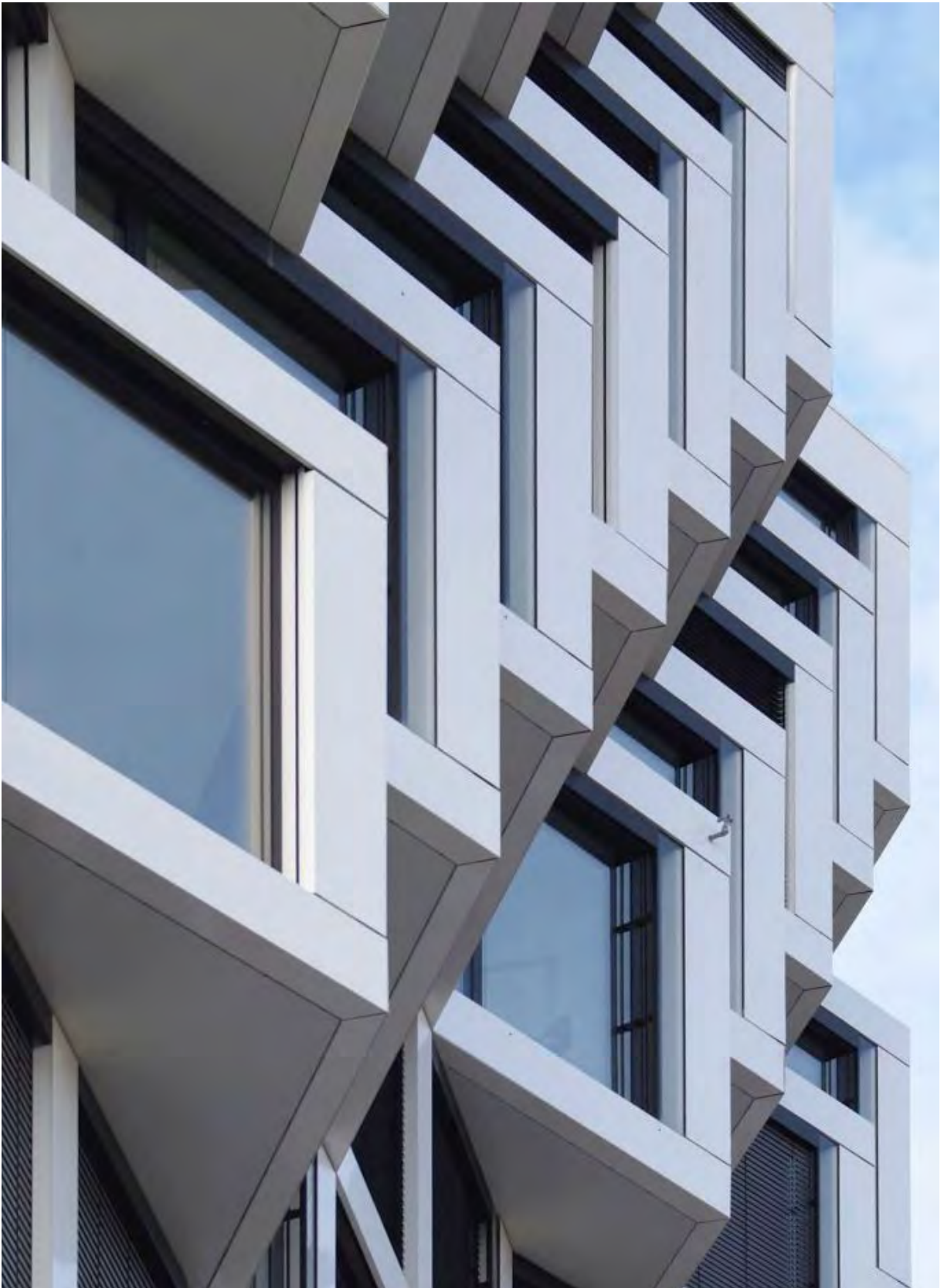
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TU Delft for the COST Action 1403 adaptive facade network



Wohntürme Friends in München / Allmann Sattler Wappner (image: M. Brzezicki)

Preface

Adaptive building envelopes can provide improvements in building energy efficiency and economics, through their capability to change their behaviour in real time according to indoor-outdoor parameters. This may be by means of materials, components or systems. As such, adaptive façades can make a significant and viable contribution to meeting the EU's 2020 targets. Several different adaptive façade concepts have already been developed, and an increase in emerging, innovative solutions is expected in the near future. In this context the EU initiative COST Action TU 1403 aims to harmonize, share and disseminate technological knowledge on adaptive facades at a European level.

According to the definition given by this COST Action, an adaptive façade is a building envelope consisting of multifunctional and highly adaptive systems that is able to change its functions, features, or behaviour over time in response to transient performance requirements and boundary conditions, with the aim of improving the overall building performance.

In order to explore the available and emerging technologies focusing on adaptive façades, Working Group 1 of the COST Action undertook research to form a database of adaptive façade case studies and projects structured in accordance with a simple classification – materials, components and systems. In addition to this, details of the purpose of the systems/components/materials with adaptive features and the working principle of each technology were also collected together with data regarding design practice, technology readiness, and economical aspects, among others.

The information was collected with the help of a specific online survey (structured in the following main sections: detailed description - metrics- characterization- economic aspects – references). The database includes 165 cases of adaptive façade systems, components, and materials that allowed a variety of analyses to be carried out. According to the classification adopted within WG1 (materials, components, systems), each of the classification terms are introduced together with examples from the case study database in the following sections. This volume ends with a section dedicated to future developments, where different issues are addressed such as embedded functionality and efficiency and biomimetic inspirations. The importance of adaptive façades through their flexibility, and intelligent design within the context of smart cities is also discussed.

The work within Working Group 1 - Adaptive technologies and products was developed within four distinct sub-groups (SG) in order to provide outputs according to the objectives of this WG and the COST Action: SG1 – Database, SG2 – Educational Pack, SG3 – Publications and Reports and SG4 – Short Term Scientific Missions (STSM).

This work was possible due to the strong commitment and work of all WG1 members: Laura Aelenei, Aleksandra Krstić-Furundžić, Daniel Aelenei, Marcin Brzezicki, Tillmann Klein, Jose Miguel Rico-Martínez, Theoni Karlessi, Christophe Menezo, Susanne Gosztonyi, Nikolaus Nestle, Jerry Eriksson, Mark Alston, Rosa Romano, Maria da Glória Gomes, Enrico Sergio Mazzucchelli, Sandra Persiani, Claudio Aresta, Nitisha Vedula, Miren Juaristi.

Laura Aelenei



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Toho Cinema in Roppongi Hills / Yu Design (image: M. Brzezicki)

Case Studies - Adaptive Façade Materials

Mark Alston, Nikolaus Nestle, Miren Juaristi, Laura Aelenei, Rosa Romano, Enrico Sergio Mazzucchelli, Jose Miguel Rico-Martinez

Introduction

Materials in the built environment play a major role in operational energy consumption and structural optimization as they are defined by boundary conditions. These materials functions sets the operational performance requirements for building component interfaces as an integrated façade system. Addington and Schodek (2005) identify 'smart materials' as systems possessing 'embedded technological functions' that involve specific environmental responses, operating either through internal physical property changes or through external energy exchanges (Velikov and Thün, 2013). Furthermore, they define the characteristics of smart materials as: 'immediacy' (real-time response), 'transient' (responsive to more than one environmental state), 'self-actuation' (internal intelligence), 'selectivity' (a response is discrete and predictable) and 'directness' (a response is local to the activating events) (Addington and Schodek, 2005).

According with these definitions, the Material chapter (and data base of a selected material grouping) will assess:

- material adaptiveness in response to boundary conditions changes defined by climate, thermal and visual comfort for well-being;
- how materials can be in real time sync with the pattern changes in their environment as an energy, matter connection;
- the dynamic relationship that is achieved through material composite function and material connectivity to building surface geometry. In order to manipulate the climatic environment and obey rules of minimum energy loss and minimized effective power outputs;
- the energy and matter system of material layers, that are nested together to form the overall emergent composition;
- a multi-layering approach at a number of levels of resolution with different spatial and temporal scales;
- the material performative specific tasks that can be classified in the control processing of functional materials, achieved by a bottom up trajectory.

Thermal, visual comfort demands are driven by the prerequisite to moderate climatic regional environments for shelter. To maintain thermal comfort the building envelope acts as a boundary working with mechanical service systems (heating/cooling, lighting) to regulate internal surrounding temperature. In opaque envelopes the technological methods of achieving good thermal insulation is well researched and advanced. However, to achieve visual comfort and contact to the outside environment, at least part of the building skin needs to be transparent. Translucent components can also contribute to visual comfort by allowing ingress of daylight while redirecting it in a way to avoid harsh shadows. By allowing the ingress of solar irradiation into the building comes with heat gain issues that require measures against overheating in warm conditions. Hence, thermal insulation properties of the current state-of-the-art in transparent and translucent building envelopes are rather poor in comparison to those of opaque elements.

Glazed facades in cities offer high value visual and day-lighting provision. Through the optical benefits of view, colour and light intensity cannot be underestimated for human well-being. There are many technical issues to manage this high energy flow between thermal gain and heat loss. Through two types of glazing properties; transparent facades that are optically clear in the visible part of the electromagnetic spectrum and translucent material allowing partial light to pass through for semi-transparent light refraction.

Materials shifting from a transparent to a translucent state is one of the most intensively studied adaptive properties of the façade to regulate transmission of visible light and solar radiation. This is driven by solar radiation impact on a material surface that adsorbs and transports this thermal energy into internal spaces and thus creates a strong need for avoiding unwanted thermal gains and losses. By mainly specifying static quantities such as the U-value and the g-value, present building codes still essentially ignoring the potential of building skin elements for adaptive performance. That directly influences active cooling systems to manage unwanted solar gains fighting internal thermal loads (lighting, equipment, and occupants) for thermal comfort. The challenges in materials with a dominant optic role is optimizing the parameters of visible light transmittance with a lower phase transition temperature for the reduction in air conditioning demand. The ability of current materials to interact with the environment by constant readjustment of functional performance is however still undetermined. In order to meet the demanding Zero Energy Building performance goals a function of adaptability in materials and their integration into component systems is required.

The most controllable form of adaptivity can be reached with materials that can be adapted by an 'extrinsic' stimulus such as an electromagnetic field or a pressure change applied to the material. Examples are electrochromic glazing, liquid crystal devices and vacuum insulation that can be switched by a controlled change in the gas partial pressure within the insulation element. To optimally harness the adaptability of such materials, they need to be integrated into special devices that allow the application of the corresponding 'extrinsic' stimuli. Another class of adaptive materials reacts to an 'intrinsic' stimulus, i.e. a change of a parameter directly relevant for comfort and energy balance of the building such as light intensity, temperature, moisture for example. The characterization of these materials include photochromic glasses, thermo-opaque or shape-memory materials. As an intrinsic environmental stimulus is used to trigger the change in material properties in this case, the integration of the material into a building is usually much simpler than for extrinsically stimulated additivity. However, the adaptivity of a facade relying on such a material is autonomous and can't be extrinsically controlled. That may lead to suboptimal adaptation effects in certain cases (for example, a temperature-induced switching of a facade element to a higher U-value at an external temperature of 12 °C .This is highly useful on a cool summer morning, however, this switching on a warm winter afternoon is unwanted. Alternatively, adaptive facade components responding to intrinsic switching stimuli do not require any connection to active building control systems and thus integration is simpler. Hence, they are extremely attractive to building designers where the aim is aim to increase functionality and performance while at the same time reducing energy use for new or existing buildings.

Further examples are presented in later chapters of the book to illustrate other methods, to realize adaptive facade elements without 'adaptive' material (e.g. Yale Sculpture facade; SELFIE facade; BIPV/T Systems). In some of those elements, the material choice nevertheless is crucial for achieving the desired adaptive functionalities in a given facade component. The database illustrates a selective grouping through defining material families and their classification. Materials that depend on a strong deformation cycle of geometry shape change for adaption without fatigue of failure is a prerequisite for this grouping. Nevertheless, it's not really the material that is adaptive

in this case and thus we have decided not to consider such materials in the materials section of this book.

Adaptive Materials Case studies database

Material properties are defined by single values such as thermal conductivity or transmission of solar radiation. Adaptive materials are characterized by a range of values depending on the respective switching parameter or they come with a “memory” for buffered energy flows such as phase change materials. Due to the diversity of these properties, not all materials in the database can be characterized by the same set of properties. Materials with adaptive heat transport properties are scarce with the most notable cases being applied in vacuum panels in which the thermal conductivity is switched by building up a sufficient partial pressure of hydrogen gas to leave the Knudsen regime and phase change materials (PCM) serving as buffer materials for heat.

In the following table, representative adaptive material families are classified according to a dynamic behaviour or performance that they are able to provide as a response to a specific stimulus. As a result, there are four main categories defined by the type of reaction: reversible colour or opacity change, reversible heat flow direction, shape changing materials and materials that absorb water or ambient humidity. Furthermore, this classification becomes more specific when we consider the environmental triggers for reactive self-responses. For instance, thermochromic, electrochromic, photochromic and thermotropic modify their solar reflection, but they do so at different operational scenarios. Thermochromics change their colour when the material reaches a defined temperature, electrochromic materials when an electrical current is applied and photochromics when they are exposed to a specific wave-length of solar radiation. This detailed Material Family Classification, is based on the response input and output, for meaningful scoping in new roles of application in façade systems. By the ability of the material to modify one of their features or properties and to understand under which circumstances that would occur. The following materials have been classified through case study examples as classified by material families and their classification according to their input and output reactions (Table 1).

Table 1 - Material families and classification according to their input and output reactions

Reversible colour / Opacity change	Reversible heat flow direction	Shape Changing Materials	Humidity absorption
Thermochromic ¹ Electrochromic ² Photochromic ³ Thermotropic ⁴	Phase Change Materials	Electroactive materials / piezoelectric materials ⁵ Shape Memory Polymers ⁶ Shape Memory Alloys ⁷ Thermobimetals ⁸ Bi-layer hygroscopic composites ⁹	Hydrogel ¹⁰ Natural Porous Materials ¹¹

Material function through Additive Material Manufacturing

The maturing of 3D printing techniques into actual manufacturing technologies will open up further space for the realization of adaptive building components and at the same time further blur the difference between actually adaptive materials and adaptive building elements, whose adaptivity is the result of a combination of several materials into a system. Recently, biomimetic hygroscopic actuators produced by 3D printing of materials with different moisture sorption properties have been demonstrated (Correa and Menges, 2017).

While additive manufacturing definitely will widen the materials toolbox to create adaptive properties in building skins, it also further aggravates the life cycle issues that come with the large-scale use of combinations of different materials at the end of their service life: without viable solutions for separating the different materials again, they will be hard to recycle appropriately. In principle, there are four ways how to deal with this issue:

- monomaterial components that are combined to an adaptive element in a way that can be easily separated again at the end of its service life;
- biodegradable materials (such as suggested in Correa and Menges (2017));
- material combinations that can be separated quantitatively by simple reprocessing techniques such as melting or dissolving a binder component that later is recycled as well;
- material combinations that can be energetically re-used without issues such as dilution of scarce elements or release of hazardous byproducts (for example by using functional carbon materials such as graphene for electrical functionalities instead of metals or inorganic semiconductors).

Conclusions

A selected range of current materials are defined through the data base. In the review to assess the control process methods for an adaptive material function. To reduce solar loads for thermal comfort, through minimizing operational cooling and artificial lighting levels. This material oriented design method will fine tune operational performance to solar gain in real time, for well-being of occupants. The capacity to respond in a dynamic manner to the physical changes of a warming climate is the challenge to advance new and innovative semi/transparent material solutions. To move towards occupant comfort and well-being that is not based on statistical averages but one that is fine-tuned to responsiveness to change. If we assess the information within the database, we realize that more experimental assessments at the façade scale is needed. In order to learn more, what could be new possible application of these materials in Adaptive Facades. However we still need to collect more critical technical data in order to scope their possible innovative applications, through scientific research and product information that are essential for optimized system assembly. We are currently reliant on the origin of the selected materials applied to building envelopes. However a bottom up formulated material approach tailored to their specific task function would advance performative task roles. Hence material composition needs to advance analytically to address the specific challenges of their fields. To enhance visible transmission and solar modulation properties for adaptive facades.



Figure 1 - Locations of case studies “materials”

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DnB NOR Building / MVRDV, Dark Arkitekter and a-lab (image: M. Brzezicki)

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3 LCRHallcrest.

4 Seeboth, Ruhmann and Mühling (2010).

5 Rossi, Augustynowicz et al. *ShapeShift* (2018); Madden (2008).

6 Fiorito, Sauchelli, et al. (2016); Ge, Sakhaei, et al. (2016); Lendlein, Jiang, et al. (2005); Jiang, Kelchand Lendlein, (2006).

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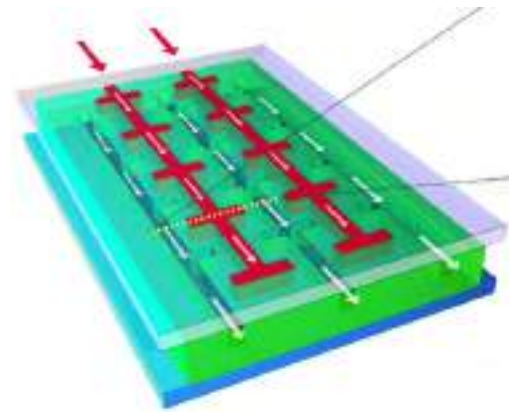
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10 Raviv, Zhao, et al. (2015); Markopoulou (2015).

11 Watanabe, Fukumizu and Ishida (2008).

**REGENERABLE PV WITH HYDROGEL, North Carolina State University (USA),
Hyung-Jun Koo and Orlin D. Velev**

Photovoltaic systems based on photosensitive organic dye molecules could be a simple and economical alternative to conventional solar cells, and have been actively developed for decades. The best examples of such devices are the common dye-sensitized solar cells (DSSCs) though other systems based on a dye-embedded hydrogel or naturally derived photoactive molecules have also been reported recently. Since the organic dyes are generally susceptible to light, high temperature or water the degradation of photoactive molecules in the dye-based photovoltaic systems could be a critical problem, which leads to deterioration of the long-term performance of these photovoltaic cells.



MATERIAL



COMPONENT



FACADE

PHOTOSYSTEM; REGENERATION; DYE INFUSION; BIOMIMETIC

BUILDING INFORMATION:

Building floor area	-	Climate Type	All of them
Building use	Energy generation	Orientation of the facade	All orientation
Building status	-	Other	-

DETAILED DESCRIPTION OF THE CASE STUDY SYSTEM

TECHNOLOGY READINESS LEVEL

01. Basic principles observed and reported/ Idea	<input type="checkbox"/>
02. Technology concept formulated/Design Proposal	<input type="checkbox"/>
03. Technology validated in lab	<input checked="" type="checkbox"/>
04. Prototype demonstration	<input type="checkbox"/>
05. Commercial product/Existing building	<input type="checkbox"/>

FUNCTION / GOAL / PURPOSE

Thermal comfort	<input type="checkbox"/>
Visual comfort	<input type="checkbox"/>
Acoustic comfort	<input type="checkbox"/>
Energy management (harvesting, storing, supply)	<input checked="" type="checkbox"/>
Mass transfer control (e.g. condensation control)	<input type="checkbox"/>
Indoor air quality	<input type="checkbox"/>
Appearance (aesthetic quality)	<input type="checkbox"/>
Structure performance	<input type="checkbox"/>
Energy generation	<input checked="" type="checkbox"/>
Personal users' control	<input type="checkbox"/>
Other (durability, accessibility, use of natural resources, etc).	<input type="checkbox"/>

TYPE OF MATERIAL

Thermochromic	<input type="checkbox"/>
Electrochromic	<input checked="" type="checkbox"/>
Photochromic	<input type="checkbox"/>
Thermotropic	<input type="checkbox"/>
Phase Change Material	<input type="checkbox"/>
Shape Memory Polymer	<input type="checkbox"/>
Shape Memory Alloy	<input type="checkbox"/>
Thermobimetal	<input type="checkbox"/>
Bi-layer hygromorph composite	<input type="checkbox"/>
Hydrogel	<input type="checkbox"/>
Natural Porous Material	<input type="checkbox"/>

MATERIAL FAMILY

Reversible colour / Opacity change	<input checked="" type="checkbox"/>
Reversible heat flow direction	<input type="checkbox"/>
Shape Changing Material	<input type="checkbox"/>
Humidity absorption	<input type="checkbox"/>
Other:	<input type="checkbox"/>

M_01

TYPE OF MATERIAL	
Liquid crystals	<input type="checkbox"/>
Phase Change Materials	<input type="checkbox"/>
Polymers	<input type="checkbox"/>
Alloys	<input type="checkbox"/>
Ceramics	<input type="checkbox"/>
Wood	<input type="checkbox"/>
Salthydrates	<input type="checkbox"/>
Other (specify): dye-sensitized solar cells	<input checked="" type="checkbox"/>

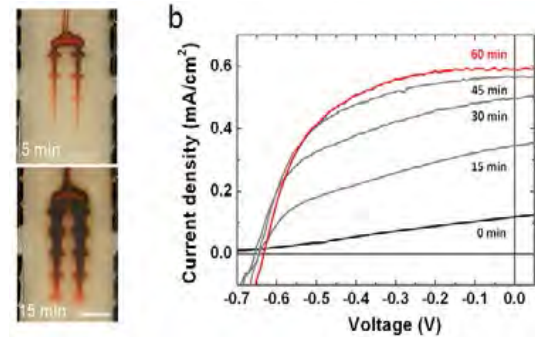
TYPE OF SHADING DEVICE	
Screens / roller shades	<input type="checkbox"/>
Blinds with slat angle control	<input type="checkbox"/>
Bi-directional transmission control	<input type="checkbox"/>
Insulating shutters	<input type="checkbox"/>
Shading with dual-axis tracking	<input type="checkbox"/>
Other (specify):	<input type="checkbox"/>

MATERIAL EFFECT HOW DOES THE MATERIAL ADAPT?	
Shape Memory Material	<input type="checkbox"/>
Bi-material effect	<input type="checkbox"/>
Electroactive material	<input type="checkbox"/>
Superabsorbent material	<input type="checkbox"/>
Phase Change	<input type="checkbox"/>
Other (specify): chemical infusion of organic dye u-FGPV	<input checked="" type="checkbox"/>

TYPE OF TRIGGER (INPUT)	
Mechanical (e.g. wind load)	<input type="checkbox"/>
Thermal (e.g. outdoor air temperature)	<input type="checkbox"/>
Electromagnetic (e.g. solar radiation)	<input type="checkbox"/>
Optical (e.g. daylight level, glare)	<input type="checkbox"/>
Air quality (humidity, CO2 concentration, etc)	<input type="checkbox"/>
Building heating/cooling load	<input type="checkbox"/>
Occupant's presence	<input type="checkbox"/>
Other (specify): energy enhance performance function of PV	<input checked="" type="checkbox"/>

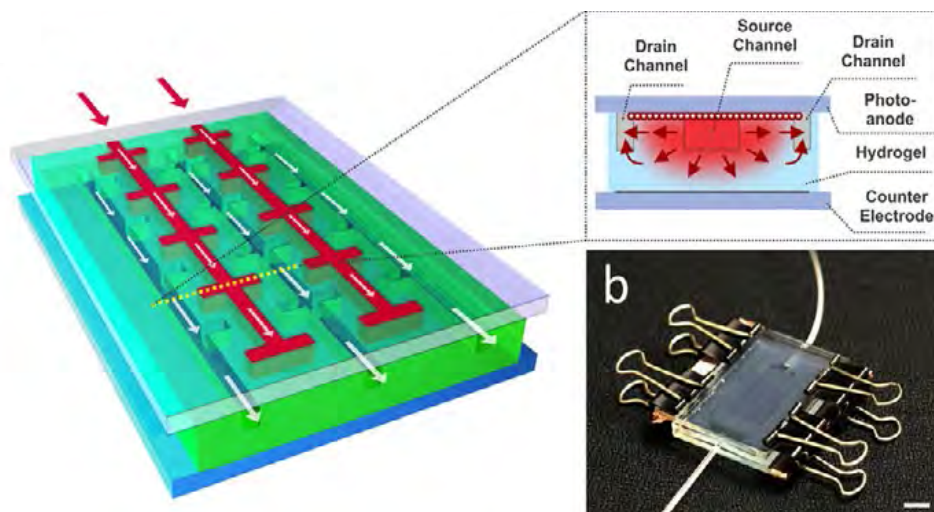
TYPE OF ACTUATOR (OUTPUT)	
Mechanical	<input type="checkbox"/>
Pneumatical	<input type="checkbox"/>
Electromagnetic	<input type="checkbox"/>
Thermal	<input type="checkbox"/>
Chemical	<input checked="" type="checkbox"/>
Other (specify): Manual	<input type="checkbox"/>

TYPE OF SWITCHABLE GLAZING	
Electro-chromic (EC)	<input type="checkbox"/>
Liquid crystal, SPD	<input type="checkbox"/>
Photo-volta-chromic	<input type="checkbox"/>
Independently tunable NIR-VIS EC	<input type="checkbox"/>
Thermo- tropic / chromic	<input type="checkbox"/>
Photo-chromic	<input type="checkbox"/>
Fluidglass	<input type="checkbox"/>
Other (specify): photoelectrochemical oxidation to reduce accelerated photo degradation for enhanced photovoltaic functionality	<input checked="" type="checkbox"/>



- (a) Images illustrating the progressive infusion of dye and electrolytes through the gel-vascular network at 5 and 15 min after injection of the solution. Scale bar = 1 cm. The injection rate is 10 µl/min. (b) I-V curves of the µ-FGPVs under illumination after the first injection of the aqueous solution of dye and electrolytes
- a) A schematic of microfluidic channel network within the hydrogel photovoltaics (µ-FGPVs). The white arrows indicate the convection-dominant transport of dye and electrolyte molecules along the microfluidic channels. The inset displays the cross section view across the dotted yellow line. TiO₂ nanoparticles and Pt catalysts are deposited on the photoanode and the counter electrode, respectively. The red arrows indicate the lateral diffusive/convective transport between the source channels and drain channels. (b) A photograph of the prototype µ-FGPVs device. The top electrode is the photoanode. Scale bar = 1 cm. The area and the thickness of TiO₂ film are 3 cm² and ~6 µm, correspondingly.
- (a) Schematics of the three-step regeneration process. (c) I-V curves of the dye-replenished

CONTROL OPERATION DETAILS



2

DETAILED EXPLANATION OF THE CONTROL/OPERATION

Regenerable Photovoltaic Devices with Hydrogel-Embedded Microvascular Network (HEMN) is a material innovation for facades innovation surfaces with biomimetic microvascular network for dye infusion for regenerative photovoltaic performance.

Photosensitive organic Dye Molecules (PoDM) reduce deterioration of long term energy operational outputs and enhance the performance of photovoltaic cells. This biomimetic network of dye infusion gives damage regeneration by chemical compounds of action and reaction have been undertaken by Hyung within self-heal photovoltaic. Vascular networks have been used as regenerative functions for hydrogel photovoltaic devices by photosensitive organic dye infusion.

Organic dyes are generally susceptible to light stress, high temperatures that reduce the long-term performance of photovoltaic cells. Embedded microfluidics within a network enables regenerative functionality by the infusion of chemical regenerative properties by transport of photoactive agents dye and electrolytes to create a microfluidic hydrogel solar cell of optimum performance for electricity generation.

CONTROL/OPERATION TYPE

Intrinsic (auto reactive) ☐

Extrinsic (requires external control) ☐

Electromagnetic ☐

Other (specify): ☒
photovoltaic of u-FGPV in a closed structure

SYSTEM RESPONSE TIME

Seconds ☐

Minutes ☐

Hours ☐

Days ☐

Seasons ☐

Years ☐

Other (specify): ☒
depending on dye infusion into network, changes response time of PoDM regeneration

SYSTEM DEGREE OF ADAPTIVITY:

On/off ☐

Gradual ☒

Other (specify) ☐

DEGREE OF SPATIAL ADAPTATION

Nanometers ☒

Micrometers ☐

Millimeters ☐

Centimeters ☐

Meters ☐

Other (specify) ☐

LEVEL OF AF VISIBILITY

01 Not visible (heat storage, phase change materials) ☐

02 Visible, no surface change (smart glazing) ☒

03 Visible, surface change (lamellas, rollers, blinds) ☐

04 Visible, size or shape change (shutters, flaps, dynamic facade elements) ☐

05 Visible, location or orientation change ☐

Other (specify) ☐

ECONOMICAL ASPECTS

IS THE SYSTEM ECONOMICALLY VIABLE?

Yes ☐

No ☐

Other (specify):

lab testing at this moment - prototype under development

ESTIMATE THE COST OF THE CASE-STUDY

Low (traditional, residential, simple prefabricated, etc) ☐

Medium (curtain walls, ventilated facades, etc) ☐

High (double skin facades, high tech, etc) ☐

Information not available ☒

SYSTEM MAINTENANCE FREQUENCY

Daily ☐

Weekly ☐

Monthly ☐

Yearly ☐

Information not available ☒

Reference

Hyung-Jun, K., Orlin, D.V. (2013), *Regenerable photovoltaic devices with a hydrogel-embedded microvascular network*, Nat Sci Rep

Reference to picture

Hyung-Jun, K., Orlin, D.V. (2013), *Regenerable photovoltaic devices with a hydrogel-embedded microvascular network*, Nat Sci Rep

Author of the sheet info

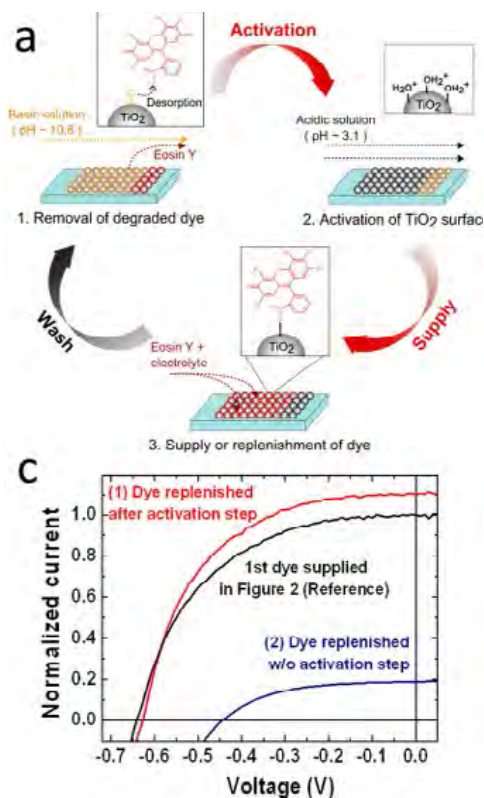
Mark E. Alston
Faculty of Engineering - Architecture and Built Environment, The University of Nottingham

Rosa Romano
Florence University, Department of Architecture

Enrico Sergio Mazzucchelli
Politecnico di Milano

Cost/m2 -

Yearly cost of maintenance -



3

μ -FGPVs with and without the activation step, showing that the activation process is essential. The device for the curve (1) was washed with aqueous NaOH solution for 3 hrs, followed by treating with HCl solution for 3 hrs before the dye replenishment. The device characterized by curve (2) was washed with aqueous NaOH solution for 6 hrs before dye replenishment. All samples were characterized after the 1 hr dye-supply step.

NITINOL (NITI)

Nichel-titanium (NiTi) alloys are commonly used in shape memory applications, although many other kinds of alloys also exhibit shape-memory effects. These alloys can exist in final product form in two different temperature-dependent crystalline states or phases: the austenite state (higher temperature); the martensite state (lower temperature).

The material in the austenite state is strong and hard, while it is soft and ductile in the martensite phase. The austenite crystal structure is a simple body centred cubic structure, while martensite has a more complex rhombic structure. With respect to the stress-strain curve, the higher temperature austenite behaves similarly to most metals. The stress-strain curve of the lower-temperature martensitic structure, however, resembles an elastomer, since it has 'plateau' stress-deformation characteristics where large deformations can easily occur with little force.



MATERIAL



COMPONENT



FACADE

SHAPE MEMORY; ALLOY; KINETIC; TEMPERATURE; REACTIVE

BUILDING INFORMATION:			
Building floor area	-	Climate Type	All of them
Building use	-	Orientation of the facade	All orientation
Building status	-	Other	-

DETAILED DESCRIPTION OF THE CASE STUDY SYSTEM

TECHNOLOGY READINESS LEVEL	
01. Basic principles observed and reported/ Idea	<input type="checkbox"/>
02. Technology concept formulated/Design Proposal	<input type="checkbox"/>
03. Technology validated in lab	<input type="checkbox"/>
04. Prototype demonstration	<input type="checkbox"/>
05. Commercial product/Existing building	<input checked="" type="checkbox"/>

FUNCTION / GOAL / PURPOSE	
Thermal comfort	<input type="checkbox"/>
Visual comfort	<input checked="" type="checkbox"/>
Acoustic comfort	<input type="checkbox"/>
Energy management (harvesting, storing, supply)	<input type="checkbox"/>
Mass transfer control (e.g. condensation control)	<input type="checkbox"/>
Indoor air quality	<input type="checkbox"/>
Appearance (aesthetic quality)	<input checked="" type="checkbox"/>
Structure performance	<input type="checkbox"/>
Energy generation	<input type="checkbox"/>
Personal users' control	<input type="checkbox"/>
Other (durability, accessibility, use of natural resources, etc).	<input type="checkbox"/>

TYPE OF MATERIAL	
Thermochromic	<input type="checkbox"/>
Electrochromic	<input type="checkbox"/>
Photochromic	<input type="checkbox"/>
Thermotropic	<input type="checkbox"/>
Phase Change Material	<input type="checkbox"/>
Shape Memory Polymer	<input checked="" type="checkbox"/>
Shape Memory Alloy	<input type="checkbox"/>
Thermobimetal	<input type="checkbox"/>
Bi-layer hygromorph composites	<input type="checkbox"/>
Hydrogel	<input type="checkbox"/>
Natural Porous Material	<input type="checkbox"/>

MATERIAL FAMILY	
Reversible colour / Opacity change	<input type="checkbox"/>
Reversible heat flow direction	<input type="checkbox"/>
Shape Changing Materials	<input checked="" type="checkbox"/>
Humidity absorption	<input type="checkbox"/>
Other:	<input type="checkbox"/>

M_02

TYPE OF MATERIAL	
Liquid crystals	<input type="checkbox"/>
Phase Change Materials	<input type="checkbox"/>
Polymers	<input type="checkbox"/>
Alloys	<input type="checkbox"/>
Ceramics	<input type="checkbox"/>
Wood	<input type="checkbox"/>
Salthydrates	<input type="checkbox"/>
Other (specify): Nichel-titanium (NiTi)	<input checked="" type="checkbox"/>

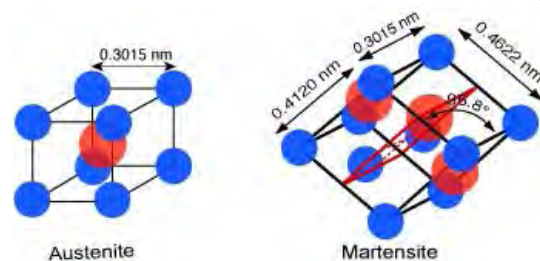
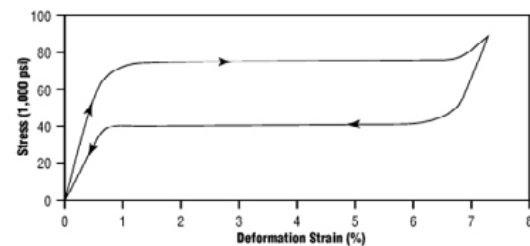
TYPE OF SHADING DEVICE	
Screens / roller shades	<input type="checkbox"/>
Blinds with slat angle control	<input type="checkbox"/>
Bi-directional transmission control	<input checked="" type="checkbox"/>
Insulating shutters	<input type="checkbox"/>
Shading with dual-axis tracking	<input type="checkbox"/>
Other (specify):	<input type="checkbox"/>

MATERIAL EFFECT HOW DOES THE MATERIAL ADAPT?	
Shape Memory Material	<input type="checkbox"/>
Bi-material effect	<input type="checkbox"/>
Electroactive material	<input type="checkbox"/>
Superabsorbent material	<input type="checkbox"/>
Phase Change	<input type="checkbox"/>
Other (specify): Shape Memory Material	<input checked="" type="checkbox"/>

TYPE OF TRIGGER (INPUT)	
Mechanical (e.g. wind load)	<input type="checkbox"/>
Thermal (e.g. outdoor air temperature)	<input checked="" type="checkbox"/>
Electromagnetic (e.g. solar radiation)	<input type="checkbox"/>
Optical (e.g. daylight level, glare)	<input type="checkbox"/>
Air quality (humidity, CO2 concentration, etc)	<input type="checkbox"/>
Building heating/cooling load	<input type="checkbox"/>
Occupant's presence	<input type="checkbox"/>
Other (specify):	<input type="checkbox"/>

TYPE OF ACTUATOR (OUTPUT)	
Mechanical	<input checked="" type="checkbox"/>
Pneumatical	<input type="checkbox"/>
Electromagnetic	<input type="checkbox"/>
Thermal	<input type="checkbox"/>
Chemical	<input type="checkbox"/>
Other (specify): Manual	<input type="checkbox"/>

TYPE OF SWITCHABLE GLAZING	
Electro-chromic (EC)	<input type="checkbox"/>
Liquid crystal, SPD	<input type="checkbox"/>
Photo-volta-chromic	<input type="checkbox"/>
Independently tunable NIR-VIS EC	<input type="checkbox"/>
Thermo- tropic / chromic	<input type="checkbox"/>
Photo-chromic	<input type="checkbox"/>
Fluidglass	<input type="checkbox"/>
Other (specify):	<input type="checkbox"/>



1. Typical Loading and Unloading Behavior of Superelastic NiTi
2. 2D view of nitinol's crystalline structure during cooling/heating cycle
3. 3D view of austenite and martensite structures of the NiTi compound.
4. Reef, New York, NY, 2009. In this sculpture Rob Ley investigates the role emerging material technology can play in the sensitive reprogramming of architectural and public space. Shape Memory Alloys (SMAs), a category of metals that change shape according to temperature, offer the possibility of efficient, fluid movement without the mechanized motion of earlier technologies.

CONTROL OPERATION DETAILS



4

DETAILED EXPLANATION OF THE CONTROL/OPERATION

Nitinol alloys exhibit Shape Memory Effect (SME) and Super Elasticity (SE). Shape memory is the ability to undergo deformation at one temperature, and recover its original undeformed shape upon heating above its “transformation temperature”.

Superelasticity occurs at a narrow temperature range just above its transformation temperature; no heating is necessary to cause the undeformed shape to recover, and the material exhibits enormous elasticity, 10-30 times that of ordinary metal.

Nitinol's unusual properties are derived from a reversible solid-state phase transformation known as a martensitic transformation, between two different martensite crystal phases. At high temperatures, Nitinol assumes an interpenetrating simple cubic structure referred to as austenite (also known as the parent phase). At low temperatures, Nitinol spontaneously transforms to a more complicated body-centered tetragonal crystal structure known as martensite (daughter phase).

CONTROL/OPERATION TYPE

- Intrinsic (auto reactive)** ☒
- Extrinsic (requires external control) ☐
- Electromagnetic ☐
- Other (specify): ☐

SYSTEM RESPONSE TIME

- Seconds** ☒
- Minutes ☐
- Hours ☐
- Days ☐
- Seasons ☐
- Years ☐
- Other (specify): ☐

SYSTEM DEGREE OF ADAPTIVITY:

- On/off ☐
- Gradual** ☒
- Other (specify) ☐

DEGREE OF SPATIAL ADAPTATION

- Nanometers** ☒
- Micrometers ☐
- Millimeters ☐
- Centimeters ☐
- Meters ☐
- Other (specify) ☐

LEVEL OF AF VISIBILITY

- 01 Not visible (heat storage, phase change materials) ☐
- 02 Visible, no surface change (smart glazing) ☐
- 03 Visible, surface change (lamellas, rollers, blinds) ☐
- 04 Visible, size or shape change (shutters, flaps, dynamic facade elements)** ☒
- 05 Visible, location or orientation change ☐
- Other (specify) ☐

ECONOMICAL ASPECTS

IS THE SYSTEM ECONOMICALLY VIABLE?

Yes	<input checked="" type="checkbox"/>
No	<input type="checkbox"/>
Other (specify):	<input type="checkbox"/>

ESTIMATE THE COST OF THE CASE-STUDY

Low (traditional, residential, simple prefabricated, etc)	<input type="checkbox"/>
Medium (curtain walls, ventilated facades, etc)	<input type="checkbox"/>
High (double skin facades, high tech, etc)	<input type="checkbox"/>
Information not available	<input checked="" type="checkbox"/>

SYSTEM MAINTENANCE FREQUENCY

Daily	<input type="checkbox"/>
Weekly	<input type="checkbox"/>
Monthly	<input type="checkbox"/>
Yearly	<input type="checkbox"/>
Information not available	<input checked="" type="checkbox"/>

Reference

Aksamija, A. (2016), *Integrating Innovation in Architecture: Design, Methods and Technology for Progressive Practice and Research*, AD Smart,

Addington, M., Schodek, D. (2012), *Smart Materials and Technologies in Architecture*, Routledge, pp. 201 - 256

<https://nitinol.com> (Accessed May 23, 2018)

<http://www.adaptronik.fraunhofer.de/> (Accessed May 23, 2018)

<http://www.rtm-medizintechnik.de/> (Accessed May 23, 2018)

Reference to picture

<http://www.g-rau.de/en/products/actuators-made-of-shape-memory-alloys.html> (Accessed May 23, 2018)

https://en.wikipedia.org/wiki/Nickel_titanium (Accessed May 23, 2018)

Author of the sheet info

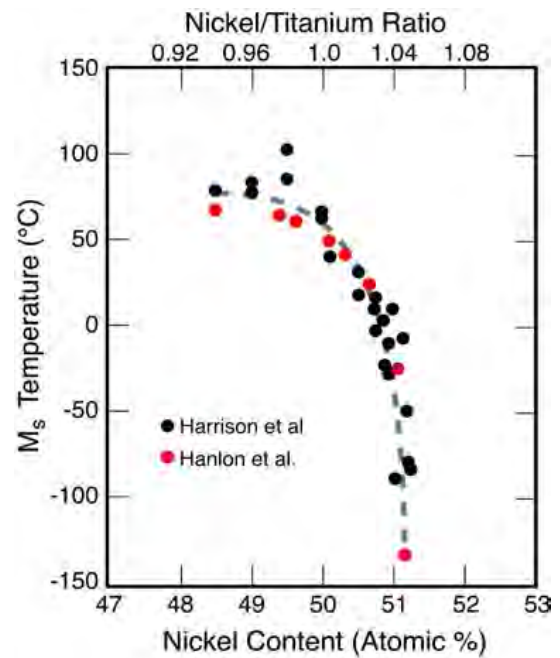
Sandra Persiani
Technical University of Munich

Rosa Romano
Florence University, Department of Architecture

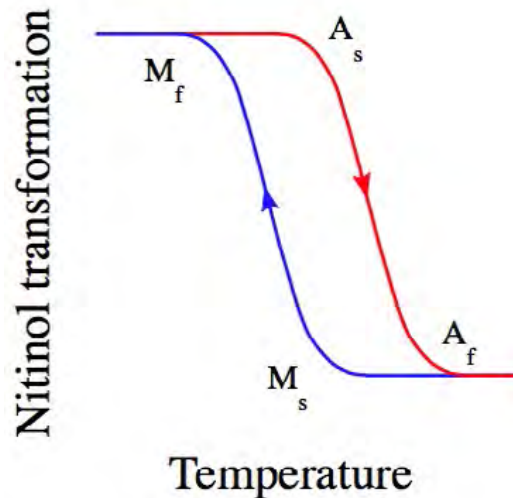
Enrico Sergio Mazzucchelli
Politecnico di Milano

Mark E. Alston
Faculty of Engineering - Architecture and Built Environment, The University of Nottingham

Cost/m ²	-
Yearly cost of maintenance	-



5



6

5. The effect of nitinol composition on the M_s temperature.
6. Thermal hysteresis of nitinol's phase transformation

Facade panels incorporating cement-based batteries, 2015 DR NIALL HOLMES

The novel cement based batteries are designed to power low-energy cathodic protection. One example is Impressed Current Cathodic Protection (ICCP) of reinforcement in concrete structures. ICCP protects reinforcing steel from corrosion by connecting it to an inert, less noble, metal and passing low-level current through it using an external power source.

The preliminary findings demonstrate that cement based batteries can produce sufficient sustainable electrical outputs with the correct materials and arrangement of castin anodes.

Work is on going to determine how these batteries can be recharged using photovoltaic which will further enhance their sustainability properties.



MATERIAL



COMPONENT



FACADE

CEMENT-BASED BATTERIES; CATHODIC PROTECTION; REINFORCED CONCRETE; PV

BUILDING INFORMATION:			
Building floor area	-	Climate Type	All of them
Building use	All type of function	Orientation of the facade	All orientation
Building status	Both new and existing	Other	-

DETAILED DESCRIPTION OF THE CASE STUDY SYSTEM

TECHNOLOGY READINESS LEVEL	TYPE OF MATERIAL
01. Basic principles observed and reported/ Idea <input type="checkbox"/>	Thermochromic <input type="checkbox"/>
02. Technology concept formulated/Design Proposal <input type="checkbox"/>	Electrochromic <input type="checkbox"/>
03. Technology validated in lab <input checked="" type="checkbox"/>	Photochromic <input checked="" type="checkbox"/>
04. Prototype demonstration <input type="checkbox"/>	Thermotropic <input type="checkbox"/>
05. Commercial product/Existing building <input type="checkbox"/>	Phase Change Material <input type="checkbox"/>
	Shape Memory Polymer <input type="checkbox"/>
	Shape Memory Alloy <input type="checkbox"/>
	Thermobimetal <input type="checkbox"/>
	Bi-layer hygromorph composite <input type="checkbox"/>
	Hydrogel <input type="checkbox"/>
	Natural Porous Material <input type="checkbox"/>
FUNCTION / GOAL / PURPOSE	MATERIAL FAMILY
Thermal comfort <input type="checkbox"/>	Reversible colour / Opacity change <input type="checkbox"/>
Visual comfort <input type="checkbox"/>	Reversible heat flow direction <input type="checkbox"/>
Acoustic comfort <input type="checkbox"/>	Shape Changing Material <input type="checkbox"/>
Energy management (harvesting, storing, supply) <input checked="" type="checkbox"/>	Humidity absorption <input type="checkbox"/>
Mass transfer control (e.g. condensation control) <input type="checkbox"/>	Other: Cement-based batteries <input checked="" type="checkbox"/>
Indoor air quality <input type="checkbox"/>	
Appearance (aesthetic quality) <input type="checkbox"/>	
Structure performance <input checked="" type="checkbox"/>	
Energy generation <input type="checkbox"/>	
Personal users' control <input type="checkbox"/>	
Other (durability, accesibility, use of natural resources, etc). <input type="checkbox"/>	

M_03

TYPE OF MATERIAL	
Liquid crystals	<input type="checkbox"/>
Phase Change Materials	<input type="checkbox"/>
Polymers	<input type="checkbox"/>
Alloys	<input type="checkbox"/>
Ceramics	<input type="checkbox"/>
Wood	<input type="checkbox"/>
Salthydrates	<input type="checkbox"/>
Other (specify): Concret	<input checked="" type="checkbox"/>

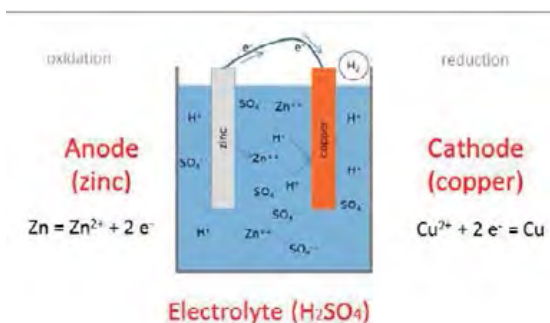
TYPE OF SHADING DEVICE	
Screens / roller shades	<input type="checkbox"/>
Blinds with slat angle control	<input type="checkbox"/>
Bi-directional transmission control	<input type="checkbox"/>
Insulating shutters	<input type="checkbox"/>
Shading with dual-axis tracking	<input type="checkbox"/>
Other (specify):	<input type="checkbox"/>

MATERIAL EFFECT HOW DOES THE MATERIAL ADAPT?	
Shape Memory Material	<input type="checkbox"/>
Bi-material effect	<input type="checkbox"/>
Electroactive material	<input type="checkbox"/>
Superabsorbent material	<input type="checkbox"/>
Phase Change	<input type="checkbox"/>
Other (specify): charging and recharging using photovoltaic elements	<input checked="" type="checkbox"/>

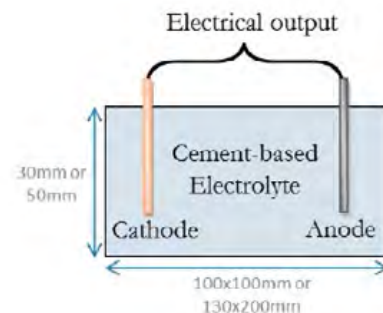
TYPE OF TRIGGER (INPUT)	
Mechanical (e.g. wind load)	<input type="checkbox"/>
Thermal (e.g. outdoor air temperature)	<input type="checkbox"/>
Electromagnetic (e.g. solar radiation)	<input type="checkbox"/>
Optical (e.g. daylight level, glare)	<input type="checkbox"/>
Air quality (humidity, CO2 concentration, etc)	<input type="checkbox"/>
Building heating/cooling load	<input type="checkbox"/>
Occupant's presence	<input type="checkbox"/>
Other (specify): embedded steel corrosion	<input checked="" type="checkbox"/>

TYPE OF ACTUATOR (OUTPUT)	
Mechanical	<input type="checkbox"/>
Pneumatical	<input type="checkbox"/>
Electromagnetic	<input type="checkbox"/>
Thermal	<input type="checkbox"/>
Chemical	<input type="checkbox"/>
Other (specify): Electrical	<input checked="" type="checkbox"/>

TYPE OF SWITCHABLE GLAZING	
Electro-chromic (EC)	<input type="checkbox"/>
Liquid crystal, SPD	<input type="checkbox"/>
Photo-volta-chromic	<input type="checkbox"/>
Independently tunable NIR-VIS EC	<input type="checkbox"/>
Thermo- tropic / chromic	<input type="checkbox"/>
Photo-chromic	<input type="checkbox"/>
Fluidglass	<input type="checkbox"/>
Other (specify):	<input type="checkbox"/>



1



2

1. Conventional battery arrangement.
2. Battery housed in a metal can.
3. Cement

CONTROL OPERATION DETAILS



3

DETAILED EXPLANATION OF THE FACADE AND OF THE CONTROL/OPERATION SYSTEM

In Cement-based batteries housed in a block both the anode and the cathode are in the form of metal plates. Plastic moulds were used to prevent short circuiting and to allow for a higher volume of sample to be made. These designs were used to compare different additives, anode materials, shapes and sizes.

This type of design is the “best-fit” for cement-based batteries for using with Current Cathodic Protection (ICCP) as they can be incorporated into a cladding panel and fixed onto a structure. For this, particular characteristics are required, namely robustness, long life and a low but consistent current output under resistance load.

CONTROL/OPERATION TYPE

Intrinsic (auto reactive)	<input checked="" type="checkbox"/>
Extrinsic (requires external control)	<input type="checkbox"/>
Electromagnetic	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

SYSTEM RESPONSE TIME

Seconds	<input type="checkbox"/>
Minutes	<input type="checkbox"/>
Hours	<input type="checkbox"/>
Days	<input checked="" type="checkbox"/>
Seasons	<input type="checkbox"/>
Years	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

SYSTEM DEGREE OF ADAPTIVITY:

On/off	<input checked="" type="checkbox"/>
Gradual	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

DEGREE OF SPATIAL ADAPTATION

Nanometers	<input type="checkbox"/>
Micrometers	<input type="checkbox"/>
Millimeters	<input type="checkbox"/>
Centimeters	<input type="checkbox"/>
Meters	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

LEVEL OF AF VISIBILITY

01 Not visible (heat storage, phase change materials)	<input type="checkbox"/>
02 Visible, no surface change (smart glazing)	<input checked="" type="checkbox"/>
03 Visible, surface change (lamellas, rollers, blinds)	<input type="checkbox"/>
04 Visible, size or shape change (shutters, flaps, dynamic facade elements)	<input type="checkbox"/>
05 Visible, location or orientation change	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

ECONOMICAL ASPECTS

IS THE SYSTEM ECONOMICALLY VIABLE?

Yes	<input checked="" type="checkbox"/>
No	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

ESTIMATE THE COST OF THE CASE-STUDY

Low (traditional, residential, simple prefabricated, etc)	<input type="checkbox"/>
Medium (curtain walls, ventilated facades, etc)	<input type="checkbox"/>
High (double skin facades, high tech, etc)	<input type="checkbox"/>
Information not available	<input checked="" type="checkbox"/>

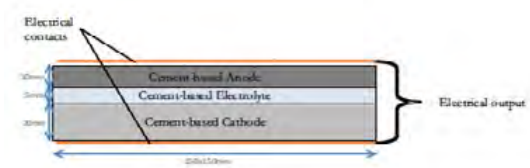
SYSTEM MAINTENANCE FREQUENCY

Daily	<input type="checkbox"/>
Weekly	<input type="checkbox"/>
Monthly	<input type="checkbox"/>
Yearly	<input type="checkbox"/>
Information not available	<input checked="" type="checkbox"/>

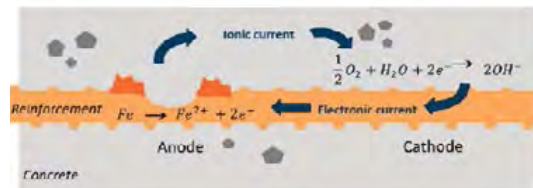
Cost/m2

-

Yearly cost of maintenance 100,00 €



4



4



6.a



6.b



6.c

Reference

Holmes, N., Byrne, A. and Norton, B. (2015), *First steps in developing cement-based batteries to power cathodic protection of embedded steel in concrete*, Journal of Sustainable Design and Applied Research (SDAR)

Byrne, A., Barry, S., Holmes N. and Norton, B. (2017), *Optimising the Performance of Cement-Based Batteries*, Advances in Materials Science and Engineering

Reference to picture

Holmes, N., Byrne, A. and Norton, B. (2015), *First steps in developing cement-based batteries to power cathodic protection of embedded steel in concrete*, Journal of Sustainable Design and Applied Research (SDAR)

Author of the sheet info

Rosa Romano
Florence University, Department of Architecture

Enrico Sergio Mazzucchelli
Politecnico di Milano

Mark E. Alston
Faculty of Engineering - Architecture and Built Environment, The University of Nottingham

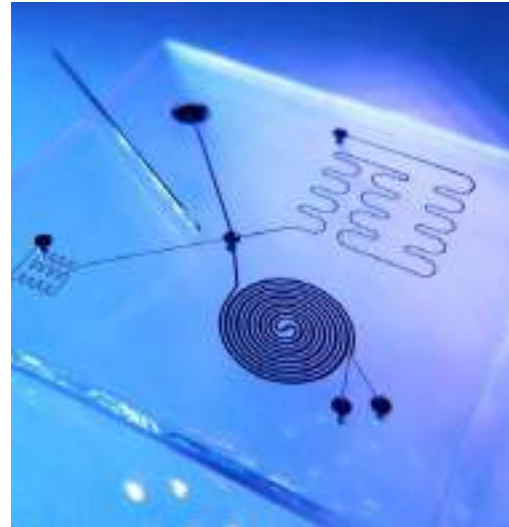
4. Layered battery schematic.
5. Corrosion process in embedded steel in concrete
6. Layered batteries cast: 6.a Layered cement-based battery; 6.b Batteries stored in water and Epsom salt; 6.c Electrical contacts (conductive copper)

MICROFLUIDIC GLASS, 2015

M.E.Alston

The research on living glass is focused on the use of an optically transparent, thermal energy adsorbing glass composite. It is in the conceptual prototype type phase. The objective is demonstrate that is possible to evolve glass into a photoactive energy system by evaluation and reactive response for thermal heat flow targeting. A living glass, is in fact, an organism that emulates the chemical reaction cycle of leaves by endothermic principles.

The metabolic cycle of biochemical triggers, can be considered are multifunctional mechanisms to progress glass into an energy, adsorbing composite. The goal of the research is describe the evolution of glass into a photoactive adsorption layer, at a integrated multiscale level, in response to climatic regionalization, in order to turn glass into a living energy organism that responds to the environment and contributes to the planet's energy needs.



MATERIAL



COMPONENT



FACADE

BIOSYSTEM, ENERGY, ADSORPTION, CONDUCTANCE, SOLAR MODULATION

BUILDING INFORMATION:			
Building floor area	device prototype	Climate Type	All climate type
Building use	glazed facades	Orientation of the facade	All orientation
Building status	new built + refurbishment	Other	-

DETAILED DESCRIPTION OF THE CASE STUDY SYSTEM

TECHNOLOGY READINESS LEVEL	TYPE OF MATERIAL
01. Basic principles observed and reported/ Idea <input type="checkbox"/>	Thermochromic <input type="checkbox"/>
02. Technology concept formulated/Design Proposal <input checked="" type="checkbox"/>	Electrochromic <input type="checkbox"/>
03. Technology validated in lab <input type="checkbox"/>	Photochromic <input checked="" type="checkbox"/>
04. Prototype demonstration <input type="checkbox"/>	Thermotropic <input type="checkbox"/>
05. Commercial product/Existing building <input type="checkbox"/>	Phase Change Material <input type="checkbox"/>
	Shape Memory Polymer <input type="checkbox"/>
	Shape Memory Alloy <input type="checkbox"/>
	Thermobimetal <input type="checkbox"/>
	Bi-layer hygromorph composite <input type="checkbox"/>
	Hydrogel <input type="checkbox"/>
	Natural Porous Material <input type="checkbox"/>
FUNCTION / GOAL / PURPOSE	MATERIAL FAMILY
Thermal comfort <input checked="" type="checkbox"/>	Reversible colour / Opacity change <input checked="" type="checkbox"/>
Visual comfort <input checked="" type="checkbox"/>	Reversible heat flow direction <input type="checkbox"/>
Acoustic comfort <input type="checkbox"/>	Shape Changing Material <input type="checkbox"/>
Energy management (harvesting, storing, supply) <input checked="" type="checkbox"/>	Humidity absorption <input type="checkbox"/>
Mass transfer control (e.g. condensation control) <input checked="" type="checkbox"/>	Other: <input type="checkbox"/>
Indoor air quality <input type="checkbox"/>	
Appearance (aesthetic quality) <input type="checkbox"/>	
Structure performance <input type="checkbox"/>	
Energy generation <input checked="" type="checkbox"/>	
Personal users' control <input type="checkbox"/>	
Other (durability, accesibility, use of natural resources, etc). <input type="checkbox"/>	

M_04

TYPE OF MATERIAL	
Liquid crystals	<input type="checkbox"/>
Phase Change Materials	<input type="checkbox"/>
Polymers	<input checked="" type="checkbox"/>
Alloys	<input type="checkbox"/>
Ceramics	<input type="checkbox"/>
Wood	<input type="checkbox"/>
Salthydrates	<input type="checkbox"/>
Other (specify):	<input type="checkbox"/>

TYPE OF SWITCHABLE GLAZING	
Electro-chromic (EC)	<input type="checkbox"/>
Liquid crystal, SPD	<input type="checkbox"/>
Photo-volta-chromic	<input type="checkbox"/>
Independently tunable NIR-VIS EC	<input type="checkbox"/>
Thermo- tropic / chromic	<input type="checkbox"/>
Photo-chromic	<input type="checkbox"/>
Fluidglass	<input checked="" type="checkbox"/>
Other (specify):	<input type="checkbox"/>

TYPE OF SHADING DEVICE	
Screens / roller shades	<input type="checkbox"/>
Blinds with slat angle control	<input type="checkbox"/>
Bi-directional transmission control	<input type="checkbox"/>
Insulating shutters	<input type="checkbox"/>
Shading with dual-axis tracking	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

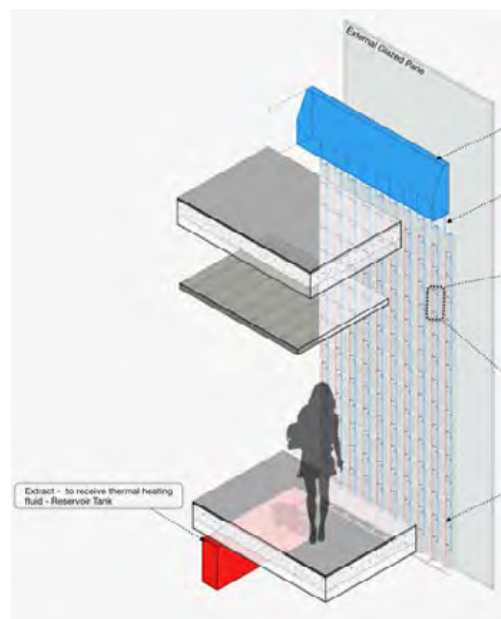
MATERIAL EFFECT HOW DOES THE MATERIAL ADAPT?	
Shape Memory Material	<input type="checkbox"/>
Bi-material effect	<input type="checkbox"/>
Electroactive material	<input type="checkbox"/>
Superabsorbent material	<input type="checkbox"/>
Phase Change	<input type="checkbox"/>
Other (specify): heat flow transport	<input checked="" type="checkbox"/>

TYPE OF TRIGGER (INPUT)	
Mechanical (e.g. wind load)	<input type="checkbox"/>
Thermal (e.g. outdoor air temperature)	<input type="checkbox"/>
Electromagnetic (e.g. solar radiation)	<input checked="" type="checkbox"/>
Optical (e.g. daylight level, glare)	<input type="checkbox"/>
Air quality (humidity, CO2 concentration, etc)	<input type="checkbox"/>
Building heating/cooling load	<input type="checkbox"/>
Occupant's presence	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

TYPE OF ACTUATOR (OUTPUT)	
Mechanical	<input type="checkbox"/>
Pneumatical	<input type="checkbox"/>
Electromagnetic	<input type="checkbox"/>
Thermal	<input checked="" type="checkbox"/>
Chemical	<input type="checkbox"/>
Other (specify): Manual	<input type="checkbox"/>



1



2

1. Building integration
2. Building integration
3. Cellular floor zoning-glass modular facade

CONTROL OPERATION DETAILS



3

DETAILED EXPLANATION OF THE CONTROL/OPERATION

Evaluation of heat flow monitoring and consequent reaction triggers are needed to actively manage nanoscale absorptivity within microvascular networks and thermal conductance effects upon the glass material. The engagement of sensors and actuators controlled by an algorithm management response will enable parameters setting in connection to solar radiation gain. This is achieved by fluidic flow rate control and load shift energy removal from the heat absorber carrier fluid. Hence nanoscale fluidic monitoring by evaluation of heat flow within the network and temperature monitoring decay, heat loss, are strategic functions. This analysis to quantify thermal flow directly relates to datum temperature point setting. This tracking of thermal flow creates a cyclic nanoscale system for conductivity regulation by energy load - unload processes. This energy load shift tracking of conduction is intrinsic to indoor set-point temperatures.

This active management of thermal heat transport flow will feed into tank reservoirs for energy unload process removal.

Once the energy is removed from the photosynthetic glass, the fluid recirculates back into the network. This feed back loop completes the close loop exothermic cycle. These are learn and apply reaction responses to changing solar radiation and absorptivity. The energy unload process is created at a localized level, serving the microvascular networks in avoidance of extended distribution feeds. This give optimization of pumping energy demands and localized energy load - unload processes. The ability to use tank storage reservoirs enables heat to electricity conversation by semiconducting engineering.

CONTROL/OPERATION TYPE

Intrinsic (auto reactive)	<input checked="" type="checkbox"/>
Extrinsic (requires external control)	<input type="checkbox"/>
Electromagnetic	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

SYSTEM RESPONSE TIME

Seconds	<input checked="" type="checkbox"/>
Minutes	<input type="checkbox"/>
Hours	<input type="checkbox"/>
Days	<input type="checkbox"/>
Seasons	<input type="checkbox"/>
Years	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

SYSTEM DEGREE OF ADAPTIVITY:

On/off	<input checked="" type="checkbox"/>
Gradual	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

DEGREE OF SPATIAL ADAPTATION

Nanometers	<input checked="" type="checkbox"/>
Micrometers	<input type="checkbox"/>
Millimeters	<input type="checkbox"/>
Centimeters	<input type="checkbox"/>
Meters	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

LEVEL OF AF VISIBILITY

01 Not visible (heat storage, phase change materials)	<input checked="" type="checkbox"/>
02 Visible, no surface change (smart glazing)	<input type="checkbox"/>
03 Visible, surface change (lamellas, rollers, blinds)	<input type="checkbox"/>
04 Visible, size or shape change (shutters, flaps, dynamic facade elements)	<input type="checkbox"/>
05 Visible, location or orientation change	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

ECONOMICAL ASPECTS

IS THE SYSTEM ECONOMICALLY VIABLE?

Yes	<input type="checkbox"/>
No	<input type="checkbox"/>
Other (specify): progression of the research	<input checked="" type="checkbox"/>

ESTIMATE THE COST OF THE CASE-STUDY

Low (traditional, residential, simple prefabricated, etc)	<input type="checkbox"/>
Medium (curtain walls, ventilated facades, etc)	<input type="checkbox"/>
High (double skin facades, high tech, etc)	<input type="checkbox"/>
Information not available	<input checked="" type="checkbox"/>

SYSTEM MAINTENANCE FREQUENCY

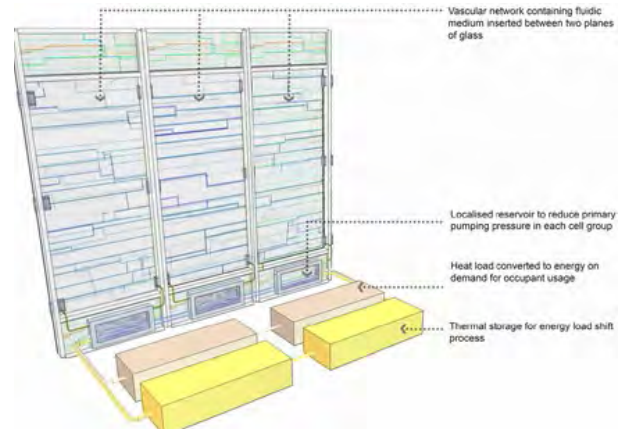
Daily	<input type="checkbox"/>
Weekly	<input type="checkbox"/>
Monthly	<input type="checkbox"/>
Yearly	<input type="checkbox"/>
Information not available	<input checked="" type="checkbox"/>

Cost/m2

-

Yearly cost of maintenance

-



4

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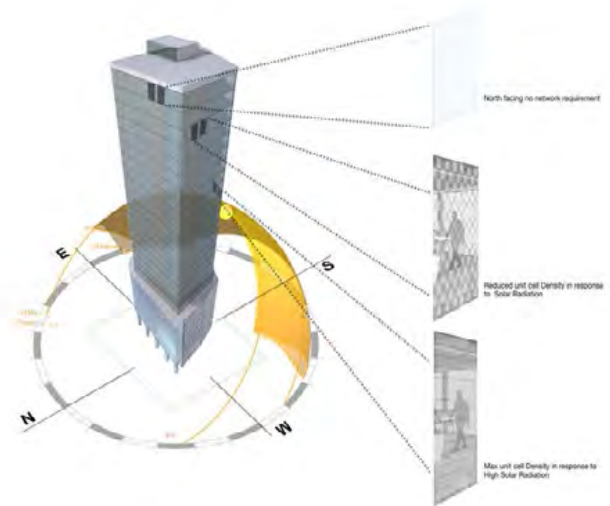
Reference to picture:

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Author of the sheet info

M.E.Alston
University of Nottingham

Rosa Romano
Florence University, Department of Architecture



5

4. Modular cellular groups
5. Vascular channel changes in response to solar orientation

THERMAL BIMETAL, "BLOOM", Los Angeles, California (USA), 2011 DOJSU Studio Architecture, Doris Kim Sung

Bloom furthers the evolution of projects in the M&A courtyard by utilizing a material that has kinetic potential without the need of a power source or any mechanical parts. The towering shade structure is supported by a self-organizing cellular panel system of laser cut custom fabricated sheet metal. The design of the project, based on research by prof. D.K. Sung and Wahlroos-Ritter, explores the possibilities of a thermally responsive metal surface which reacts to both the change in temperature and direct solar radiation. When the temperature of the metal is cool, the surface will appear as a solid object, but once the afternoon heat penetrates the metal, the panels of custom woven bimetal will adjust and fan out to allow air flow and increase shade potential. The thermo-bimetal alloys used in the project expand the notion of surface and structure in architecture.



Latitude -34.08, Longitude: -118.26



MATERIAL



COMPONENT



FACADE

THERMAL BIMETAL, SMART MATERIAL, BIOMIMETICS, SELF VENTILATING

BUILDING INFORMATION:

Building floor area	device prototype	Climate Type	All climate type
Building use	architectural purpose	Orientation of the facade	All orientation
Building status	new built, refurbishment	Other	-

DETAILED DESCRIPTION OF THE CASE STUDY SYSTEM

TECHNOLOGY READINESS LEVEL

01. Basic principles observed and reported/ Idea	<input type="checkbox"/>
02. Technology concept formulated/Design Proposal	<input type="checkbox"/>
03. Technology validated in lab	<input type="checkbox"/>
04. Prototype demonstration	<input checked="" type="checkbox"/>
05. Commercial product/Existing building	<input type="checkbox"/>

FUNCTION / GOAL / PURPOSE

Thermal comfort	<input checked="" type="checkbox"/>
Visual comfort	<input checked="" type="checkbox"/>
Acoustic comfort	<input type="checkbox"/>
Energy management (harvesting, storing, supply)	<input type="checkbox"/>
Mass transfer control (e.g. condensation control)	<input type="checkbox"/>
Indoor air quality	<input type="checkbox"/>
Appearance (aesthetic quality)	<input type="checkbox"/>
Structure performance	<input type="checkbox"/>
Energy generation	<input type="checkbox"/>
Personal users' control	<input type="checkbox"/>
Other: Self ventilating, no additional energy necessary (sustainability)	<input checked="" type="checkbox"/>

TYPE OF MATERIAL

Thermochromic	<input type="checkbox"/>
Electrochromic	<input type="checkbox"/>
Photochromic	<input type="checkbox"/>
Thermotropic	<input type="checkbox"/>
Phase Change Material	<input type="checkbox"/>
Shape Memory Polymer	<input type="checkbox"/>
Shape Memory Alloy	<input checked="" type="checkbox"/>
Thermobimetal	<input type="checkbox"/>
Bi-layer hygromorph composite	<input type="checkbox"/>
Hydrogel	<input type="checkbox"/>
Natural Porous Material	<input type="checkbox"/>

MATERIAL FAMILY

Reversible colour / Opacity change	<input type="checkbox"/>
Reversible heat flow direction	<input type="checkbox"/>
Shape Changing Material	<input checked="" type="checkbox"/>
Humidity absorption	<input type="checkbox"/>
Other:	<input type="checkbox"/>

M_05

TYPE OF MATERIAL	
Liquid crystals	<input type="checkbox"/>
Phase Change Materials	<input type="checkbox"/>
Polymers	<input type="checkbox"/>
Alloys	<input type="checkbox"/>
Ceramics	<input type="checkbox"/>
Wood	<input type="checkbox"/>
Salthydrates	<input type="checkbox"/>
Other (specify): Bimetal	<input checked="" type="checkbox"/>

TYPE OF SWITCHABLE GLAZING	
Electro-chromic (EC)	<input type="checkbox"/>
Liquid crystal, SPD	<input type="checkbox"/>
Photo-volta-chromic	<input type="checkbox"/>
Independently tunable NIR-VIS EC	<input type="checkbox"/>
Thermo- tropic / chromic	<input checked="" type="checkbox"/>
Photo-chromic	<input type="checkbox"/>
Fluidglass	<input type="checkbox"/>
Other (specify):	<input type="checkbox"/>

TYPE OF SHADING DEVICE	
Screens / roller shades	<input type="checkbox"/>
Blinds with slat angle control	<input type="checkbox"/>
Bi-directional transmission control	<input type="checkbox"/>
Insulating shutters	<input type="checkbox"/>
Shading with dual-axis tracking	<input type="checkbox"/>
Other (specify): Bi-material effect	<input checked="" type="checkbox"/>

MATERIAL EFFECT HOW DOES THE MATERIAL ADAPT?	
Shape Memory Material	<input type="checkbox"/>
Bi-material effect	<input type="checkbox"/>
Electroactive material	<input type="checkbox"/>
Superabsorbent material	<input type="checkbox"/>
Phase Change	<input type="checkbox"/>
Other (specify): Bi-material effect	<input checked="" type="checkbox"/>

TYPE OF TRIGGER (INPUT)	
Mechanical (e.g. wind load)	<input type="checkbox"/>
Thermal (e.g. outdoor air temperature)	<input checked="" type="checkbox"/>
Electromagnetic (e.g. solar radiation)	<input type="checkbox"/>
Optical (e.g. daylight level, glare)	<input type="checkbox"/>
Air quality (humidity, CO2 concentration, etc)	<input type="checkbox"/>
Building heating/cooling load	<input type="checkbox"/>
Occupant's presence	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

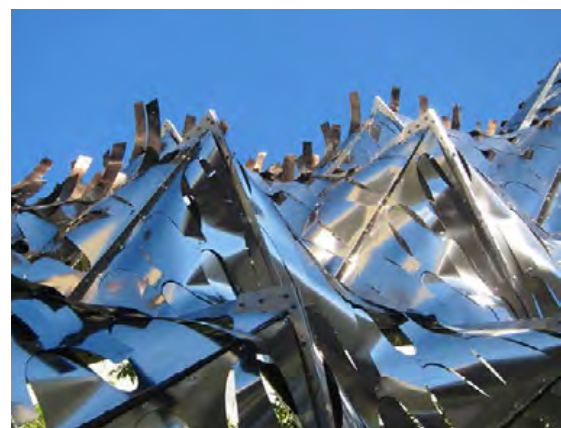
TYPE OF ACTUATOR (OUTPUT)	
Mechanical	<input type="checkbox"/>
Pneumactical	<input type="checkbox"/>
Electromagnetic	<input type="checkbox"/>
Thermal	<input type="checkbox"/>
Chemical	<input type="checkbox"/>
Other (specify): No actuator	<input checked="" type="checkbox"/>



1



2



3

1. The Bloom in courtyard space image
2. Prototype of the Bloom facade
3. The Bloom", Breathing Architecture Installation

CONTROL OPERATION DETAILS



DETAILED EXPLANATION OF THE CONTROL/OPERATION

Made primarily out of a smart thermobimetal, a sheet metal that curls when heated, the form's responsive surface shades and ventilates specific areas of the shell as the sun heats up the Bloom surface. With the aid of complex digital softwares, the surface, made up of approximately 14,000 lasercut pieces, is designed for peak performance on spring equinox, in March 20, 2012.

Composed of 414 hyperbolic paraboloid-shaped stacked panels, the self-supporting structure challenges the capability of the materials to perform as a shell. The panels combine a double-ruled surface of bimetal tiles with an interlocking, folded aluminum frame system. Like the undulation of the surface, the frame, by nature of its folds, is designed to appear on the inner or outer surface at the same cadence of the peaks and valleys. The final monocoque form, lightweight and flexible, is dependent on the overall geometry and combination of materials to provide comprehensive stability. In some areas of "Bloom", the hyper panels are made stiffer by increasing the number of riveted connections, while, in other areas, the panels are deeper to increase structural capability. The severely twisted panel shapes aid in the performance of the surface and challenge the digital and fabrication capabilities of parametric design. Within a single panel, portions of the surface directly face the sun, while the other side is in the shade and requires no reaction or curling. The result is variation in tile shapes and function within each panel.

CONTROL/OPERATION TYPE

Intrinsic (auto reactive)	<input checked="" type="checkbox"/>
Extrinsic (requires external control)	<input type="checkbox"/>
Electromagnetic	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

SYSTEM RESPONSE TIME

Seconds	<input checked="" type="checkbox"/>
Minutes	<input type="checkbox"/>
Hours	<input type="checkbox"/>
Days	<input type="checkbox"/>
Seasons	<input type="checkbox"/>
Years	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

SYSTEM DEGREE OF ADAPTIVITY:

On/off	<input type="checkbox"/>
Gradual	<input checked="" type="checkbox"/>
Other (specify)	<input type="checkbox"/>

DEGREE OF SPATIAL ADAPTATION

Nanometers	<input checked="" type="checkbox"/>
Micrometers	<input type="checkbox"/>
Millimeters	<input type="checkbox"/>
Centimeters	<input type="checkbox"/>
Meters	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

LEVEL OF AF VISIBILITY

01 Not visible (heat storage, phase change materials)	<input type="checkbox"/>
02 Visible, no surface change (smart glazing)	<input type="checkbox"/>
03 Visible, surface change (lamellas, rollers, blinds)	<input type="checkbox"/>
04 Visible, size or shape change (shutters, flaps, dynamic facade elements)	<input checked="" type="checkbox"/>
05 Visible, location or orientation change	<input type="checkbox"/>
Other (specify)	<input type="checkbox"/>

ECONOMICAL ASPECTS

IS THE SYSTEM ECONOMICALLY VIABLE?

Yes	<input checked="" type="checkbox"/>
No	<input type="checkbox"/>
Other (specify): progression of the research	<input type="checkbox"/>

ESTIMATE THE COST OF THE CASE-STUDY

Low (traditional, residential, simple prefabricated, etc)	<input type="checkbox"/>
Medium (curtain walls, ventilated facades, etc)	<input type="checkbox"/>
High (double skin facades, high tech, etc)	<input type="checkbox"/>
Information not available	<input checked="" type="checkbox"/>

SYSTEM MAINTENANCE FREQUENCY

Daily	<input type="checkbox"/>
Weekly	<input type="checkbox"/>
Monthly	<input type="checkbox"/>
Yearly	<input type="checkbox"/>
Information not available	<input checked="" type="checkbox"/>

Reference

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Author of the sheet info

Jonathan Pham

UPV San Sebastian

Rosa Romano

Florence University, Department of Architecture

Cost/m2

-

Yearly cost of maintenance

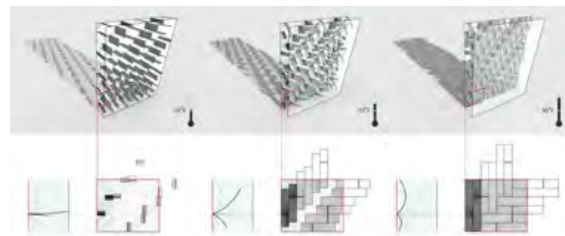
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4

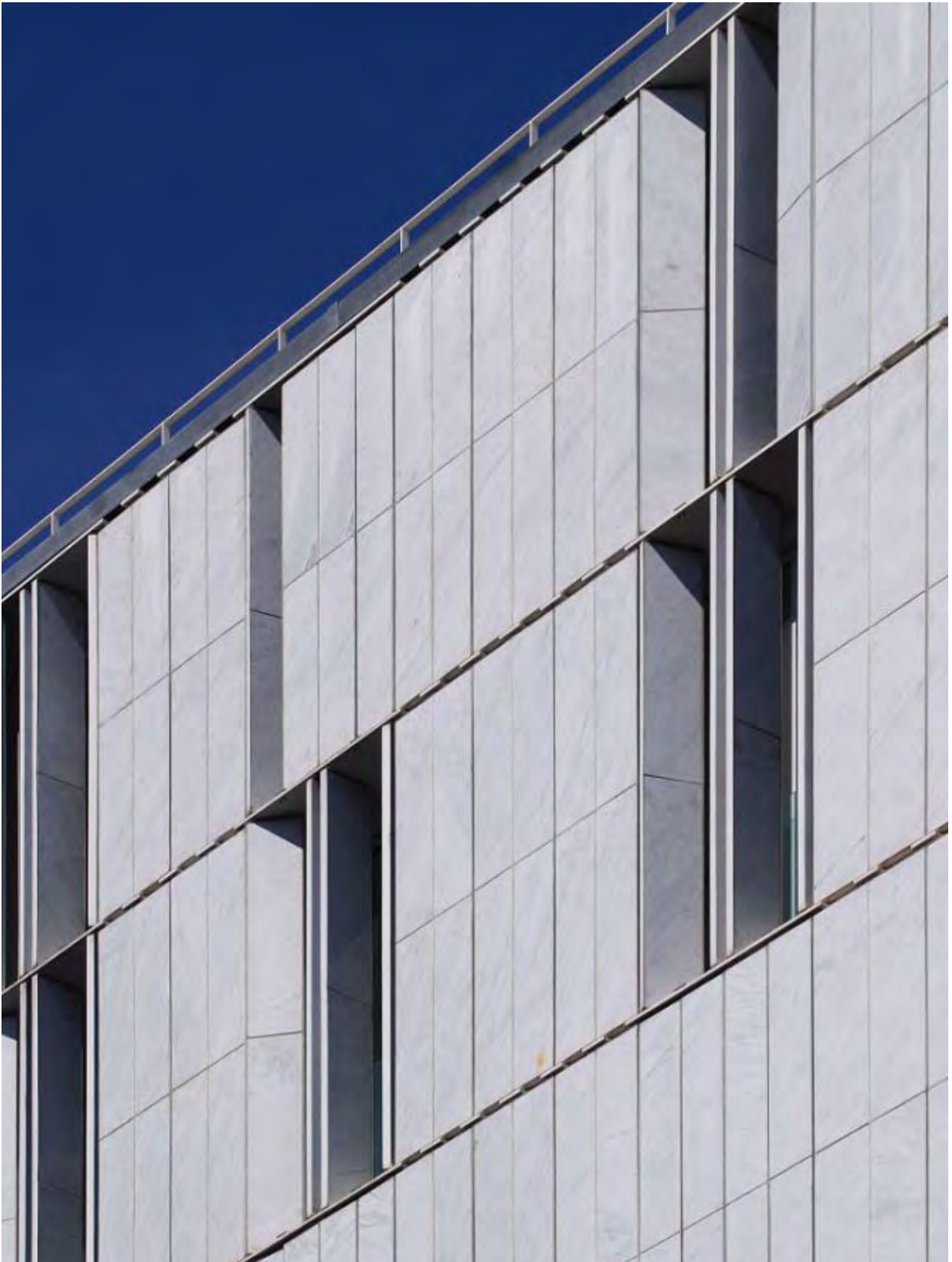


5



6

4. In courtyard space image
5. 3D model structural analysis image
6. Smart thermobimetal pattern sequence



Lisbon Stone Block / Alberto de Souza Oliveira (image: M. Brzezicki)