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ABSTRACT

In a context of global warming and our needs to reduce CO₂ emissions, building envelopes will play an important role. A new imperative has been put forth to architects and engineers to develop innovative materials, components and systems, in order to make building envelopes adaptive and responsive to variable and extreme climate conditions. Envelopes serve multiple functions, from shielding the interior environment to collecting, storing and generating energy. Perhaps a more recent concern of terrestrial habitats is permeability and leakages within the building envelope. Such air tight and concealed envelopes with zero particle exchange are a necessity and already exist in regard to space capsules and habitats.

This paper attempts to acknowledge existing and visionary envelope concepts and their functioning in conjunction with maintaining a favourable interior environment. It introduces several criteria and requirements of advanced façades along with interior pressurization control. Furthermore, the paper also takes a closer look at the principles of 'biomimicry' of natural systems combined with the most up-to-date building materials and construction technologies, trying to integrate the notions of adaptation – where the capacity to survive depends on the ability to adjust to the environment – within the concept of technological evolution and innovation. An 'adaptive' attitude in the way in which we conceive our built structures provides a conceptual basis for the advanced building design of our future, as well as one concerned about the efficient management of the available resources. Built environments of the future (in extreme climates or not) will need to respond to Renewable, Adaptive, Recyclable and Environmental (R.A.R.E.) concepts in order to co-exist in a sustainable way with their surroundings.

ENVELOPES ANALOGOUS TO NATURE

A previous paper of this organization addressed a comparison between the building envelope and the nature of a cell membrane (Luther, 2000). It is perhaps useful to reiterate these constructs, providing a background to the forthcoming context of the present paper.

Buildings are often assimilated to organisms whose enveloping membranes maintain a constant and favourable internal environment by carefully controlling the inputs and outputs of resources and energy. In order to accomplish such, the control must be dynamic and responsive to both its external as well as internal environmental conditions. The processes which take place to achieve this are both passive and active diffusion including osmosis. There are many different roles required by the membrane, which, for example, has to select the organic and inorganic needs to maintain the integrity of the cytoplasm, while, at the same time, providing for the removal of wastes and the acceptance of food. It is suggested here that our building envelopes could mimic the role of a cell membrane.

A BACKGROUND TO BIOMIMETIC CONCEPTS

Biomimicry represents – in a society that has for so many centuries been convinced of its capacity of dominating or, sometimes, even 'improving' Nature – a radically novel approach, a revolutionary era based on what we can learn from Nature rather than, as we have been doing since the Industrial Revolution, merely extracting from it (Beynus, 1997).

Looking at the ecology of our planet, we may realise that there is more to discover than to invent. Life, imaginative by its own nature, has probably already solved most of the problems that we face every day, as the struggle for food, water, space and shelter. The challenge for us is to understand those strategies and tools and mimic them in our own lives.

If we compare our recently developed HVAC systems to the termites towers, our architectural structures to bamboo stems, our radars to bat's multi-frequency transmission system, our innovating envelope materials to human skin, we realise that many of our findings have already been adopted from historical existence. And still, a lot is yet to be discovered and fully understood before
being imitated: bioluminescent algae iridescence, polar bears translucent hollow hairs, chameleons and cuttlefish changing and adapting colours, turtles and bees satellite-less GPS system, ants’ transportation capacity, the dynamic stability of wastes and resources that characterise the life of intricate and multi-species communities like forests and barrier reefs.

In addition, although it may seem obvious, it is quite amazing how Nature, in all of its processes, uniquely runs on sunlight. Photosynthesis, which literally means “putting together with light”, is the process by which green plants transform solar energy, carbon dioxide and water into oxygen and nutritive sugars particularly rich in energetic content; and we are still scrupling the surface of understanding how all this may be possible! In the meanwhile, animals take that oxygen and sugar and transform them back into carbon dioxide, water and energy. Thanks to sunlight, life sustains itself, supplying all the energy needs without burning even a single drop of fossil fuel.

Nevertheless, although these concepts are known amongst the scientific community, there is no doubt that the way our technology has evolved in the last few centuries is radically different from natural principles. Our planes do not fly like birds and insects; although we travel faster than an eagle, by muscle power alone we are much slower (Forbes, 2005).

Maximum economy, multiple function, structural and behavioural adaptation, and, above all, integration, have been the strategies that Nature has exploited through millenary evolution. If, as a species, we truly want to prosper and guarantee our well-being and long-term sustainability in a planet of finite resources, we will have to re-learn how to co-exist and integrate our activities within the dynamic ecosystems that houses and nourishes us, making our built structures – whether in conventional or in extreme conditions – adapt to their surrounding environment (Forbes, 2005).

ADAPTATION TO EXTREME CLIMATE CONDITIONS

The last 12,000 years have encountered a relatively stable climate. Obviously, there have always been slight variations in local weather conditions, but usually changes took place so slowly that living beings did not notice it; animals, plants and other forms of life have had time to adapt or migrate.

Today, architecture is expected not only to serve the simple task of a filter against the elements, but also to provide the service functions that we are accustomed to. As the limited resources of our planet are now acknowledged, scientific and technological advances should contribute to make our buildings become energy resources, instead of simple ‘consumers’ (Hawken, Lovins, Lovins, 1999). This raises the practical question of how to make building design progress in order to keep pace with alterations in the climate.

In response to a new building typology, a design process has evolved that could potentially lead towards an innovative and progressive architecture, one that could be easily and, in a sense, sustainably applied to conventional, as well as extreme, climatic conditions. This new pioneering design process is described as being Renewable, Adaptive, Recyclable and Environmental (R.A.R.E.) (Luther, Altomonte, Coulson, 2006).

The innovative notion of R.A.R.E. Architecture, in its most basic concept, can be paradoxically considered as the oldest, albeit nowadays scarcely exploited, form of architecture in the world. In the acronym, actually, the four letters stand respectively: “R” for Renewable, energy-conserving and energy-producing products and materials; “A” for Adaptive, topography-, weather- and season-sensitive, climate responsive; “R” for Recyclable, flexible, reusable, simple to construct, relocate and deconstruct; “E”, finally, for Environmental, working with Nature and its forces, touching and/or impacting upon the earth lightly. Obviously, the principles behind each letter are not to be considered individually, but rather it is the combination of all principles (letters) together that has to be regarded as an integral part of the design and construction process on all architectural projects.

The acronym R.A.R.E. and the term Architecture, hence, do not have to be considered as an oxymoron. Actually, architectural forms based on adaptation to human needs and environmental conditions can be seen around the world and from every culture and age. The Tepee of the North American Plains Indians, the Bedouin Tents of Northern Africa and the Middle East, or the Yurt of the Mongolians, were, and still are, easily constructed of pre-made pieces, completely built of renewable materials, integrated with their surroundings and easily taken-apart or disassembled. However, while these structures manage to exemplify some of the concepts that lie behind a R.A.R.E. Architecture, a more interrelated and sophisticated interface between the building components and the external elements is required to satisfy all the complex functional needs that are inherent to a construction which could be adaptable and responsive to extreme and/or changing conditions.

For these reasons, a theoretical framework of the R.A.R.E. principles has been developed, based upon eight Sustainable Building Categories derived as relevant to the research and development of a R.A.R.E. Architecture (Altomonte, Luther, 2006):

1. Sustainable Site & Climate Analysis; comprising the analysis of site, exposure, orientation, climatic and topographical factors, local constraints and the range and availability of ecologically sustainable forms of energy seen in relation to the duration and intensity of their use (Olgyay, 1963).
2. Flexible & Adaptive Structural Systems; acknowledging the scope of the structure, its permanence or temporariness, its integration with other building components such as interior, envelope
or mechanical systems, the fixing to the footings or founding materials and, obviously, the desired aesthetic effect (Rush, 1986).

3. **Renewable & Environmental Building Materials;** concerning the efficiency of a material or a product, size available, standardization, structural adequacy, complexity, appropriateness, cost, labour involved, plantation origin, method of growth (especially for natural materials), embodied energy (i.e. total energy required to create, harvest, transport, use, maintain and dispose a product), recycled and reused content (deconstruction, adaptability), toxicity level (wastes, pollution), etc. (McDonough, Braungart, 2003).

4. **Modular Building Systems;** exploring construction and assembling methods of building components in order for the various single elements to be eventually isolated and or substituted without adverse complication to the whole, thus allowing for shorter times of construction, reduced energy consumption and wastes, maintenance and/or replacements, flexibility and interchangeability (Bachman, 2003).

5. **Innovative Building Envelope Systems;** investigating, the role, components and specific devices acting as an interface, a filter between interior and exterior environments able to control the energy flows that, directly or indirectly, enter (or leave) an enclosed volume (Wigginton, Harris, 2002).

6. **Renewable & Non-conventional Energy Systems;** integrating in built structures sources of energy that can be exploited without reducing or exhausting their point of origin and which could be collected directly on site or in centralized areas with little or no ecological impact (Smith, 2003).

7. **Innovative Heating, Ventilation & Air Conditioning Systems;** developing strategies to provide acceptable interior conditions for the occupants in terms of thermo-hygrometric and air quality comfort, exploiting mechanically regulated, hybrid, or, preferably, totally passive techniques (ASHRAE, 2001).

8. **Water Collection & Storage Systems;** analysing the methods, system and strategies to collect, store, distribute, use, recycle and reuse water, a vital element for life and a fundamental resource in all inhabited buildings (Roaf, 2005).

Although building envelope systems have their own category, they are inherently embedded in the concepts of the others. For instance, we would expect our façades to use renewable and environmental materials, be modular, respond to the orientation and climate, as well as promote innovative air conditioning systems.

An example of a R.A.R.E. habitat responding to an extreme cold climate is illustrated in Richard Horden’s Ski Haus Project (1996), where advanced materials and operations are employed to provide a highly insulated protective and transportable environment. Structurally, this habitat exhibits a minimal connection with the ground and the conditioned capsule is lifted, minimising heat exchange with its surrounding surfaces (Figure 1).

![Figure 1. Richard Horden Associates – Ski Haus Project, Kronenburg, R. (1996).](image)

Another design principle for extreme hot conditions is illustrated in the sketches provided by Architect Mick Pearce (Figure 2). In this case, the exposure of the building envelope to direct solar radiation is minimised, while the external skin also acts as an excellent emitter of heat at night time. In addition, special selective ceramic coatings could be applied as a substrate on metal roof claddings in order to enhance this functioning principle, making the surface even more effective in solar load reductions and cooling.

![Figure 2. Prickly Bodies are Poor Solar Absorbers but Excellent Emitters (image courtesy of Mick Pearce)](image)
All organisms have adaptations that help them survive and prosper. Some adaptations are structural, i.e. physical features of an organism, like the bill on a bird or the fur on a bear. Other adaptations are behavioural, with the term meaning the things organisms do to survive. All organisms are uniquely adapted to their environments.

The idea of our buildings evolving through adaptation may be considered as an attempt to integrate in architecture the notions of responsiveness to the environment (as seen in natural evolution) with the idea of environmental responsibility: the striving for optimal performance and increased comfort, provided by the minimum consumption of energy.

For decades, we have been designing buildings like machines; but now, instead of a “machine for living in” (as Architect Le Corbusier used to define the highly mechanised buildings of the 20th century), we should evolve our building techniques and try to design an adaptive machine that is actually alive.

Flexible, adaptive, responsive and dynamically changing buildings offer us new ways of organising our lives; these concepts encourage a vibrant society and reinforce the social dimension of environmental sustainability. Naturally, as mentioned earlier, this implementation of sustainability will probably revolutionise the form of buildings, but this approach could be exploited by architects and engineers as an innovating tool to humanise and beautify their built structures.

A PLACE FOR TECHNOLOGY

The challenge we face today is to move from a system that exploits technological development for pure profit to one that has sustainable objectives.

Technology must be focused by the human for the benefit of the human. The question, then, becomes how to use technology, at what scale, and for what purposes. At one extreme, in fact, one may argue that an increased use of advanced technologies in architecture could turn it away from the environment, ecological awareness, and perhaps even from a sustainable future. On the other hand, if appropriately used, it is actually possible that technology could move us forward in an ecologically responsive manner. We should always consider, anyway, that technology is not the absolute answer, although it is a fundamental means to achieve proposed objectives.

Technology is the breakthrough which has revolutionised the process of designing low-energy buildings. Software available can generate models that predict the air movement, light levels and heat gains in a building while it is still on the drawing board. This significantly increases our ability to refine those aspects of the building's design, exploiting the natural environment to reduce the consumption of precious resources.

In a context of predicted significant climate alterations and global warming, through strategic design and the integration of innovating 'adapting' building strategies and technologies, we should try to exploit the interactions between human inhabited spaces and the dynamic of our surroundings so as to guarantee comfortable conditions into built environments with a more efficient use of energy, reducing greenhouse gas emissions and maintaining human biological rhythm in connection to the rhythms of Nature. The challenge is now to define which are the strategies and the design methodologies that could be implemented in order to make our built structures adapt to climate change and, at the same time, guarantee their sustainable co-existence with extreme external conditions.

One possible stream of development is actually to rely on the thorough and balanced integration to buildings of cutting-edge high performance materials, components, techniques and/or control systems which are currently available on the market or in advanced stage of development (also eventually proposing unattempted technological hybrids that combine existing and new knowledge).

In this context, various different envelope components have been recently developed, for example, to shield the internal environment from excessive solar overheating (solar control glazing, tinted glass, reflective coatings), optimise the transmission of incident visible light (optiwhtie glass, anti-reflection layers), reduce the thermal losses to the outside (low-E coatings, vacuum glazing, transparent insulating materials, geometric media, aerogels), reduce the risk of disability glare and adaptation (Double Glazed Units with integrated photovoltaic cells), become energy generators (DGU with laminated semi-transparent photovoltaic cells), flexibly change the optical properties of the glass according to contingent needs (chromogenic glazing), both passively (photochromic, thermochromatic glass) or actively (electrochromic, gasochromatic glass, Liquid Crystal Displays, Suspended Particle devices), self-clean (active glass), etc.

However, an alternative, less high-tech, approach could also turn out to be quite beneficial to the adaptation of built structures to extremes conditions. This line of research actually looks at the 'vernacular' and natural aspect of building envelopes and their occupants' behavioural adaptation, defining, according to different climates, the various materials, building typologies and strategies which have been traditionally developed and put in place to respond to specific conditions, thus including climatic aspects, as well as cultural and social issues (the igloo may be, for example, a case in point).

Integrating new and ancient knowledge, architecture has to change in response to environmental demands. The future is here, but its impact is only just beginning.
PHYSICAL PROCESSES IN THE BUILDING ENVELOPE

The previous analogy suggests that our buildings can, and may in fact, mimic Nature. What we need most is to understand how we can synthesize with the forces of Nature to our advantage. The forthcoming examples provide a few solutions.

PRESSURE BALANCE IN THE BUILDING FACADE

One of the primary functions of the cell membrane is to regulate pressure within the cell in response to external conditions. Similarly, building science developments have provided the 'rain screen principle' to stabilise wind pressurization across the building envelope (Figure 3).

![DIAGRAM](image)

**Figure 3. The Rain Screen Principle in a Façade Cross-section**

The principle is to provide a pressure balance between the external and internal environment and, in doing so, successfully accommodate condensation, weathering and wind forces. The 'rain screen principle' actually provides for a cavity of external pressure balance within its construction through Pressure Equilibrium (P.E. holes). These holes allow for capillary action to take place, providing for water and condensation runoff. Similarly, the ventilation system in an automobile requires an internal pressure release from outlets where a negative pressure zone resides.

Another example of pressure control across the building envelope from the exterior is evident in the 'toilet plumbing' siphon concept used in the natural venting of the double envelope façade represented in Figure 4. In a sense, this is an evolution of the rain screen principle; yet, now the wind force is acting as a generator, creating positive and negative pressure zones which drive the wanted ventilation through the envelope cavity.

**Figure 4. A Siphoning Effect due to Pressure Differences in a Double Envelope Façade (Commertz Bank, Frankfurt, Germany; Architect: Norman Foster)**

CONTROLLING VENTILATION AND AIR LEAKAGE THROUGH PRESSURIZATION

Ventilation is the transport of air to provide acceptable indoor air quality in buildings. It is inclusive of wanted fresh external air and suitably treated re-circulated air (ASHRAE Fundamentals, 2001). The literature defines ventilation as the 'wanted and known' quantity of air coming into a building. Generally, this 'known' quantity applies to mechanical ventilation systems, as the absolute quantity of 'fresh external air'.

The study of air flow within buildings pertains to developing an understanding of the mechanics of ventilation (Liddament, 1996). Ventilation air quantities under natural conditions, entering through façade openings, are quite complex to obtain and regulate. There are several reasons for this. Firstly, the wind pressure and the stack effect will vary around a building quite continuously, changing from a negative to a positive pressure. Such changes are temporal as well as spatial. In addition, a pressure range can also be quite extreme across an envelope. Secondly, the location of façade openings, as well as their orientation in regards to wind direction, can be quite variable. Both of these conditions can make it quite difficult to maintain a building under 'favourable' pressurized conditions.

Building envelopes contain openings by nature of design and allow for air leakage. Unknown air leakage quantities through cracks and building envelope cavities cause air losses or gains. This phenomenon is known as infiltration (air entering) or exfiltration (air leaving) and can be problematic in building façade damage.
The goal should be to:

A. Quantify leakage;
B. Reduce excessive leakages;
C. Control leakage by managing air pressures with the HVAC system (Ask, 2003).

The solution to interactive façade design in extreme conditions is the realisation that such requires building pressurisation control. All buildings require dynamic building pressurisation control to adjust for substantial wind and stack boundary conditions. The 'secret' lies in measuring and controlling the building differential pressure set-point to a minimum (Solberg, 2003). Such has been proposed by Bauer Optimising Control Technologies control system (Bauer) and its principles are explained by Solberg (Figure 5).

**Figure 5. A Building Pressurisation Control System (as proposed by Solberg)**

The regulation of this pressurised control is achieved by damper adjustments on fresh air supply, return and exhaust as well as through variable speed fan drives (Solberg, 2003).

As a result of these new control principles, the interior conditioning of buildings provide for:

- the elimination of down draughts;
- the elimination of air temperature stratification;
- a reduction in background noise;
- improved operational energy savings by +30%;
- improved occupant comfort;
- provide 100% fresh air while reducing CO₂ levels.

The result is a comfortable building interior controlled with laminar (non-turbulent) air movement through interior pressurization. Such pressure differences allow the air to move where it belongs instead of it being forced. Heat transfer (losses) within the building envelope are also minimised through the reduction of convective processes at the interior air film. Air changes are between 2 to 4 (ACH) and there is no return of air contaminants.

**MATERIALS, FILTERS AND BARRIERS**

Also in the way materials are manufactured, Nature shows us some tricks.

First of all, all the materials available in the natural world are processed under life-friendly conditions, in water, at room temperature, without dangerous chemicals or the use of high pressures. Natural materials – a miracle in themselves – can usefully live their life and then be absorbed by another form of life without creating wastes or hazardous substances into an endless cycle of life, death and renewal. Secondly, most materials and structures show an internal organisation that calls for self-assembly and an ordered hierarchy; and, regardless of its apparent "simplicity", Nature manages to craft materials of a complexity and functionality that, for the time being, we can only imagine to mimic with our current techniques and knowledge.

Nevertheless, to truly develop our skills, materials and application in a sustainable manner, more than just trying to replicate the structures and the architectures of Nature’s design or create our materials in a similar fashion, we should be able to imitate their manufacturing processes, thus learning how natural living organisms manage to grow, reproduce, create materials and form their structures with them.

For example, the inner shell of the abalone, a sea creature, is twice as tough as our most developed ceramic materials. The study of the organic templating of the seashells could be applied to the manufacturing process of thin films to insulate windows, a technology immediately useful in the automotive industry in order to reduce the energy load on the engine and keep passengers comfortable. Thin films, by the way, because they are so thin, can also be built up into multilayered devices composed of a semiconductor layer, an oxide dielectric layer, a magnetic layer, or a ferroelectric layer for electro-optical devices.

**SWITCHABLE GLAZED FACADES**

This new technology could contribute to give buildings increasingly sensitive electronic sensors able to register internal and external conditions and respond to specific needs. New materials are being developed that can generate power, that can dynamically and adaptively change from highly insulating to transmitting and from opaque to transparent, that can react organically to the environment and transform themselves in response to daily needs and seasonal cycles.

In 1981, Mike Davies presented the idea of a polyvalent wall, a congregation of several electrically and chemically active layers in one single unit which could control the energetic properties of a glass window. The idea was absolutely revolutionary for the time, showing the interest towards the integration of various properties into a self-contained glazed panel (Davies, 1981).
After 25 years, we seem to have been able to develop the technologies needed to make that dream come true. As previously mentioned, advanced glazing materials coming from scientific experimentation offer a wide range of options to enhance the visual and thermal characteristics of transparent facades, and to improve comfort, appearance and the energy related performance of building envelopes.

However, regardless of these huge advances in technology, architects and engineers often find it hard to thoroughly acknowledge and integrate these components and techniques within their designs. As stated earlier, technology has not to be taken for granted as an answer for its own sake, but rather - as it happens with most of Nature's structures - it has to be carefully exploited for the simultaneous benefit of the buildings, their users and the environment that surrounds them.

Transparent glass facades are probably the most difficult system to design in a building, since they always have to find a balanced compromise between needs of transmission and protection.

A light beam entering a room may be quite beneficial in the morning to entrain the human metabolism (circadian system) of occupants as long as it does not strike directly in their field of view: nonetheless, the same incoming solar radiation can be detrimental to the thermal environment, increasing the requirement for air conditioning. At the same time, a façade characterised by a solar control glass can reduce the risk of passive heating (and, thus, minimise the cooling load) but, simultaneously, it may reduce the availability of natural light, increasing energy consumption for artificial lighting and decreasing the visual (physiological and psychological) comfort for the occupants. Yet, a glass characterised by advanced thermal properties, such as Low-e coatings or vacuum glazing, can improve the thermal comfort of buildings in winter, reducing the heating load due to a cut in thermal losses, but will be detrimental in summer on orientations that are exposed to large amounts of solar heat gains (e.g. east and west).

Consequently, in the design of buildings - especially for large glazed areas - a "one-size-fits-all" response in the choice of envelope components cannot be considered as a sustainable response to the variable requests that the environment, the changing climate, the occupants, as well as the flexibility in the use of spaces, now demand. Obviously, this awareness is of fundamental importance especially when applied to extreme conditions, where external agents can toughly interact with the façade and also change abruptly, thus requiring an appropriate adaptive response by the building envelope.

Switchable façade technologies, which can adjust dynamically to the changing external climate conditions or can be switched according to internal needs of users, if thoroughly integrated can be an answer to some of these needs (Altomonte, 2002) (Figures 6 and 7).

![Figure 6. A Switchable Electro-chromic Glass Façade System (Altomonte, 2002)](image)

![Figure 7. Internal Structure of an Electrochromic Laminated Glass Pane (Altomonte, 2002)](image)

As a matter of fact, switchable façades can be designed to adapt in an almost 'living' way to variations in luminous and solar radiation levels and user requirements, so as to concurrently reduce the energy consumption of the building, create a pleasant environment for the people who live and work inside, and make use of natural, renewable energy sources in as environmentally compatible a way as possible.

Nevertheless, it is important to highlight that a technology such as innovating switchable glazing represents just one tool to exemplify a totally new approach to building
design, in which built structures need to minimise their confrontation with natural forces, respecting their laws and interacting with them. The further challenge is how to integrate these innovating technologies into an equally innovating overall strategy for architectural design.

A typical conventional façade is one acting as a static barrier. There is no built-in intelligence to the external conditions and the response is reactive (at best) rather than proactive. An example, as measured through thermal imaging with the Mobile Architecture and Built Environment Laboratory (MABEL) unit (Luther, Schwede, 2006) in Australia, is shown in Figure 8.

![Figure 8](image)

**Figure 8. Screen Output of a Thermal Imaging Camera Showing a High Surface Temperatures during Low Temperature Air-Conditioning (Note: X's indicate locations of collected data).**

Here the interior environment is air-conditioned to a seemingly comfortable 24°C. What is missing is an understanding of total heat transfer principles. The façade is actually boiling hot, radiating its energy to other bodies (occupants) of the space. A large radiative surface heat transfer from the façade to the occupant is neglected and cannot be accommodated by the conditioning system. Consequently, the comfort of the occupant is sacrificed. This is an example of an extreme climatic condition where the elements of the façade must go beyond mere insulation if they are to effectively support the conditioning of the interior.

A solution to the above may suggest that we effectively bring Nature and its adaptive dynamism into our buildings. One possibility is to include natural elements at the envelope as done through the integration of plants. A recent example is given by the design of the Melbourne City Council House 2 (CH2), the first six-Green star rated sustainable building in Australia (Figure 9).

![Figure 9](image)

**Figure 9. A Scaffolding of Vegetation as a Climate Modifier (City of Melbourne, Australia)**

In this case, a scaffolding of plants provides shading and cooling to the building skin as well as air purification at the building openings. To decrease the risk of intolerable glare on the north façade (equator-facing), actually steel trellises and balconies – supporting a series of vertical gardens that run the full height of the building alongside the windows – filter light entering office spaces and form a ‘green’ microclimate. The four metres vines are grown from boxes situated to the east and west of each balcony on every storey via stainless steel mesh stretching from the ground to the roof. The presence of the vines contributes to increase visual comfort for the users, both in terms of glare reduction and the positive physiologic effect due to a ‘green’ presence in office areas. The external air at the building envelope is cooled through the evaporation of a spray-mist which waters the plants.

**THE FAÇADE AS A CLIMATIC CONDITIONER**

Under conventional practices, the building envelope has been regarded as a barrier separating the interior from exterior environment. The need to conserve energy has triggered a re-evaluation of the envelope’s role into one conceived as a dynamic boundary (Bradshaw, 1993).

The envelope concept is evolving into one which is dynamic in its expectations. Its role may be to act as a climate modifier: shading, reflecting, collecting, storing energy, light diffusing as well as providing visibility, protection and comfort. Until recently, the façade remained as a separate building component, providing several of these features. It is from this point that the evolution has now continued even further where manufacturers are beginning to research the possibilities
of the façade replacing the centralised mechanical conditioning plant of the building. German manufactures such as Schucko and Wicona are making advancements where decentralised conditioning systems are contained (or in close proximity) within the façade system. In fact, it is one of the primary goals of façade manufacturers to eliminate a centralised mechanical plant and let the façade become the actual building conditioner.

Such advancements are quite revolutionary to contemplate and suggest an evolution of the façade beyond a 'climate modifier' into one which is a 'climate controller' as well as an energy generating source. Previous concepts by the author in Figure 10 (Luther, 2000) illustrate a combination of various scientific advancements integrated into a 4200x1200 mm modular façade system approaching this concept.

In such multiple panel systems, for example, the internal cavity could be connected with the outside air (as it would be convenient for cooling reasons in hot climates) or could be totally sealed from the external environment, thus retaining as much as possible the heat generated inside the building (cold climates). This latter strategy would be, for instance, enormously important in extreme environmental conditions where, obviously, a dynamic exchange of fluids with the outside may not be possible or desirable (as in space habitats or under the sea).

A sealed multiple skin façade could, for example, be applied for the construction of settlements in which extreme external conditions cannot permit a continuous 'osmosis' with climatic factors. Referring specifically to space habitats, it is quite obvious that a ventilation of the multiple skin cavity utilising air exchanges with the outside environment is not desired. Yet, a layered envelope system can be designed in order to maximise the optimisation of internal conditions (especially in terms of heat and light management), while at the same time ensuring protection from hazardous external agents. In this case, a possible solution could envisage the application to the envelope system in space habitats of technologies which are currently being investigated and applied for responding to extreme cold conditions on Earth. Amongst them, the Active façade system developed by Permasteelisa (Figure 11).

In an Active façade system, a second internal single window pane is placed behind an outer Double Glazed Unit (DGU), with a shading device (expressively tailored to the conditions that the façade has to meet) mounted in the cavity between the DGU and the interior glazing.

**Figure 10.** An Integrated Façade System (Luther, 2000)

**Figure 11.** The Active Façade System developed by Permasteelisa Group of Companies

DOUBLE AND MULTIPLE SKIN FACADES

In the past 25 years the building skin (façade) has encountered a revolutionary transformation. Much of this development is in efforts towards reducing the internal building load, thus making it easier to condition. In fact, the purpose of the building façade often gets lost in the desire to apply the advancements of technology. It is often forgotten that its primary purpose is to enable and improve the conditioning of the interior environment providing comfort to occupants.

Double and multiple skin façades are a further example of these developments, in the attempt to reduce the effect of unwanted external agents, minimising infiltration and heat transfer as well as allowing for shading control in the cavity. Such envelope systems have reduced infiltration to nil, totally omitting an unknown air leakage quantity in building loads. In addition, multiple layered façades present an opportunity to differentiate in various levels the numerous functions that a building envelope has to simultaneously perform (light ingress, solar protection, reduction of thermal losses, ventilation, air quality, energy generation, etc.), thus referring back to the very principles that Nature uses in many of its structures (multi-functioning, integration of tasks, etc.).
The inner cavity is continuously ventilated using the exhaust air from the internal building ventilation system. If applied to space habitats, this specific assembly, other than just protecting with a three-layer system the internal environment from harmful external factors (solar winds, dusts, etc.) and ensuring a sealed separation between internal and external space, can be quite versatile in its functioning in order to respond to extreme situations.

During cold periods, thanks to the continuous flow of pre-treated room stale air return into the air cavity, the inner glass can be kept closer to room temperature (within 1-2°C) thus eliminating any radiation and material convection effects, sensibly reducing thermal losses to the outside, and, at the same time, allowing greater use of the perimeter area of the built structure. At the same time, in periods when the internal environment has to be shielded from unwanted direct and diffuse radiation (for example to avoid excessive overheating), the blinds inside the cavity could intercept much of the incoming solar energy, reflecting it to the outside and/or absorbing and reradiating in the form of long-wave radiation. This long wave radiation (heat) can be extracted from the internal cavity and used, together with a heat exchanger, to aliment the HVAC system or to produce hot water. In this case, the Solar Factor which is achievable by an Active façade is comparable to that of external protection devices (SF <0.15), although it depends on the design and material of the blind and the air volume flow rate extracted via the cavity. Better shading and thus a lower shading factor can be provided with increasing volumes of ventilation air. The U-values of this type of façade also depend on the volume of ventilation air and would vary according to the properties of the glazing and, obviously, the external conditions the façade would be exposed to in extreme environments (Permasteelisa, 1998).

THE NEED FOR INTEGRATED DESIGN

Back on Earth, for a multiple skin façade, other than creating a buffer zone, the cavity between panes, is characterised by controllable thermal and hygrometric conditions. It can accommodate solar protection (or collection) devices that could thus be effectively protected from external agents such as wind, pollution and weathering. These shading devices could, in their turn, perform a number of roles, such as protecting from unwanted solar radiation, reflecting the available light deeper into the rooms, contributing to the collection of sensible heat gains, and so forth (Compagno, 1995).

Obviously, numerous different arrangements could be proposed in which the multiple skin façade, due to the solar radiation received and the convective air movements this could trigger, can become the 'engine' that drives the controlling of interior conditions inside enveloped spaces as well as a place for the generation of renewable forms of energy (PV panels, heat exchangers, air circulation, etc.). It is quite important, then, that the choice of components and integrating strategy is optimised according to the specific needs of the project and the peculiar climate condition that has to be faced, in order to finely tune every aspect of the delicate "mechanism" that a multiple skin façade could require for its efficient functioning.

However, there have been a number of shortcomings of the multiple envelope system - especially in mild and hot climates - which have not yet been fully proven to actually provide significant energy savings. The authors believe that the main reason for a potential increased energy use is the lack of an integrated system, i.e. the building envelope operation in sequence with the HVAC system control (as suggested by Solberg, 2003).

Excessive internal cooling occurs because the building experiences minor heat losses and, therefore, requires its gains to be controlled totally by the mechanical system. Note that leaky buildings gain as well as loose energy easier than tightly sealed buildings. The conditioning of air, still remains as one of the critical factors of mechanical systems which can recycle up to 7/8 of their total conditioned air allowing only a minimum of fresh air entering into the interior. Furthermore, 'stale air' pollutants are recycled and mixed with 'fresh air' thus degrading it. Unless the paradox of 100% fresh air intake is understood as economical, such as in the control theories provided by Bauer and Solberg, there will be no improvement in such buildings.

A possible solution to the multiple envelope façade problems is the air-flow window proposed in Figure 12. This system allows for various options of a naturally ventilated façade. In this case, the fresh air intake may be introduced into the interior directly. The short comings of direct ventilation are the loss of a pressure differential within the interior. The challenge rests in a solution to several of the ventilation possibilities:

- Direct Ventilation: in this mode there is no building pressurization, the exhaust fan is running.
- Mixed Ventilation: perhaps this air needs to be ducted to the HVAC plant directly.
- Room Circulation: the pressurization control is extended to the window cavity.

These solutions are a hybrid to pressurisation control and further research is needed. Yet, the possibilities of façade integration with interior conditions are recognised.

Figure 12. Natural Ventilation Concepts in an Air-Flow Window (M. Luther)
CONCLUSION

The age of ‘Climate Crisis’ is upon us. The suggestions made here are that we can look, learn and imitate Nature to solve most of the problems we struggle with today. ‘Energy harvesting’ is the design paradigm we need to work under (Cheung, 2005). It is defined as eliminating squander, and distributing energy potential on-site to other services for the building to function efficiently. Several possibilities for creating and producing a natural, yet dynamically functioning, building skin are introduced in this paper. The key issue is that the building interior functions optimally together with the façade when an interior pressure differential is maintained. In other words, we should consider the façade functions in conjunction with and as serving our interior conditioned air volume.

Flexible and environmentally responsive building ‘skins’ will not be designed as passive shelters, separate components protecting the building interior from external agents, but rather they will involve the use and integration of advanced materials and systems able to optimize their internal environment according to external conditions, while also possibly become generators of energy. In order for such to take place, existing knowledge gaps with respect to how built structures can evolve and adapt to extreme conditions must be filled, impacting on form, fabric, and functioning so as to ensure their long-term sustainability.

The question may be: why haven’t we always been working with something that was compatible with Nature? Wouldn’t that have been more easy and avoided a lot of problems? Ironically, it always takes dramatic circumstances and a menacing shift in the current situation to become aware of the need to take responsibility of our own actions and adopt all the possible remedies.

After two centuries of Industrial Revolution, we are only now realising that the world we have artificially built is strictly interconnected with the real, natural, biological one. Yet, it is this ‘natural world’ that has sustained us so far, cradling and nourishing us, making all of our (sometimes insane) actions possible.

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