

Redefining the Wall: Architecture, Materials and Macroelectronics

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As a principle element of architecture, technology has allowed for the wall to become an increasingly dynamic component of the built environment. The traditional connotations and objectives related to the wall are being redefined: static becomes fluid, opaque becomes transparent, barrier becomes filter and boundary becomes borderless. Combining smart materials, intelligent systems, engineering, and art can create a component that does not just support and define but significantly enhances the architectural space. This paper presents an ongoing research project about the development of a new class of architectural wall system by incorporating distributed sensors and macroelectronics directly into the building environment. This type of composite, which is a representative example of an even broader class of smart architectural material, has the potential to change the design and function of an architectural structure or living environment. As of today, this kind of composite does not exist. Once completed, this will be the first technology of its own.

I. INTRODUCTION

Recent developments in digital technologies and smart materials have created new opportunities and are suggesting significant changes in the way we design and build architecture. Traditionally, however, there has always been a gap between the new technologies and their applications into other areas. Even though, most technological innovations hold the promise to transform the building industry and the architecture within, and although, there have been some limited attempts in this area recently; to date architecture has failed to utilize the vast amount of accumulated technological knowledge and innovations to significantly transform the industry. Consequently, the applications of new technologies to architecture remain remote and inadequate.

One of the main reasons of this problem is economical. Architecture is still seen and operated as a sub-service to the Construction industry and it does not seem to be feasible to apply recent innovations in Building Technology area. Another reason lies at the heart of architectural education. Architectural education does not follow technological innovations Watson [1], and that “design and technology issues are trivialized by their segregation from one another” Fernandez [2]. The final reason is practicality and this is partially related to the previous reasons. The history of architecture is full of visions for revolutionizing building technology, ideas that failed to achieve commercial practicality. Although there have been some adaptations in this area recently, the improvements in architecture reflect only incremental progress, not the significant discoveries needed to transform the industry. However, architectural innovations and movements have often been generated by the advances of building materials, such as the impact of steel in the last and reinforced concrete in this century. There have been some scattered attempts of the creation of new materials and systems but currently they are mainly used for limited remote applications and mostly for aesthetic purposes.

We believe a new architectural material class is needed which will merge digital and material technologies, embedded in architectural spaces and play a significant role in the way we use and experience architecture. Accordingly, this paper reports the progress of an ongoing research project about the development of a new class of architectural enclosure system by incorporating distributed sensors and macroelectronics directly into the building environment. Briefly, we have developed a new architectural composite material that will be part of the architectural space and includes circuit elements - transistors, resistors, capacitors, diodes, etc. — equipped with sensing and computational capabilities in the form of a lightweight, flexible thin film laminate that can be either be applied on top of the wall surface or used as a partition-wall element in itself. This new material is capable of displaying different visual properties on demand.

2. THE WALL - DEFINITIONS AND CASE-STUDIES

2.1. Traditional | modern wall

As a principal element of architecture, technology has allowed for the *wall* to become an increasingly dynamic component of the built environment. The traditional connotations and objectives related to the wall are being redefined: opaque becomes transparent, static becomes fluid, barrier becomes filter, and boundary becomes borderless. Combining smart materials, intelligent systems, engineering, and art can create a component that does not just support and define space, but significantly enhances it.

2.2. 90 | 360

One of the many things new technology has fostered is the visualization and realization of once unthought-of forms, specifically curved forms. A new wave of architecture even sprung from this realization, *blobitecture*. One example of this is Bernhard Franken's *Bubble for BMW* (see Franken-Architecture [3]). In this project, the wall is the ceiling and the floor; it is a 360 degree surface instead of the traditional orthogonal geometry. In this project, a computer program was used to simulate water droplets combining, which was the inspiration for the form and corresponded to BMW's theme for the exhibition: Clean Energy (hydro and solar). This basic design was input into other programs to smooth out the form and make it structurally stable. From those calculations, the wall, composed of load-bearing aluminum beams and individual plexi-glass panes, was created..

The wall has been shredded of its bulk and exposed as a malleable surface sculpted and shaped by forces in this project. It is a thin membrane that crosses the line of public-private with its transparency, and architecture-or-sculpture with its form. Nonetheless, the wall no longer serves as a square container, but a fluid surface without boundaries because of modern tools and materials. Technology allowed for the walls in this project to be conceptually developed, structurally planned, and even produced all with the aid of computers. It reflects the advancements architects like Frank Gehry made for architecture, and opens the possibility of creating forms that once seemed structurally challenging or unsound.

2.3. Static | dynamic

Calatrava, who is known for creating movable parts to expand, open, or alter interior space, has thoroughly combined architecture and engineering to broaden the potential of a wall. His first building in the United States, The Milwaukee Art Museum in Wisconsin, has a great portion of the building that is moveable. The part is a sunscreen that can be raised or lowered to adjust the intensity of natural light on the interior. This *brise soleil* rests on top of the Museum's glass-enclosed reception hall. With fin size ranging in length from 26 to 105 feet, the sunscreen's wingspan spreads

217 feet at its widest point, wider than a Boeing 747-400 airplane, and weighs 90 tons. Unprecedented in American architecture, the brise soleil's design is also unique to any European architecture created by Calatrava (MAM [4]). L'Hemispheric in Valencia, Spain is another piece that utilizes movable parts. Resembling an eye, the "eyelid," or wall, has the ability to move up and down, opening the interior to the water and nearby park. In Calatrava's designs, wall movement means area expansion, natural ventilation, protection from the elements and, more interestingly, unique form and space. These engineering feats have welcomed the challenge of creating dynamic space with walls that are beneficial and interesting to the inhabitants.

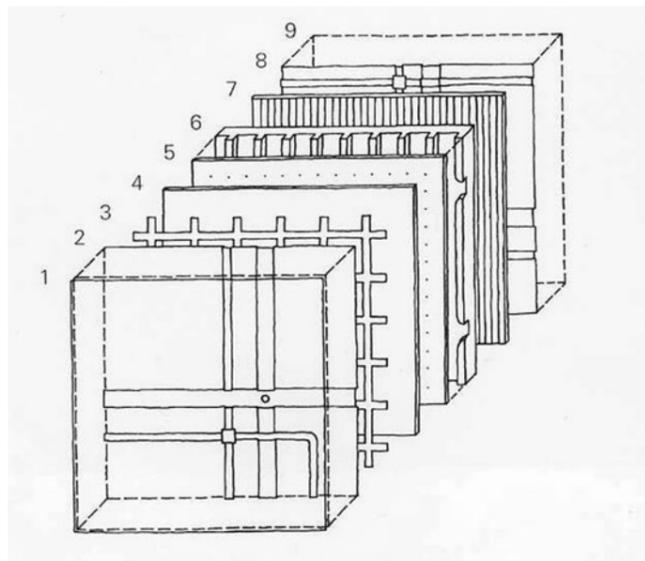
2.4. Sculpture | machine

The movements of Calatrava's walls are manual, but today because of modern technology and materials, movement can be a response of an environmental force, and that response can enhance space. Rather than being a sculpture or container, the building becomes a living machine. This thought is evident in l'Institut du Monde Arabe in Paris by Jean Nouvel (1987). Nouvel created a wall that is adaptable, serving as a sieve from the exterior to the interior, contrasting the solidity of traditional architectural walls which are barriers or protectors from the elements and simply containers for the inhabitants. One element is embraced in this project and used for gain in the interior, natural light. The southern facing façade contains 240 windows with thousands of individual irises or machines that control light and heat passing thru the wall. The little openings are composed of metal pieces of various sizes that act as shutter of a camera; limiting bright light in the summer and maximizing it in the winter. The wall is an active design, engaging the interior with the exterior. Another beneficial factor of the wall is that it revealed to the public a combination of art, culture, architecture, and technology. Often the public can have a negative impression of what technology can do for the environment and for inhabitable space. This wall brings it down to a personal, interactive, and visual scale.

2.5. Barrier | filter

Energy concerns have motivated many architects to take an environmentally responsive approach to design. The wall plays one of the most important factors in this naturally because of its separation of the exterior and interior. English architect Mike Davies developed a theoretical but potentially applicable wall in 1981. He entitled it the *polyvalent wall*, a wall for all seasons. The wall would control the flow of energy from the exterior to the interior using extremely thin layers that are multifunctional. The membrane would have the ability to absorb, reflect, filter, and transfer energies from the environment. In his own words, he says it will become

the envelope of a building and “remove the distinction between solid and transparent” Davis [5]. It will have the properties of glass, but also the opacity changes of an electrochromic window, the ability of energy collection like a photovoltaic cell, and the ability to produce comfortable heat levels like thermoelectric heat pumps, not to mention it would still need the capability to ventilate like traditional windows. According to Davis [5], it would continuously adapt and change to the surrounding conditions and act as a filter in both directions, interior and exterior



◀ Figure 1: Composition of polyvalent wall

The conceptual layers of Polyvalent Walls

1. Silica weather skin and deposition substrate
2. Sensor and control logic layer, external
3. Photoelectric grid
4. Thermal sheet radiator/selective absorber
5. Electro-reflective deposition
6. Micro-pore gas flow layers
7. Electro-reflective deposition
8. Sensor and control logic layer, internal
9. Silica deposition substrate and inner skin

2.6. Canvas for | exchange of information

In this approach, the walls are the medium for expression rather than the container for it. Proposed by dECOi as explained in the writings of Goulthorpe and Burry [6], Hyposurface is an excellent example of a wall that is a participant in communication exchange. It was developed for a

competition for an interactive art-work for the foyer of The Birmingham Hippodrome Theatre and has since become an excellent architectural element, accent, and marketing tool. This wall is creating and accentuating space with its forces and interactions.

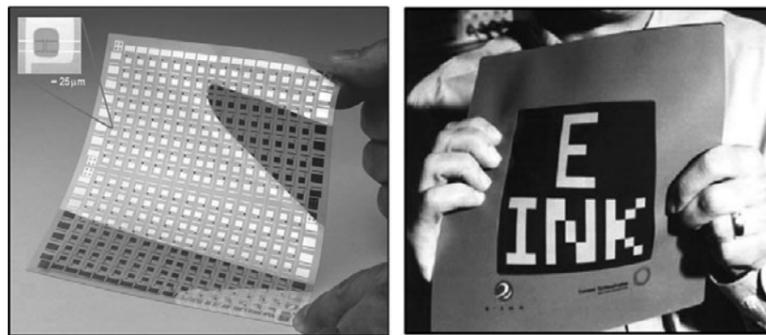
3. MICROSTRUCTURED SEMICONDUCTORS: WALL REDEFINED

Based on the inspirations and encouragements from the case-studies and previous attempts as briefly described above, we have developed a new approach for the enclosure systems. In our on-going project, re-defined, re-designed and re-engineered wall with microstructured semiconductors reversibly switches its properties in response to an external demand. Our wall system material is a flexible, polymer-based composite that we can be used as a wall system in the future. On this new material, colors and patterns can be set, changed, and adjusted to different tastes, furniture, mood and design trends. Various visual projections -or presentations- would be available, too. For example, picture frames can be created on defined areas on demand and in theory every wall could become a TV screen, including the ceiling! Figures 2 and 3 illustrate concept drawings and actual prototypes by Rogers, Bao [1], Rogers [2] of the types of systems that we are utilizing

The crucial element for these types of systems is the ultralow cost distributed electronics that can control the colors of the pixel elements. We are designing these circuits to have layouts and performance comparable to the circuits that are used in liquid crystal computer displays. Static images as well as full-motion video will be possible. For the composite, it must be possible to build the circuits at a small fraction of the cost of those that use conventional silicon on glass. In addition, due to considerations of weight and installation, they must be constructed on lightweight, flexible, rugged substrates such as plastic rather than traditional electronic substrates such as glass or silicon. The materials and engineering technologies that can enable circuits of this type do not currently exist. It is one of the main issues of our research to develop and demonstrate the necessary materials and fabrication techniques.

► Fig 2 Living space enhanced with thin, wall mountable large area displays. Adapted from a presentation by Philips.





◀ Fig 3. Flexible electronic circuit (left) and paper-like display system constructed with it (right).

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We believe that the most promising material for the semiconductor component of these circuits is a printable form of single crystal silicon, which we refer to as microstructured silicon ($\mu\text{s-Si}$) (see Menard, Lee [3]). This new material is just now emerging from our labs. The basic approach in this case is to use specialized etching procedures to slice a standard silicon wafer into microscopic pieces - ribbons, wires, platelets, disks, etc.- depending on the application. These pieces can then be dispersed in a liquid solvent from which they can be cast onto nearly any substrate, including low cost plastics. The necessary circuits can then be constructed out of the $\mu\text{s-Si}$ material. The advantages of this approach are: (i) it enables a high-quality semiconductor to be integrated onto a wide range of substrates at room temperature and in open air, (ii) it relies on very well-developed materials technology - single crystal silicon wafers, (iii) it exploits all of the knowledge of how to build circuits out of silicon, and (iv) it is compatible with printing techniques and other low cost, non-cleanroom-based methods for making the circuits. Figure 4 shows an image of some of this material, in the form of collections of microscopic ribbons (see Menard, Lee [3]).

► Fig. 4. Microstructured silicon, in the form of long narrow ribbons. The inset shows a solution suspension of this material.

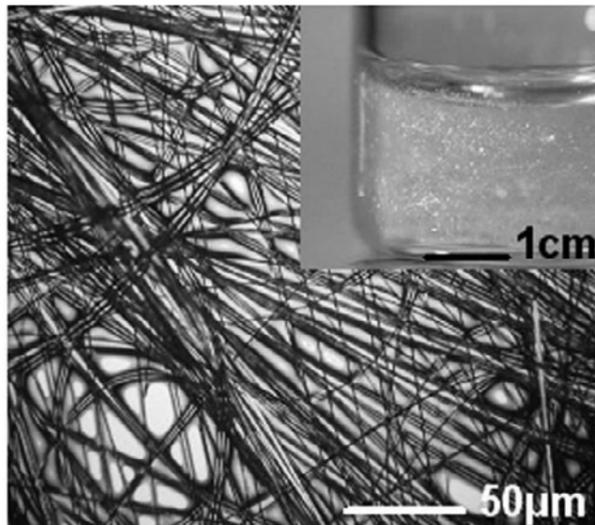
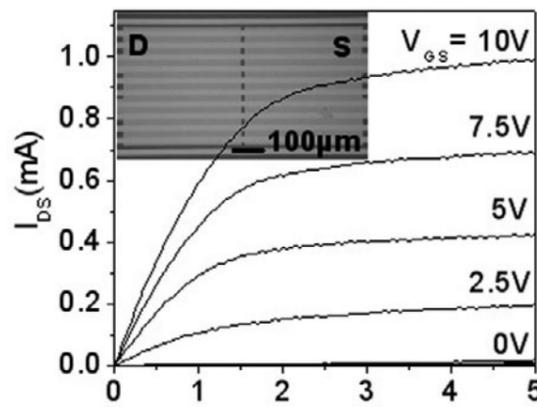


Figure 5 illustrates an array of such ribbons integrated into a device that operates like a high performance, conventional transistor (see Menard, Lee [3]). The switching characteristics of devices such as these are almost as good as well-engineered transistors on silicon substrates. They are considerably better than those of conventional silicon transistors on glass. This new μ s-Si technology allows one to consider, in a realistic way, the types of smart architectural surface materials described in this paper.

► Fig.5. Current-voltage characteristics of a device that uses μ s-Si as the semiconductor.

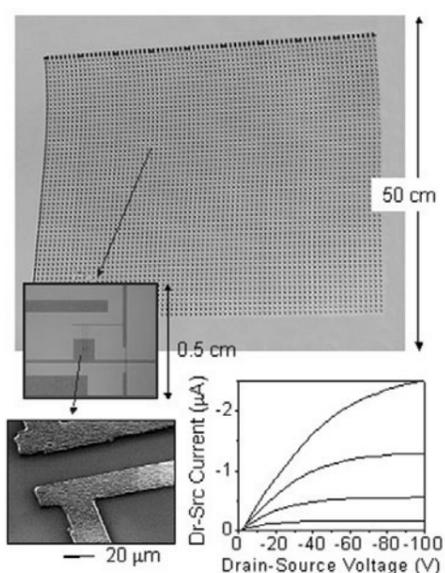


4. METHODOLOGY

The developing prototype will be initially applied as an external sheet on top of the existing wall surface. At its technology base, it will rely on innovative ways to build circuits out of the μ s-Si material described previously. We are developing these concepts and applying them to large

area circuits on plastic substrates with designs that specifically address the digital wallpaper application.

We are adapting for use with $\mu\text{-Si}$ the printing techniques and circuit designs that we developed in the past for organic semiconductor based circuits Rogers, Bao [7], Blanchet, Loo [10]. Figure 6 shows an example of a 50x50 cm flexible active matrix circuit that we formed by printing Blanchet, Loo [10]. New methods must be invented to deposit and pattern the $\mu\text{-Si}$ to yield similar circuits for digital wallpaper. We are pursuing approaches based on silk screen printing and ink jet printing for this purpose. We are also developing methods for integrating other components of the circuits (e.g. dielectrics and electrodes) directly onto the $\mu\text{-Si}$ before this material is printed onto the final devices substrates. We believe that these strategies will enable high performance circuits to be formed directly on conventional building materials such as paper and polished stone or wood.



◀ Fig. 6. Large area printed circuit that uses organic semiconductors. Similar systems that use $\mu\text{-Si}$ will enable high performance, robust operation.

4.1. Properties

Various layers of audio-visual components are identified; their functions are defined and pressed together into a single composite 'smart' material. This new polymer composite has its own sensors, printed speakers, and computation firmware built-in in its layers. Based on this integration, this new composite performs multiple functions by changing its properties dynamically in direct response to user's preferences and demands.

5. CONCLUSION

We believe this study lays the fundamental groundwork for a new paradigm in surface engineering that may be of considerable significance in architecture, building and construction industry, and materials science. Our current challenge is to develop the first phase of the prototype and test it in a non-clean-room based environment. As of today, large scale, flexible display material does not exist. Once completed, this will be the first technology of its kind.

In addition to our work, all other existing studies demonstrate that the evolution of the wall is on course, but greater risks need to be taken until we can achieve a wall that has the environmental capabilities of the *polyvalent wall* with the fluidity and response of dECOi's *Hyposurface*, the beautiful dynamic spaces of Calatrava's designs, the thinness and structural stability of the *Bubble*, and still with the connection to culture like the *Arab Institute*. The wall will be more than a barrier or structure; it will be a fully integrated system: an energy source, structure, protection, and a connection to the environment.

When that wall is achieved, we will be able to personally alter and create our spaces. In time inhabitants will be able to manually adjust space, whether it is the control of light and heat comfort levels, the color of an element, the location of a seat, a piece of art, or the size of a room. It would be a significant contribution to architectural spaces. When employees have control over their environment, they will most likely be more productive. It would also be beneficial for smaller spaces, which is important because of the ever-growing city populations. Minimum space with maximum comfort and efficiency will be created by these walls. Spaces could become non-hierarchical and boundary-less.

Buildings will also automatically adjust to different environmental conditions. There will be specific responses to adjust for maximum energy gain, light intensities, and heat levels. A structure will be able to respond and increase stability or protection after detecting severe weather. Our ideas about context and site may change dramatically. Urban fabrics, now dictated by linear elements, will take on a whole new aesthetic. Experiencing a city street in the future could be much more dynamic and involve different levels of transparencies, fluid movements of walls, and new structural feats. At the same time the environment may be cleaner, with fewer pollutants and waste. Architectural diction and vocabulary may also significantly change. Vocabulary may be geared more toward engineering and environmental terms and ideas. The development of new vocabularies will correspond to the new modes of thought and new digital technologies available for expressing an architectural thought.

Overall, architecture is getting more interactive. The static space as seen today has become in sharp contrast with the dynamic of ever-changing spaces that will be in our future. Architecture is embodying information and

communication. It is becoming an action-reaction system for personal needs and environmental conditions.

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