NANO-TECTURE: Developing Smart Skins in Architecture

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ABSTRACT

This paper surveys a brief history of architectural skin materials and presents an ongoing research project about the development of the materials and fabrication concepts for a fundamentally new class of architectural composite. 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 living environment. We believe this study will lay the fundamental groundwork for a new paradigm in surface engineering that may be of considerable significance in architecture, building and construction industry, apparel and textile science.

Keywords: architecture, apparel, textile, smart, materials

1 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. 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. This relationship –between new technologies and 'new architecture' is very significant and has always played a significant role in architectural field so that architecture in modern times is characterized by its capacity to take advantage of the scientific developments and technological innovations [1].

Based on the digital and technological advancements and the introduction of new design and fabrication tools to architecture, a new way of design thinking has emerged – ways to express an idea as well as ways to create –fabricate and manufacture- usable and meaningful designed environments. These developments are seen as mind-extending or as a catalyst to stimulate designers, to facilitate new problem structuring and construction activities, such as conception, representation, reflection, and production. As a result, a new architectural formal language and grammar, where structure and skin form a new kind of composite materiality, has been emerging. Consequently, an interesting relationship is established between the new geometries and "new materials where new architectural geometries opened up a quest for new materials and vice versa" [2].

The composite nature of these new materials is created by the combination of multiple separate layers of different materials into a single material. Certain cognition-driven terms, such as 'smart' and 'intelligent' are started to be used to describe the interactive and built-in programming nature of the composites. There are some scattered attempts of the creation of these materials but currently they are mainly used for limited applications and mostly for aesthetic purposes. A new architectural composite 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.

This paper surveys a brief history of architectural surface materials and introduces a new architectural composite material that will be part of the architectural space. This new composite is a high performance textile-based material capable of displaying different visual properties on demand. Our approach uses three major pertinent domains in this area: architecture and design; engineering and material science; and apparel and textile sciences. Together, this confluence will produce an innovative surface material that lies at the intersection of the involved domains. See Fig. 1.

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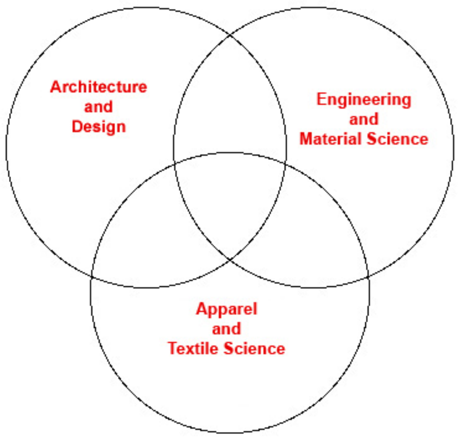

Figure 1: Converging Domains: Architecture & Design; Engineering & Material Science; and Apparel & Textile

2. FROM CONCRETE TO SMART SKINS

The environment, with its resources and geological conformation, has characterized the architecture since its beginning. Probably when the mankind left the house-cave, the first two materials used in construction were stone and wood. Even if it is impossible to define a start line for both materials, some excavations allows us to believe that stone and wood were used before the Neolithic period and today it is impossible to think of architecture without this two materials. In addition, another material, brick, was used widely. It is the first manmade material and its use was encouraged by an easy production and transportation.

2.1. Wood

Wood is probably man's oldest natural resource. Archaeological excavations have uncovered wooden utensils and bowls dating back thousands of years. While wood does not have the historical longevity of stone and there are not evidences of the first wood buildings, the find of wood tools proves that the mankind was able to work this natural material. Consequently it is assumed that wood was used in building construction also because it is a cheap natural material which is widely spread. Wood, as material in construction, has its natural evolution with composite wood. Historically, the composite woods were created to resolve the natural dimensional limits of trees, from which it was impossible to attain long beams. In fact it was impossible to cover distances of 20-30 meters and it was also impossible to curve the wood with big sections.

2.2. Stone

The second material used widely was stone. The first structures in stone were the megaliths, usually dated at Neolithic period, before the Egyptian and Mesopotamian civilizations. Evidences of those monuments are in different geographical areas, from Europe to Africa passing through Asia. However this material has much in common with their structure.

2.3. Glass

Glass's most abundant and basic component is silica (quartz sand). At least 2000 years ago it was learned how to lower the melting temperature of silica by adding lime and soda before heating. This resulted in a glass containing sodium and calcium oxides. The sand is mixed with soda and lime and heated (roughly at 550° C or 1022°F) until it becomes a liquid. It is then shaped and cooled. In the 1950s the most widely used method to this day was invented by Sir Alastair Pilkington, a process called float glass. In this process, the molten glass is poured onto one end of a molten tin bath. The glass floats on the tin, and levels out as it spreads along the bath, giving a smooth face to both sides. The glass cools and slowly solidifies as it travels over the molten tin and leaves the tin bath in a continuous ribbon. The glass is then annealed by cooling in a temperature controlled oven called a "lehr". The finished product has near-perfect parallel surfaces. With further refinement of the manufacturing of the glass and concurrent technologies, new things began to be possible with glass. For instance the introduction of bigger panes, multiple panes laminated together to form structural glass, films applied to the glass and different elements being melted into the glass during the manufacturing process.

2.4. Iron/Steel

Iron is a strong, hard, heavy gray metal. It is found in meteorites and is also found combined in many mineral compounds in the earth's crust. Iron is used to make steel, an even harder and tougher metal compound. Steel is formed by treating molten iron with intense heat and mixing it (alloying) with carbon.
Until 19th century, steel was an expensive material and only used for a limited number of purposes, such as tools. Today, steel is one of the most widely used structural materials in architecture.

2.5. Composites

Composites are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct within the finished structure. Engineered composite materials are advanced composites and formed to shape. This involves strategically placing the reinforcements while manipulating the matrix properties to achieve a melding event at or near the beginning of the component life cycle. A variety of methods are used according to the end item design requirements. These fabrication methods are commonly named molding or casting processes, as appropriate, and both have numerous variations

2.6. Composites

Smart skins are advanced composite materials which constitute a category comprising carbon fiber reinforcement and epoxy or polyimide matrix materials. These are the aerospace grade composites and typically involve laminate molding at high temperature and pressure to achieve high reinforcement volume fractions. These advanced composite materials feature high stiffness and/or strength to weight ratios.

2. OUR APPROACH

In our approach, new 'smart skin material' is a strong fiber such as kevlar, Dyneema and carbon fiber that gives the material its tensile strength, while another component is a resin such as polyester that binds the fibers together, transferring load from broken fibers to unbroken ones and between fibers that are not oriented along lines of tension. This approach prevents the fibers from buckling in compression (Figure 2,3, and 4). On this 'smart skin', any fibers serve to resist tension, the matrix serves to resist shear, and all materials present serve to resist compression, including any aggregate.

Figures 2-4 illustrate concept drawings of the types of smart skin systems.

2.1. Visualization and Display

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 (μs -Si) [3]. This new material is just now emerging from the 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 μs -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 non-cleanroom based methods for making the circuits. Figure 5 illustrates an array of such ribbons integrated into a device that operates like a high performance, conventional transistor [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.

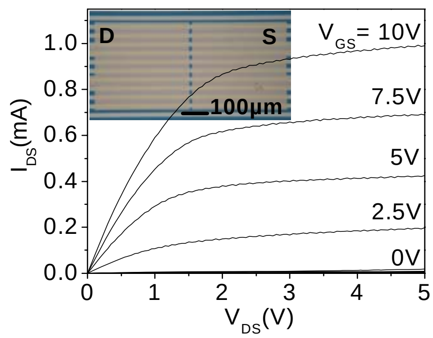

Fig.5. Current-voltage characteristics of a device that uses μs -Si as the semiconductor.

3. METHODOLOGY

At its technology base, Smart skin relies on innovative ways to build circuits out of the μs -Si material described previously. We are developing these concepts and applying them to large area circuits on plastic substrates with designs that specifically address our approach.

We are adapting for use with μs -Si the printing techniques and circuit designs that we developed in the past for organic semiconductor based circuits [4; 5]. New methods must be invented to deposit and pattern the μs -Si to yield adaptable circuits for smart skins. 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 μs -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 glass and aluminum.

4. CONCLUSION

This is an ongoing research and our current challenge is to develop the first phase of the prototype concept in a non-clean-room based environment. As of today, this kind of composite material does not exist. Once completed, this will be the first technology on its own. Next step is the addition of the structural stability to the material and use it as a ‘digital’ wall which we believe will replace the structural systems in the near future. In architecture and construction industry, this material can make significant changes in building design, especially in wall-systems and enclosures.

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