MATERIAL INNOVATIONS:

Transparent, lightweight, malleable & responsive

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This paper will comment on the issue of weightlessness in architecture and design and the importance of new material research through a brief examination of transportable buildings and building components. In the instances where the act of portability becomes a form-generator in architecture and design, a different approach to available technology and material resources is required. The author will demonstrate, through designed examples that research on new materials and construction methods will continue to play an important role in the development of innovative design applications for transportable environments.

Introduction: Transformation of Materiality in Architecture

> 'We have only begun to speculate upon the uses of these new materials in architecture. Characteristic properties have begun to emerge however, in recently developed materials that are the opposite of many conventional materials now in widespread use. ... Dramatic changes in the properties of recently developed materials will ultimately transform architecture... Beyond infatuation [with new materials] ... lies a world of purposeful form yet to be explored, a world in which materials will be selected based upon properties relevant to use' (Kieran & Timberlake, 2004, p.121).

Material innovations are as much a part of the current debate about architecture as they were in any period in history. In western architecture and design over the last one hundred and fifty years, the discovery of new materials such as titanium, synthetic polymers, artificial ceramics or, new applications for existing materials such as steel, concrete, glass and paper have served to transform ideas of materiality from monolithic to ever more ethereal and ephemeral constructions (Beukers & Hinte, 2001, p.13; Manzini, 1989, p.107).

In addition to formal and construction innovations, we have recently become more aware of how materials in architecture and design are extracted, cut, processed, treated with high pressure or temperatures that use vast amounts of energy and simultaneously release toxic substances, transported to construction sites, utilized in a building and ultimately discarded as waste or debris at the end of the building's life cycle. Sustaining our natural and built environments by avoiding depletion of natural resources, lowering energy consumption during material production, employing recycling processes, and achieving higher performance of materials in their built state, all force artists, designers, engineers, builders and scientists alike to seek material innovations that go beyond what is conventionally available in current building industry.

It is my contention that architects and designers in the present context of technological developments would benefit from the incorporation into the future practice of the design disciplines of what I will provisionally call ‘material responsiveness’. With this term I want to suggest that architects and designers will develop a new relationship to materiality in general, moving away from the model of simple assemblage of traditional, pre-existing, and standard material choices, and the inherent conservatism of the construction industry at large, to be directly involved with the conception and development of the new materials and material properties along with their applications in construction. In this paper I will examine selected material innovations through a review of current research and specific design case studies, however marginal or isolated they may be, to give emphasis to developments as well as attempting to foresee new directions in the material landscape of transportable environments.

New materials cannot transform the design and construction industry in a day, or even a decade, as it was imagined the bold use of plastics would do in the 1960s and 70s. I acknowledge that new materials and methods will continue to coexist with what is currently available, even with what is considered traditional. Nevertheless, I believe that the material landscape is currently in a state of transition in which our current practices will inevitably be transformed in a direction compatible with the theme of transportable environments. To this end, the paper will position research and case studies under the thematic sections of Transparency, Lightweights, Malleable Matter, and Material Responsiveness.

Transparency

With the technical advances in the production of large plates of glass from the beginnings of the 19th century to today, glass - composed of silicates and an alkali fused at high temperatures - has been one of the most widely used construction materials. The Crystal Palace, an exhibition hall built by Joseph Paxton and the engineers Fox & Henderson in 1851, is still considered one of the great icons of lightweight, modular and transparent architecture, making use of mass production processes for iron and glass. Using industrial prefabrication and assembly techniques, the Crystal Palace was designed such that it could be dismantled after the exhibition, reflecting an attitude toward mobility that was ahead of its time (Schulte, 2000, p.22). Current research into coating techniques, solar control technology, the integration of microelectronic circuitry, and energy generation capacity with Building Integrated Photovoltaics (BIPV) is giving glass a new place in construction innovation by aiming to eliminate the negative effects of heat gain or loss, glare and reflection, and sound transmission through the glazed surfaces (Weinstock, 2002, p.120). At the same time, these innovations are radically transforming design ideas of window and wall, transparency and opacity, and day lighting and shading in buildings.

Many different kinds of glass have recently entered the construction industry; for example, photochromic glass responds to light, or thermochromic glass that responds to heat. Although not yet widely used in architecture, photochromic glass is used in aircrafts, vehicles, appliances and popular sunglasses and ski-goggles. Transmitting electricity or battery power, electrochromic technology changes the transparency of glass partitions or cladding from perfectly clear to completely opaque. This is achieved by passing low-voltage electrical charges across a microscopically-thin coating on the glass surface that can be activated either manually with a switch or by sensors which react to light intensity. Thus the glazing can control the level of solar transmission into the building, allowing the minimization of heating or cooling and the optimization of artificial lighting. (‘Electrochromic glass’, 2003)

Although relatively heavy due to double glazing, a typical application for this technology can be seen with Saint Gobain Glass’s PRIVA-LITE®, an electrochromic laminated glazing, comprising two sheets of glass, either clear or tinted, and a liquid crystal film that allows the glass to achieve variable opacity. It is used widely for interior partitions as well as in storefronts (‘Transparency or intimacy’, n.d.). Applicable to single glazing, SPD-Smart® technology, invented by Research Frontiers, allows one to control how transparent or opaque glass and plastic is, and adjust the light transmission of the product manually or automatically by a thin, flexible Suspended Particle Device (SPD) film activated by less than 0.6 watts /ft2 or battery power. Suspended-particle systems are aligned allowing light through in their active state and light is absorbed or reflected in their random, inactive state ('Light-control technology', n.d.). Mostly used for privacy control in office settings, these windows also are capable of sensational effects when used for change rooms, as in Prada Store, New York by Office for Metropolitan Architecture (OMA), or for washrooms in bars and night clubs.

In architecture, the transparency of glass or plastic is translated into an active and changing filtering of light imitating the thermal resistance of an opaque material (Manzini, 1989, pp.167-169). Werner Sobek's R128 House (figure 1) uses light control technology to combine transparency of windows with maximized energy efficiency at the scale of a full building. At the same time, the assembly, dismantling and recycling of the house was built into the design process by choosing a lightweight, modular, steel structure and glass cladding (Herwig, 2003, p.77). In his efforts to create a building shell that adapts itself to various levels of light transmission, absorption, and ventilation needs, Werner Sobek proposes to integrate numerous mono-functional cells into glass that alter their chemistry to minimize energy input into this building (Blaser, 1999, pp.59-63).

Figure 1: R128 House, Werner Sobek

His subsequent computer study for the proposed R129 House (figure 2) shows transparent cladding with a so-called intelligent plastic membrane that is coated with scratch and chemical resistant glass and solar cells to provide the majority of building's energy supply. This thin electrochromic membrane is also capable of changing partially or entirely from opaque to transparent as there is no need for any individual material to be exclusively transparent in this energy conscious environment (Herwig, 2003, p.79).

In buildings that require large areas of glass cladding or large span roofs, weight, limited span capabilities, and the expense of glass seem to be deterrent facts. In spite of their cyclical reputation, from cheap and environmentally unfriendly to providing innovative forms and surfaces in architecture and design, many new qualities of plastics such as transparency and energy efficiency, make them an attractive replacement for glass. For example, the use of the advanced plastic ETFE (ethyltetrafluorethylene) pneumatic cushions as cladding for the Eden project (figure 3), the largest plant biosphere in the world, and Leicester Space Center projects by Nicholas Grimshaw & Partners in 2001, demonstrates a number of desirable qualities.

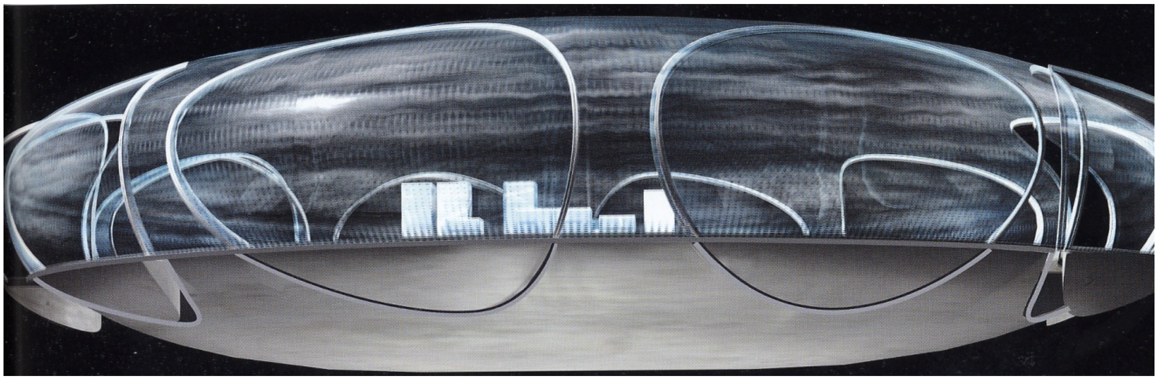

Figure 2: R129 House, computer model, Werner Sobek

Beside the fact that this plastic foil is more transparent than glass, the inflatable three-layer pillows used in Eden project weigh only 1% of the equivalent glass cladding. The material efficiency of lighter-than-glass cladding systems also allows a lighter supporting structural grid (Topham, 2002, p.148). ETFE, extruded into a thin but resilient film does not deteriorate in polluted atmospheric conditions, from ultraviolet light, or collect grime due to its low adhesive properties. Finally, it is environmentally friendly since few additives are used in its manufacturing process (Weinstock, 2002, p.121). Varying in size from 5 to 11 meters in diameter, the hexagonal cushions were inflated immediately after being installed on to extruded aluminum perimeter frames with a permanent flexible tube feeding air into each cushion. (LeCuyer, 2003, pp. 104-107)

Figure 3: Eden Project, Nicholas Grimshaw & Partners

The concept of 'Smart Wrap' (figure 4 & 5), as explained by James Timberlake and Stephen Kieran of Kieran Timberlake Associates LLP, aims to revolutionize the building industry by using a single sheet of film as a building skin (McCormack, 2003). This concept has been demonstrated with a small, temporary installation at the Cooper Hewitt National Design Museum that experiments with the most common plastic material (polyethylene terephthalate, used in water bottles) to provide an overall cladding that eliminates the need to define permanently fixed transparent and opaque surfaces.

Figure 4 & 5: Smart Wrap, Kieran Timberlake Associates LLP

In this example, ‘Smart Wrap’ incorporates emerging technologies in heating, cooling, visual display, lighting, and energy collection onto its surface through a printing process that is similar to that of inkjet printers. Climate control is achieved through micro-capsules of phase change materials embedded in the plastic cladding that provides latent heat storage for thermal moderation (i.e. absorbing, storing, or releasing heat as they change state). The ‘Smart Wrap’ of this installation also uses Organic Light Emitting Diodes (OLED), such as used for the displays of mobile phones or palm pilots, deposited on to a glass or plastic substrate. Thin film silicon solar cells in the ‘Smart Wrap’ are used to power the OLED technology. According to Kieran and Timberlake, this innovative cladding material is an ideal solar collector, moderates temperatures through phase change materials, and is able to provide lighting and information displays. KTA imagine that this technology will become commercially available within a couple of years as a customizable printed façade that anyone can design at a computer terminal at Home Depot. It would arrive at the construction site within a week, ready to be applied (McCormack, 2003; Northrop, 2003).

When we think of transparency or translucency, concrete is definitely not a material that comes to mind. The word concrete connotes something solid and durable, attributes that are largely due to its opacity and weight. Concrete, along with stone and brick, is one of the most common building materials used in construction today. However, as words linger a lot longer than built environments, one wonders how concrete is concrete in construction today. In order to make this material stronger, lighter, and better reinforced, new ingredients are being sought in addition to the common elements of cement, sand, water, chemical admixtures and aggregates. These include supplementary cementitous material and reinforcing materials, including fibrous reinforcement. High Performance Concrete (HPC) increases durability of concrete structures with the extra ingredient of fly ash that makes it impermeable to chemicals and water. It is predicted that smart materials ranging from sensor-laced concrete to hybrid concrete materials will be able to respond to environmental conditions and warn of failures (Hart, 2003).

Of the many programs of research into concrete currently underway, a provocative example related to the theme of transparency is Bill Price’s work on translucent concrete (figure 6), made of glass and polymerized synthetics. A professor at the University of Houston’s Gerald D. Hines College of Architecture, Price experimented with the idea when he was working on a competition with Rem

Koolhaas at the Office for Metropolitan Architecture (OMA) in Rotterdam. With the product in development stage, Price hopes to form an alternative for traditional ways of building with concrete and glazing (Onna, 2003, p.66; Solomon, 2003). When it finally is commercialized, such an interesting experiment will set new precedents for material research that attempt to change and improve the properties of other existing materials.

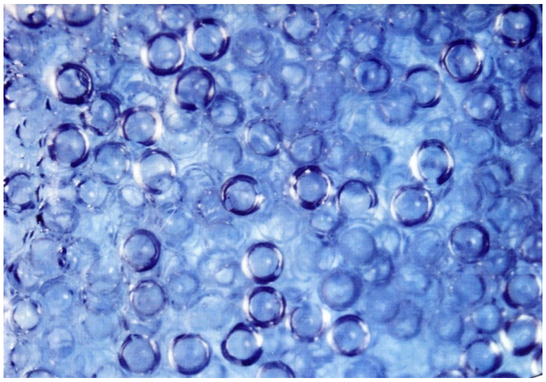

Figure 6: Translucent concrete, Bill Price

Lightweights

One of the unmistakable trends in architectural materiality that I will focus upon, as previously seen in modern icons such as Joseph Paxton's glass and steel Crystal Palace (1851), Frei Otto's fabric covered structures, but also reflected in the pervasive design ideology of free-floating structures in modern architecture, is a movement towards the use of ever more lightweight construction materials. The discussion about achieving lightness in architecture is manifold. While the aesthetic quality of lightness has become an attribute achieved through transparency of glass, the airy look of free floating forms, planes and minimalist detailing, these strategies do not necessarily generate a lighter weighing building or building component.

Physical qualities of lightweight structures on the other hand tend to concentrate on structural ingenuity and better technical performance of structural members by use of lighter material substances or structural compositions. For example, a space frame, honey comb structure or fabric membrane is considered lightweight compared to a concrete beam or thin-shell-concrete structure since the comparable ratio of height, depth and span is much less than the latter. The goal of lightweight construction thus becomes the integration of material research and design application.

According to Ezio Manzini, 'creating the light and resistant should be viewed as an area that does away with the traditional divisions of expertise between the chemist (who works with the properties of materials) and the designer (who works with the form of the finished product)' (Manzini, 1989, p.89). He proposes that the form of the object, the macrostructure of the material, and the microstructure of the individual material component must be resolved as a whole. Many new Computer Aided Design and Manufacturing (CAD-CAM) processes allow and contribute to the material developments in this area.
In this section I will examine materials that offer extraordinary weight reduction in buildings in comparison with conventional materials of the same category. It must nevertheless be noted that lightweight is relative involving a comparison of suitable materials.

Originally developed by Steven S. Kistler in 1931, the world's lightest material, silica aerogel (figure 7), known also as 'frozen smoke' or 'solid air', weighs only three milligrams per cubic centimeter (Wilson, 2003, pp.6-7). The National Aeronautics and Space Administration (NASA) has used aerogel for insulation on its spaceships, on its Mars exploration vehicles and on the Stardust mission to collect particles from Mars's surface and the debris of the comet named 'Wild 2' ('Aerogel', 2004).

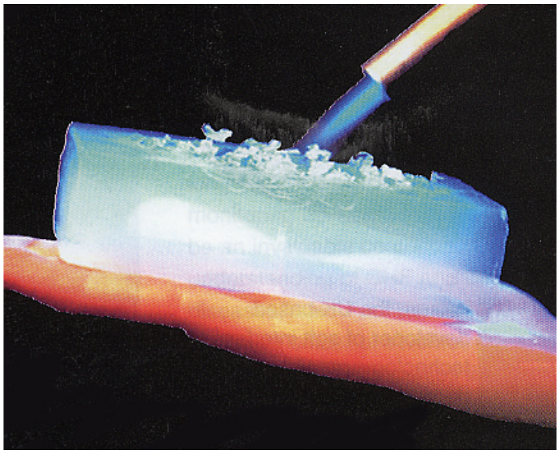

Figure 7: Aerogel, Aspen

Two innovative companies, Cabot and Kalwall Corporations, leaders in specialty chemicals and construction, have together been looking into commercial applications for aerogel. They have recently developed insulated day-lighting panels with Nanogel, a translucent aerogel ('Kalwall & Nanogel', n.d.). So far the commercial applications have been primarily the provision of magic insulation: a one-inch thick (25mm) layer has an insulation value of R8. Panels by Kalwall Corporation are made with 2-3/4 inches thick Nanogel and have the same R-20 insulation value as a required for a standard house or building wall while at the same time allowing about 20 percent of the outside daylight to flow through (Howe, 2002). The first architectural use of Kalwall's composite sandwich panel with Nanogel was over the swimming pool of a Comfort Inn Hotel in New Hampshire in 2003 (Solomon, 2003).

Honeycomb structures in architecture are known for their lightness and high strength to weight ratio. A number of companies have produced composite materials that feature aluminum, cardboard or synthetic honeycomb core sandwiched between two surface materials. Architects Christian Mitman, Emmanuelle Bourlier and Andreas Froech have developed a line of lightweight panels, named Panelite® (figure 8), that employs a honeycomb process used in the aerospace industry. This bonded honeycomb sandwich panel with translucent facings is a versatile building material providing a lightweight, self-structural panel for interior applications. Panelite offers varying degrees of visual privacy by transmitting, pixelating, coloring or diffusing light. A comparative study based on a 48"x96"x3/4" panel shows that Panelite, at 32lbs, is 4.5 times lighter than acrylic and 10 times lighter than glass. ('Panelite panels', n.d.). They arrive at various honeycomb cell geometries, such as hexagonal, over-expanded, quadrilateral, and tubular through an iterative-evaluative process that allows for experiments and errors with structural and light-transmitting properties of the materials used.

The Panelite insulated glass unit can be used on the exterior facades and combines the transparency, durability and weather-resistant nature of glass facings with the directionally translucent, customizable properties of the tubular polycarbonate honeycomb core (Bourlier, Mitman, & Froech, 2002, pp.35-36). This provides an innovative solution for glazing and curtain wall applications such as used at the Illinois Institute of Technology (IIT) McCormick Tribune Campus Center by Office for Metropolitan Architecture. Panelite's material development division is devoted to developing new materials in-house, ranging from mica laminates to structural fabrics (Ermann, 2003).

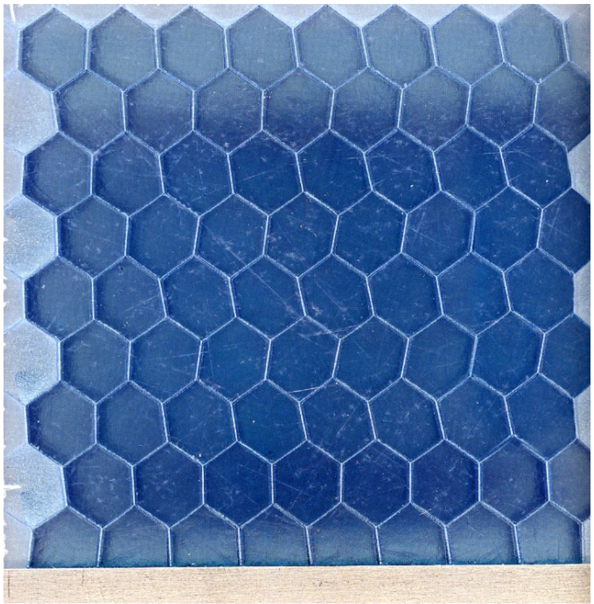

Figure 8: Panelite®

In relation to lightweight properties, composite materials form another area of significant research due to their stiff yet slim material properties. Composites are combinations of two or more materials with different, often complementary properties. Currently, 'composites are generally looked upon as compounds of polymers and other substances' (Beukers & Hinte, 2001, p.70). However, they can be any combination of two kinds of materials - not only plastics - usually different in nature. The result is a material that features the best characteristics and material properties of both. Probably, the crudest composite of all used in construction is reinforced concrete, mixing concrete and steel. Plastics laminated with wood form the oldest example of advanced composites. Most laminated countertops, for example, consist of layers of wood with one layer of phenolic plastic on top (Beukers & Hinte, 2001, p.73). Another common composite is fiberglass, a name that refers to only the fiber part of the complete composite material ('Definition of composites', n.d.).

There are a number of recent examples of the interesting use of composite materials in architecture. Architect Toshiko Mori, Chair of the Department of Architecture at Harvard University, turned to fiberglass to design an exterior staircase for a house along Florida's coast. Fiberglass is a composite material valued for its strength, lightness and flexibility for building boats, elements of marine environments, and recreational sports equipment. For the staircase, fiberglass is used in a structural application to combat harsh climactic conditions such as bright sun, hurricane winds, rain and salt water (Solomon, 2003).

The 147 meter high Millennium Tower in Glasgow, conceptually designed by Richard Horden Associates, developed by Building Design Partnership and engineered by Buro Happold and Peter Heppel, is an example of the use of lightweight composite materials and metals usually employed in aeronautical engineering applications. The entire structure is mounted on a turntable and a bearing ring that tapers to fit a single 300 mm stainless steel bearing which allows it to turn towards the wind like a sailboat to minimize the wind forces. This aerodynamic design contributes to the slenderness of the primary steel structure which would have been shorter and stockier otherwise. 'Sensors near the tower's base and top monitor wind speed and direction once per second and calculate the average; they signal the motors [that power the tower] to turn the leading edge of the tower to face the mean wind direction every 20 minutes, moving at a rate of 18 degrees per minute' (LeCuyer, 2003, p.29). A steel tube clad with aluminum and located behind the tower balances it aerodynamically, working much like a boat rudder. The viewing cabin of the tower is built out of glass fiber reinforced polymer, similar to the construction of a helicopter cabin or a boat hull. The 25 m tall mast located behind the viewing cabin is built out of a carbon fiber composite that improves the natural frequencies of a steel tower. The aerodynamic engineering of this tower relocates the construction away from the realm of static or fixed structures to a building that moves with the wind forces to achieve better material and building performance (Weinstock, 2002, p.121; Horden, 1999, pp.20-21; LeCuyer, 2003, pp.28-33).

Carbon fiber reinforced plastics (CFRP) have stiffness and strength that can be double that of steel, with only one quarter of its density (Definition of composites, n.d.). The development of the use of CFRP in the aerospace sector shows one area where the demand for structures with high strength and elasticity, particularly when used in high temperature environments, is evident. Since its commercialization in the mid-seventies, the carbon-fiber industry is promoting the accessibility of CFRPs beyond aerospace applications to improve the quality of mass produced items, such as cars, construction components and sports equipments. By changing the complexion of the fibers, CFRP has been made relatively cheaper over time (Bucquoye, 2002, p.24). Recently, Peter Testa and his partner Devyn Weiser of TESTA Architecture & Design have undertaken the design of a high-rise tower using composite materials, particularly carbon fiber (figure 9 & 10). According to Testa, their use of complex computer modeling tools is a major factor that allows them to design and develop new buildings employing new materials, and products. (Knecht, 2003).

Figure 9: Carbon-fiber Tower, TESTA Architecture & Design

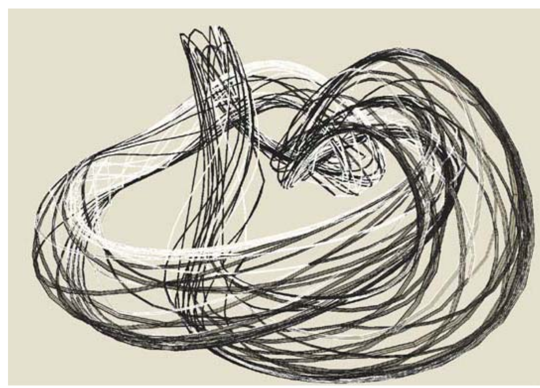

Figure 10: Carbon-fiber

Perhaps the lightness that the composites offer in architectural construction has not been given the credit it deserves due to unfamiliarity of the material and the ecological issues that arise in their processes of production and recycling (Bucquoye, 2002, p.165).

> 'Most composite structures contain phenolic, epoxy or polyester resins reinforced with glass, carbon, or aramid fibers. Although these formulations can be very strong, they are also expensive and rely heavily on nonrenewable resources: petroleum is a major component of the resins, and lots of energy is consumed in the production of fibers' (Solomon, 2003).

Nevertheless, composites have been recently promoted through exhibitions and innovative design work. The Composites-on-tour mobile exhibition, organized by the Department of Metallurgy and Materials Engineering of the University of Leuven (K.U.Leuven) and the Leuven Composites Processing Center, has been on tour of major European capitals since June 2002. This exhibition aims to raise awareness of composite materials through a hands-on method and illustration of their diverse applications ranging from sport equipments, aerospace, to art (‘Definition of composites’, n.d.). Within the framework of this mobile exhibition, Design Museum Gent, held an exhibition titled ‘From Bakelite to Composite’, focusing on the development of composites in furniture, lighting, construction, sportswear, transportation and medicine since early 1950’s (Bucquoye, 2002, p.5).

Marcel Wanders has set carbon and aramid fibers, known for their stiffness, in resin to make his well known knotted chair. However, his interest in these fibers extends beyond furniture to projects for large scale structures. One such project is a plan to build a replica of the Eiffel Tower (figure 11) directly adjacent to the original tower. He calls this conceptual project a virtual collaboration with Gustave Eiffel and the famous tower. From a helicopter, wanders intends to hang an ‘A frame’ made from knotted aramid rope and impregnated with epoxy with the same general shape as the eiffel tower. Flexible at firts, the frame will harden within a matter of hours and gravity will give Eiffel 2 its final form. (M. Wanders, personal communication, February 13 & March 25, 2004)

Figure 11: Sketch of Eiffel Tower from knotted aramid fiber, Marcel Wanders

A recent trend in lightweight materials combines biotechnology and composite materials. When it is seen how genetically engineered foods are used within the context of the advanced construction materials with improved performance and minimal environmental impact, we might be more accepting of them within this context than in our kitchen. Composite materials from renewable plant sources made their first appearance in January 2003 in a car called Model U Car by Ford. It has ‘soy based body panels, seat foam and grease, as well as corn-based tires and sunflower-seed-based engine oil (Wilson, 2003, cover). The University of Deleware’s Affordable Composites from Renewable Sources (ACRES) Group is experimenting with various resins and fibers based on plant sources such as soy, corn and hemp and they expect that these bio-based structural composites will appear shortly in building construction. Lightweight bio-based foam from soy oil might replace the commercially available foam. (Solomon, 2003). Flax and hemp fibers could offer a sustainable source of renewable raw materials for a range of industries, according to speakers at a Link Seminar, held recently at the Manchester Materials Science Centre. ‘Potential uses of the fibers developed from ‘non-food crops’ range from replacement for fiberglass in composites for the automotive industry to short-fiber flax suitable for cotton spinning, to produce high value textiles’ (Sustainable composites, 2003). Nexia Biotechnologies Inc., a company located in Montreal, Canada, develops and manufactures complex recombinant proteins for use as biomaterials and biopharmaceutical products with mostly medical and industrial applications (‘Nexia Biotechnologies’, n.d.).Their Biosteel®, obtained from genetically engineered goat milk that has the spider-silk protein, is the strongest fiber yet produced. Spider silk is five times as strong as steel with much higher tenacity. Jeff Turner, head of Nexia, thinks that in the far future it will be possible to make a space elevator stretching from and to extra-terrestrial locations using Biosteel, rather than lifting objects into orbit by space rockets (Newman, 2003, p.70).

Buckminster Fuller asked the famous question ‘How much does your building weigh?’ in relation to his experiments using aluminum as a lightweight alternative for building structures and cladding as early as the 1930’s. Now, composite materials are taking away the reputation of lightness given to metals, skeletal steel frames and metal cladding in architecture since the beginning of the 20th century. There exists, however, an interesting example of the use of the best of both materials by Kas Oosterhuis of ONL. Perhaps unintentionally following the footsteps of Buckminster Fuller, their interactive pavilion at the 2002 Dutch Floriade (figure 12) uses a paper thin metal composite material, Hylite®, made of a polypropylene core sandwiched between two layers of aluminum totaling to 2mm across to form a flexible architectural skin on top of an innovative folded steel plate structure. Owing its lightness to both the invention of the folded 3d triangular grid of the steel construction and to the elastic properties of the Hylite® aluminum sheets, ONL strove to provide a building reminiscent of a spaceship (‘Interactive expo’, 2002) that could ‘land’ at different locations.

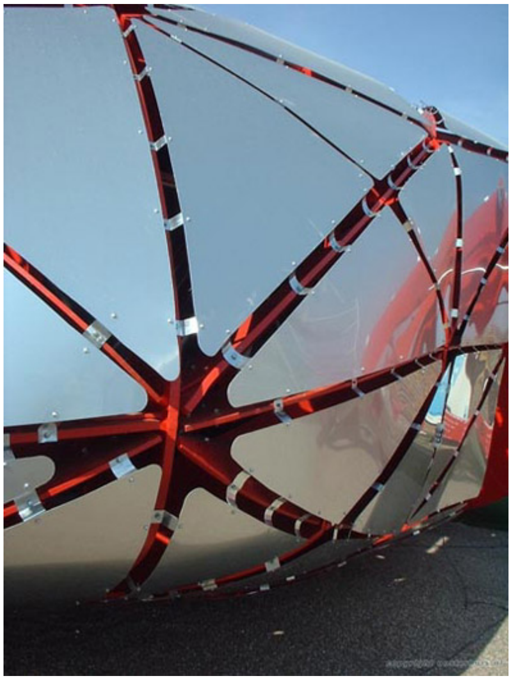

Figure 12: Interactive Pavilion, Kas Oosterhuis, ONL

What we know as steel or ‘low carbon steel’, the material that predominantly frames many buildings today is an alloy of iron and carbon. It’s widespread use is a result of being cheap, strong, tough and easily formable. In her book ‘Steel and beyond: New strategies for metals in architecture’, Annette LeCuyer comments that extremely light alloys, technology and digital processes transferred from other industries are changing the use of metals in building construction both in the design applications of structural frames and building skins (LeCuyer, 2003, pp. 7-15). High-strength or light metal alloys of aluminum, magnesium and titanium offer advantages of forming at lower temperatures and providing higher strength and toughness, despite their high cost, in comparison to the typical carbon steels. Although the presence of some of these metals on earth’s crust is abundant, extracting them proves to be an energy intensive and costly process. These lighter weight metal alloys have found their application in compact laptops, house-hold electronics, aerospace applications, surgical implants and prosthetic devices, but their use in construction to date remain limited and costly (Ashby & Johnson, 2002, pp.218-221).

Foamed metals, at densities less than one tenth of water, also present ultra lightweight, cost effective, rigid, and fire and impact resistant alternatives in construction. Previously confined mostly to auto industry, these foamed metals offer uses as sandwich beams and building panels that primarily use aluminum foam as a core in contrast to structural foams based on polymers (‘Metal foam’, 1998). Alusion® (figure 13), a % 100 recyclable panel of stabilized aluminum foam (SAF), brings the lightness of foam together with the strength of aluminum, is used as wall or ceiling panels and for furniture (Onna, 2003, p.73). A one inch thick bench is capable of bearing 4,000 lbs, providing great potential for future explorations (‘Alusion’, n.d.).

Figure 13: Alusion®

Malleable Matter

The concept of design flexibility is widespread throughout fashion, furniture, industrial design and architecture. The term flexible in design embodies the concept of malleability of matter, form and space, emphasizing the stretchable, expandable or contracting qualities of construction (Klassen, 2003). As the most immediately known form of malleable matter, fabrics and textiles have been around as long as mankind and used in nomadic structures or shade-providing building components.

Fabrics are most often made either of natural fibers such as wool, cotton and silk or their synthetic counterparts. Some synthetic fibers are nylon, polyester, high-strength carbon fibers called aramids, and high-temperature resistant fibers such as Nomex and Zylon (Newman, 2003, p.57). The engineered textiles in construction are mostly known as PVC (Polyvinyl Chloride), ETFE (ethyltetrafluoroethylene) foils and their coatings such as PTFE (polytetrafluoroethylene). The new developments in engineered textiles, used either in tensile structures (tension supported), or inflated structures (air-supported) (Scharfe, 1988, p.128) along with new textile coatings seem to bring this malleable matter to the forefront of lightweight or portable architectural applications as a replacement for heavier construction materials.

The strength of inflatable high-strength fabrics is being tested in fabric beams, columns and heavy cargo lifting that goes beyond the architectural applications of large span structures and inflatable portable buildings. Pressurized air beams provide an ability to rapidly erect large and lightweight structures such as aircraft hangers. Air beams are manufactured by braiding a high-strength three-dimensional Vectran fabric over an air-retention ‘bladder’ (Taylor, 2002). The Cargolifter Airship hangar, designed by SIAT Architektur + Design and Arup Engineering, is noted as the world’s largest free-standing aircraft hangar spanning 225 meters with steel arches. It is covered by a woven fiberglass substrate with Teflon PTFE coated roofing membrane (Onna, 2003, p.74). It is designed to contain two of CL160 Cargo Lifters also known as ‘airships’ that can ‘carry 160 tones of cargo up to 10,000 km at a cruising speed of 56 km/h without the need to refuel’ (Slavid, 2002, pp.14-15). Filled with noncombustible helium, these pressurized structures act as heavy cargo balloons. Some admittedly fantastic potential applications include the realm of tourism, lifting a whole hotel to a new location without the worry about roads and traffic and the relocation of an entire house when the need to move arises (Newman, 2003, pp.70-71).

Inflatable structures are not only foreseen for the earth but have been investigated for applications in space exploration. Conceptualized by NASA’s Johnson Space Center, TransHab (The Transit Habitat) (figure 14) Module for ISS (The International Space Station) proposes an inflatable and deployable future habitat in orbit. The flexible fabric shell is foreseen to withstand the extremes of temperatures in space while also able to break-up space debris and meteorites. The outer shell is made of Kevlar webbing, a bullet-proof fabric, rated to withstand impacts of 12,500 pounds. Separated from the upper layers by foam rubber, the underneath layers are made out of Nextel, a ceramic fabric. These are the layers that protect the occupants from temperatures that range from 250 degrees Fahrenheit to minus 200 degrees Fahrenheit (Bonsor, n.d.). The inside layer, Nomex cloth, is used for scuff protection. Though developed for the extreme conditions of space, this innovative technology is certain to instigate new portable building applications on earth (Hart, 2002).

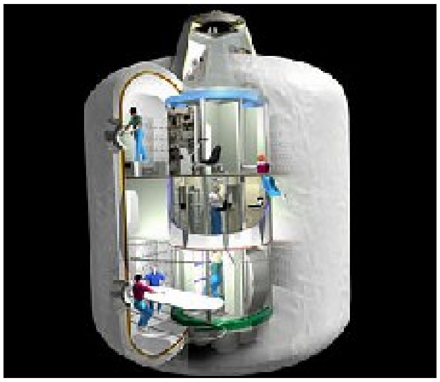

Figure 14: The Transit Habitat, NASA

FTL Design Engineering Studio has been exploring the feasibility of cladding a skyscraper with tension fabric membranes (figure 15). Todd Dalland, one of the architects involved with the project feels that conventional curtain walls can be reinterpreted as tension fabric membranes.

> ‘These conceptual explorations reveal that single layers of fabric can provide structural spans and environmental barriers over large vertical surfaces. In addition, double and triple wall fabric constructions of approximately 5x30 meters can be pre-stressed using heated airflow at very low pressures, to provide the acceptable levels of thermal insulation at a fraction of the weight and cost of more conventional materials’ (Watt, 1995, p.49).

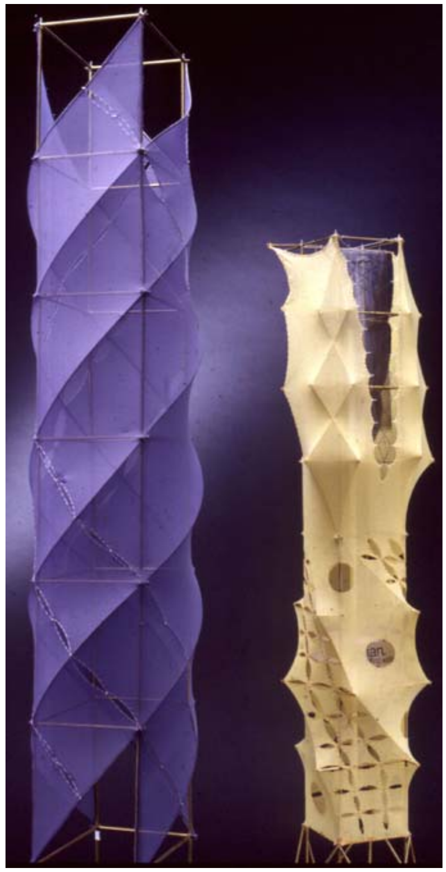

Figure 15: Recyclable and Portable Skyscraper, FTL Design Engineering Studio

Truck trailers form the ground floor of the skyscraper to provide power and services to the upper floors that are made with scaffolding, clip-on floor planks and equipped with stackable toilets and construction elevators (Lupton, 2002, pp.102-103).

Recalling the earlier discussion of glass and plastic wraps for buildings, the integration of graphics, luminosity, and energy efficient photovoltaics to fabrics presents designers with a challenging area of innovation. The Cooper Hewitt National Design Museum's exhibition in 1998, entitled 'Under the Sun', displayed the first tensile structure with integrated photovoltaics. A solar pavilion, designed by FTL Design Engineering Studio, used a woven fabric as a structural skin with integrated photovoltaic technology to transform sunlight into power. 'The tent skin consists of amorphous silicon, thin-film photovoltaic modules, just .005 inches thick, encapsulated and laminated to contoured panels of woven fabric' ('Solar tensile', 1998). Showing its versatility in a lightweight energy conscious application, this fabric also can be used for sunshade/ power generator applications in both urban and rural areas, from parking lots to open fields, from recreation areas to temporary structures for the military and for disaster relief (Willmert, 2002).

Beyond the innovations for construction discussed above, the field of textiles appears to be one of the most dynamic areas of material innovation currently weaving the future.

> '... the field [textile industry] is poised on the edge of a new era. The newest generation of textiles may be so high-tech and smart that they take you into outer space, allow you to

> communicate (by wearing your phone, not just your heart, on your sleeve), and even save your life' (Newman, 2003, p.57).

Passing beyond the hyperbole of such statements, there are nevertheless a number of thought-provoking innovations and applications that illustrate significant developments in textile design and manufacture that may ultimately influence building construction. The Japanese company Mitsubishi Heavy Industries produces a paper-thin material that is being tested on an amphibious suit for the Navy. Sandwiched between two layers of stretchable polyester fleece, this fabric literally breathes allowing body heat to escape by becoming porous when exposed to air or retaining heat in water by closing the membrane (Newman, 2003, p.63). Further, high-tech fabrics such as Kevlar, Nomex and Zylon, known for their very high temperature resistance, are making it beyond aerospace applications into the clothing of firefighters and race car drivers. France Telecom's R&D department has designed a flexible screen prototype made of woven optical fibers that allow clothing to act as a graphical communication interface offering access to internet, video and e-commerce (Wilson, 2002, p.9). This demonstrates that innovations in the area of wearable electronics all depend on pliable or malleable fabric material. The 'smart' shirt by Sensatex shows that it is feasible in the future that our clothing won't just wrap our bodies but may save our life by transmitting and displaying vital data without the hassle of cords and monitors (Newman, 2003, p.60).

Material Responsiveness

The term 'intelligent materials' suggests certain properties of materials that react and respond to pre-determined conditions or situations. These properties of advanced materials are planned and built into their atomic structure. For example, making a material hydrophilic or hydrophobic depends on integrating the action of a thermally sensitive copolymer into the fabric (Serra, 2002, pp.7-8). Though still at an early stage of development, the selected examples illustrated below reveal a great potential for material innovation.

Current manifestations of intelligent materials involve advanced embedded technology that responds to environmental conditions and warn of failures. However, so-called intelligence can also be achieved by integrating small amounts of materials that alter their state under stress or temperature change. T. N. Gupta, the executive director of the Building Materials and Technology Promotion Council in India, in his article entitled 'Materials for the Human Habitat' predicts that well-engineered structures that actively resist earthquakes and peak wind pressures will gain increasing interest. He states that the achievement of this form of intelligent structure will require new forms of lightweight and low-cost composite materials that have high tensile and shear strengths along with improved compressive load capacities (Gupta, 2000, p.61). In the hands of material scientists this may mean the development of a type of advanced concrete or steel that not only gives warnings by discoloration in the face of structural malfunctioning but also counterbalances or provides temporary increase in strength at anchorage points to deflect the extreme forces of nature (Gupta, 2000, p.62). Nevertheless, the integration of materials that change their static state through deformation or even destruction under stress or temperature presents a scientific as well as a design challenge.

> 'In the past, a change in a material's properties (its elasticity, say, or its volume) in response to a change in the environment was generally seen as a potential problem, as a thing to be avoided…
> …Even in applications where one might imagine a dumb material would suffice, a degree of smartness may prove tremendously useful…A house built of bricks that change their thermal insulating properties depending on the outside temperature, so as to maximize energy efficiency?' (Ball, 1999, p.104).

In his book ‘Made to Measure’, Philip Ball predicts that there will be always room for so-called ‘dumb’ materials that do not change their properties or display their changing characteristics. Nevertheless, it will increasingly pay to be ‘smart’ in the manner discussed above, although he maintains that this is still not nearly sufficient. In the future, material scientists hope that materials will be developed that are able to take into account changes, maintaining ‘a memory of what has transpired before and that learn from these previous experiences’ (Ball, 1999, p.105) and becoming more active and ‘smarter’ as they get older. He further comments that in 1995, in an aircraft prototype developed by researchers at Auburn University,

> ‘all of the ailerons and tail flaps that are used to control the flight of conventional aircraft were replaced by wings and tail fins containing piezoelectric actuators [that convert electrical to mechanical energy] that altered their shape [in response to flying conditions]. One advantage of smart wings is that they can be continually adapted to maximize aerodynamic (and thus fuel) efficiency in a way that is just not possible for today’s aircraft’ (Ball, 1999, p.118).

A final category of intelligent materials is based on the idea of adaptability based on phase-change. For example, water is a phase change material that transforms from gas to water to solid at low temperatures. Outlast Technologies Inc., that has already developed a phase change textile material (figure 16) for use in sports clothing to keep us cool or warm, hopes to develop a similar material for the building industry. Phase change particles can be encapsulated at microscopic level and integrated into the fabric either as a surface coating or an integral part of the fabric’s fiber using a wet-spinning process (Braddock & O’Mahony, 1999, p.156; Gilbert, 2003).

Figure 16: Phase change microcapsules, Outlast Technologies Inc.

Conclusion

As designers we can no longer afford to only imagine the appearance of the objects and spaces we create while ignoring the need to imagine their disappearance or transformation over a given time period, inevitable changes in function, and reuse and/or rebuilding in new constructions. In architecture and design, size, weight, and longevity matter. As designers we should downsize, make things more lightweight and offer increased transformability to prolong the life span of built spaces, objects, and materials. A change in attitude of both designers and consumers should emphasize transportable and transformable design, not as a one-off design solution, but as an integral part of the design and production processes. At the same time, the creation of lightweight and transformable construction elements in architecture and design can remain compatible with stability and longevity, qualities that are more commonly associated with weight and fixity (Klassen, 2003, p.48).

A transformation of design attitudes emphasizes the importance of research on new materials and construction methods as well as new uses for existing materials. Considering material science and technology transfers from other industries as instigators for design, Kieran and Timberlake see new materials as opportunities to save weight, add strength and durability to construction while lowering costs and economizing construction time (Kieran & Timberlake, 2003). They hope that,

> '... there will be regular affiliations and alliances with material scientists and product engineers, working together as models of collective intelligence, making large parts of buildings in high quality, controlled settings, using materials they're not using now, purposeful materials, not just collections of neat-looking materials.' (Ermann, 2003)

Kennedy and Violich (KVA) is another progressive firm looking at the integral relationship of light, information, thermal control and material properties. KVA have a working group on the design and research of new materials directly in their office. Sheila Kennedy states that 'the architectural imagination is well suited to take on interdisciplinary problems and coordinate strategies for idea production and fabrication in architecture' (Mori, 2002, p.11). Finally, Peter Testa, the founding director of the Emergent Design Group (EDG) in the Department of Architecture and Artificial Intelligence Laboratory at the Massachusetts Institute of Technology formulates the main goal at EDG as research into structural morphology and new spatial models with a focus on the emergent properties of material forms in architecture. A secondary goal is to develop simulations, tools, prototype designs and building systems that test these principles in practical applications. The projects at EDG initiate new developments by combining innovations in modeling theory, intelligent systems, organizational theory and the science of dynamics to transform the way designers use a range of currently available technologies (Testa, n.d.; Knecht, 2003).

Being a designer or an architect does not only imply giving form to materials chosen from a catalogue but now also requires the sensitivity and knowledge of a chemist and a biologist to alter materials' molecular structure. Scientific research has produced materials that last longer, reduce waste, change form and adjust to environmental conditions in different contexts. Architects and designers should have the knowledge, ethics, and creativity to transfer these technological innovations developed by other industries into the built environment. Achieving or expressing absolute truth of design through autonomous artistic organization and material embellishments no longer seem to provide a convincing goal for many innovative architects. In contrast, many architects are becoming involved in 'alchemy' of construction**,** translating advanced material innovations into a more responsive and responsible built environment.

> 'Contemporary designers are facing the challenge of defining its [materials'] new multifaceted manifestations. The mutant character of materials, as expressive as it is functional and structural, generates new forms and a more experimental approach toward design (Antonelli, 1995, p.17).

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