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Innehållsförteckning

Sammanfattning

Val av byggmaterial är en fråga som blir allt intressantare i takt med utvecklingen av de nya industriella byggmetoderna, kraven på energieffektivitet, kundernas kravställning och ökande priser. Det pågår något av en revolution inom nya material[1]. Det är hög tid att på allvar börja resan bort från beroendet av enbart konventionella material – betong, stål, trä och tillhörande montageprocess - svets, skruv och spik.

I detta projekt utreds förutsättningarna för ett antal nya material att underlätta industriell tillverkning och ge låg energiförbrukning. Nya material ger också nya möjligheter i form och funktion. Det är sannolikt att multifunktionella material (inklusive kompositer) kan spela en viktig roll i denna funktion. Implementering av ”nya” material från annan industri kommer att ingå som en naturlig del i arbetet. Slutrapporten kommer att ge vägledning i vilken roll nya material kan spela i utvecklingen av byggandets industrialisering och energieffektivitet, exemplifierat med några produkter/koncept.

Byggbranschen går i allt högre grad mot industrialisering – där material, halvfabrikat och element sammanfogas i en fabriksliknande miljö och endast monteras på plats. Högpresterande och smarta material har högre pris än konventionella material men tack vare att de möjliggör effektiva processer kan de vara en god affärsmöjlighet. Starka material ger mindre dimensioner. Fiberbaserade material kan göra det möjligt att utveckla komponenter med inneboende möjligheter till flexibilitet eller enstyckes specialutformning. Idag är dock byggsektorns kunskap låg om nya material och deras plats i industriella processer.

Byggbranschen går också mot stigande medvetenhet om resurseffektivitet. I takt med stigande energipriser tar energifrågan allt större utrymme i debatten och i konsumenternas medvetande. Köpkraften dras till produkter med profil av ”smartness” (multifunktionalitet) och uthållig tillverkning. Vi har redan sett hur ekologiska produkter slagit igenom i detaljvaruhyllorna – det finns all anledning att tro att utvecklingen kommer att bli densamma i byggandet. Det blir en konkurrensfördel att ha kunskap om material med möjligheter att resurseffektivt användas för flera ändamål. Exempelvis kan smarta fibrer vävas till gardiner och tapeter som lagrar energi vilket kan sänka energiförbrukningen och bidra till en bättre inomhusmiljö.

Prisnivåerna på konventionella byggnadsmaterial är också en fråga att hantera. Medan den övriga industrin har genomgått deflation – med successivt lägre priser på insatsvaror – har vi i byggbranschen haft inflation. Kostnaderna i byggsektorn har ökat oavsett om det varit hög- eller lågkonjunktur. Mellan 2000 och 2006 steg materialkostnaden med

[1] Blaine Brownell: The Revolution in Building Materials. BusinessWeek online, February 2006. http://www.businessweek.com/innovate/content/feb2006/id20060228_541223.htm

18% i byggbranschen, medan den sjönk 2% i den fasta industrin. Ett sätt att attackera detta är att arbeta med inköp, bryta invanda mönster och logistikkedjor och öppna upp för nya aktörer att ta sig in på marknaden. Ett kompletterande sätt att hantera priserna på konventionella byggmaterial är att utveckla vår egen materialanvändning. Exempelvis steg priserna på armeringsstål med drygt 80 procent mellan 1998 och 2006, enligt statistiska centralbyrån (SCB). Inflationen under samma tid var 10 procent. Nya typer av fibrer och fiberbetong är en lösning på problemet ett annat alternativ ett helt nytt material.

I denna rapport diskuteras multifunktionella material baserat på fördelar i projektering, process och beteende. Ett antal intressanta trender när det gäller utveckling av nya material och produkter identifieras och diskuteras. I rapporten förslås ett nytt sätt att klassificera material så att nya material lättare kan tas upp av byggsektorn. Ett antal källor till nya material anges och beskrivs.

Ett stort hinder för nya material är byggsektorns i det närmaste totala fokusering på projekt, där man inte enkelt kan kalkylera om en investering är lönsam. I byggsektorn använder vi exempelvis i stort ett material till ett syfte. I rapporten visas exempel på material som är mer resurseffektiva att använda genom att de är multifunktionella – ett material kan fylla fler funktioner än ett. Ett enkelt exempel är att utfackningsväggen av reglar, isolering, asfaboard och spacklad gips kan bytas ut mot en massivträskiva. Med multifunktionella material kan vi spara tid och minska littera. För industriellt tänkande är dessa möjligheter särskilt intressanta, eftersom materialkostnaden där kan sättas in i sitt sammanhang, i relation till andra kostnader. Genom att man har kunskap om var kostnaderna finns i processen kan man enkelt kalkylera om den marginellt dyrare självkompakterande betongen är lönsam för systemet som helhet genom att den sparar tid och arbete, jämfört med konventionell betong.

Om vi tillåts raljera en stund: Det pågår en revolution i materialindustrin, och byggbranschen är inte delaktig. Arkitekter har ett naturligt intresse för nya material, främst tack vare deras möjligheter till nya uttryck, men få i byggsektorn har upptäckt de process- och affärsmässiga fördelarna med multifunktionella material. Det är hög tid att vi tar del av denna revolution.

“Our way of life has been influenced by the way technology has developed. In future, it seems to me, we ought to try to reverse this and so develop our technology that it meets the needs of the sort of life we wish to lead.” Prince Philip, *Men, Machines and Sacred Cows*, 1984. (*A Dictionary of Environmental Quotations*, Simon & Schuster)

1 Introduction

For any type of construction, building materials are required. The total amount of materials needed for construction purposes in Europe exceeds two billion tonnes per year, making it the largest raw material consuming industry. This is equivalent to 10 tons of aggregates per capita per year being used for construction. The materials form an essential part of the buildings we live and work in, and of the roads, bridges and tunnels we use for transport, networks of drinking and waste water, etc. Materials, and their different combinations, create the aesthetic expression and provide structural strength and durability for buildings and structures. In the coming years, building materials will not merely be selected on their ability to do the job, but on the impact of their whole lifecycle. With between 50 and 60 thousand different materials found in the average house, there is a lot of scope for innovation and improvement.

Building materials have an important role to play in sustainable development through their energy performance and durability, as this determines the energy demand of buildings throughout their lifetime. By developing the use of materials and their combinations, significant improvements of the environment and quality of life can be achieved. Together with the energy and the raw materials used during their manufacturing, it becomes obvious that the production of building materials has a significant environmental impact due to the sheer quantities involved. On the other hand, just small improvements will have a major beneficial impact on the environment. Over the long-term, knowledge generation and better use of building materials can impact beneficially on many areas of our daily life. Other important challenges in the construction industry to which the building materials industry can contribute are the improvement of productivity, a better working environment and the creation of architectural added value.

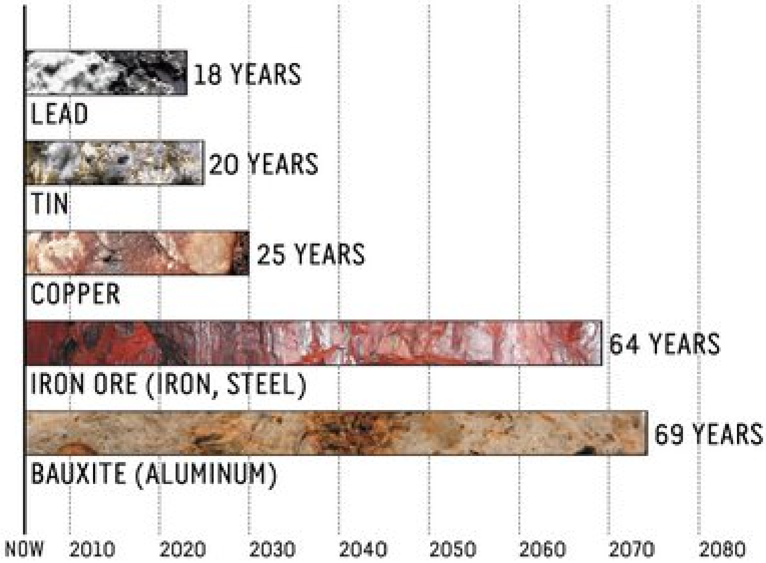

Figure 1 Remaining lifetime of some important metals

A recent United States Geological Study informs us that we will exhaust known stores of several vital metals within the next two to three generations, based on a reasonable estimation of 2% growth in extraction[2], see Figure 1. While recycling efforts have accelerated, virgin materials are still being harvested at an alarming rate.

What will the world be like when we have run out of copper or steel? The concrete industry faces similar problems with the natural sand and stone resources becoming regulated and limited. The average building today relies upon a great quantity of these resources for its construction. Faced with these facts, we can easily imagine a future in which industry has completely re-engineered its handling of material resources. After all, there seems to be no other choice.

In the future, new functional and reduced-scale materials that are currently in the forefront of technology will be hybridized into designer materials that can perform dramatic "tailorable" functions in large engineered systems. These performance-tailored structures will have the ability to change or adapt the performance or style of a structure on demand. Today, engineers can imagine designing adaptive flight profiles from morphing aircraft-wing structures; comfort tailored performance, such as active structural vibration and noise suppression or temperature compensation, from louvered or pore-based "smart skins"; energy-efficient structures, such as tropical-plant-inspired solar

[2] Brown, Lester, *Plan B 2.0*, New York: W. W. Norton, 2006. p. 109

structures; adaptive structures that can compensate for distortion or heal themselves; and structures reconfigured to satisfy style preferences. Imagine, for example, being able to commute to work in a stately professional car that can be reconfigured into a sportier car for the weekend.

As system-operating scenarios become more constrained by space and logistics limitations, the ability to adapt a structure's performance at will is becoming increasingly attractive. Currently multi-mission objectives are met with multiple structures (i.e., one car to drive to work and another one for the weekend). These solutions work if there is excess capacity in the system (e.g., a two-car garage), but as the number of mission objectives increases, the procurement, storage, and maintenance of a large number of structures become prohibitive.

Until relatively recent times, most periods of technological development have been linked to changes in the use of materials (eg the stone, bronze and iron ages). In more recent years the driving force for technological change in many respects has shifted towards information technology. This is amply illustrated by the way the humble microprocessor has built intelligence into everyday domestic appliances. However, it is important to note that the IT age has not left engineered materials untouched, and that the fusion between designer materials and the power of information storage and processing has led to a new family of engineered materials and structures.

2 Smartness in the materials per se

2.1 What is a smart material?

Smart materials and systems are now being used in virtually all areas of technology, and in many high and low-tech applications and products. This course will focus in the basic principles and mechanisms of smart materials and structures, and provide a spring board for further study. What is a smart material? The term “smart material” means a lot of things to a lot of people. The basic definition is: a “smart material” is a general term for a broad category of multifunctional materials for which a specific property (optical, mechanical, electronic, etc.) can sense the environment and can be controllably modified. Many of these materials and structures emulate biological systems that can adapt to changes in their environment, and development of these materials involves combining several technological disciplines, including materials science, chemistry, solid state physics, biotechnology, nanotechnology, and robotics. The course will address the basic principles and mechanisms of smart materials and provide examples of the most important types of smart materials. Virtually all properties of smart materials can be related to the structure of the crystal lattice, the change in crystalline phase, polarizability of the lattice and microstructure. Stimuli include pressure (force), electric and magnetic fields, heat, light, and sound. The course will describe piezoelectric, ferroelectric, magnetic, shape memory, thermochromic, electrochromic, photochromic, nonlinear optical, and biological smart materials and thin films. Applications include actuators, smart sensors, smart windows, photosensitive lenses, acoustic sensors, artificial lung, blood flow monitors, pace makers, artificial limbs, and even something as mundane as a toaster. The technology relies on microfabrication and MEMS (Micro Electro-Mechanical Systems) to a great extent, as will as microelectronic device technology.

2.2 ‘Dumb Materials’

Most familiar engineering materials and structures until recently have been ‘dumb’. They have been preprocessed and/or designed to offer only a limited set of responses to external stimuli. Such responses are usually non-optimal for any single set of conditions, but ‘optimised’ to best fulfil the range of scenarios to which a material or structure may be exposed. For example, the wings of an aircraft should be optimised for take-off and landing, fast and slow cruise etc. However, despite the partial tailoring of these structures by the use of additional lift surface, which we see deployed as each passenger aircraft approaches an airport, such engineering components are not fully optimised for any single set of flight conditions.

Similarly, advanced composites such as glass and carbon fibre reinforced plastics, which are often thought to be the most flexible engineering materials since their properties (including strength and stiffness) can be tailored to suit the requirements of their end application, can only be tailored to a single combination of properties.

2.3 Biomimetics

'Dumb' materials and structures contrast sharply with the natural world where animals and plants have the clear ability to adapt to their environment in real time. The field of biomimetics, which looks at the extraction of engineering design concepts from biological materials and structures, has much to teach us on the design of future manmade materials. The process of balance is a truly 'smart' or intelligent response, allowing, in engineering terms, a flexible structure to adapt its form in real time to minimise the effects of an external force, thus avoiding catastrophic collapse.

The natural world is full of similar properties including the ability of plants to adapt their shape in real time (for example, to allow leaf surfaces to follow the direction of sunlight), limping (essentially a real time change in the load path through the structure to avoid overload of a damaged region), reflex to heat and pain. The materials and structures involved in natural systems have the capability to sense their environment, process this data, and respond. They are truly 'smart' or intelligent, integrating information technology with structural engineering and actuation or locomotion.

2.4 Applications of Smart Materials

A smart materials system is a system composed of materials that react to the environment they are in and adjust accordingly. A smart material senses a change in its environment and through the use of a feedback system, adapts to correct or eliminate such a change. Among the most common smart materials are piezoelectric materials, electroactive polymers, shape memory alloys, electrorheologycal fluids, etc. Each one of these materials has its advantages and disadvantages according to the application they would be used on. Their applications range from medical instrumentation, optics, computers, ultrasonics, artificial muscles, microsurgery, etc. Because of the variety of applications and the environments that these materials are used, studying their properties is critical.

Characterization of the structure-property is crucial for several reasons. First, investigations of the material properties provide a link between the manufacturing process and the material's performance to yield tailorability to a particular application. Second, the engineer can investigate prospective materials for applicability to a specific need. Material parameters obtained through characterization can be used to develop and validate analytical models. Insights gained through characterization have led to many new devices and uses.

There are many possibilities for such materials and structures in the man made world. Engineering structures could operate at the very limit of their performance envelopes and to their structural limits without fear of exceeding either. These structures could also give maintenance engineers a full report on performance history, as well as the location of defects, whilst having the ability to counteract unwanted or potentially dangerous conditions such as excessive vibration, and effect self repair. Basically, smart materials and structures must solve engineering problems with hitherto unachievable efficiency, and provide an opportunity for new wealth creating products.

2.4.1 Smart Materials in Aerospace

Some materials and structures can be termed ‘sensual’ devices. These are structures that can sense their environment and generate data for use in health and usage monitoring systems (HUMS). To date the most well established application of HUMS are in the field of aerospace, in areas such as aircraft checking.

An airline such as British Airways requires over 1000 employees to service their 747s with extensive routine, ramp, intermediate and major checks to monitor the health and usage of the fleet. Routine checks involve literally dozens of tasks carried out under approximately 12 pages of densely typed check headings. Ramp checks increase in thoroughness every 10 days to 1 month, hanger checks occur every 3 months, ‘interchecks’ every 15 months, and major checks every 24000 flying hours. In addition to the manpower resources, hanger checks require the aircraft to be out of service for 24 hours, interchecks require 10 days and major checks 5 weeks. The overheads of such safety monitoring are enormous.

An aircraft constructed from a ‘sensual structure’ could self-monitor its performance to a level beyond that of current data recording, and provide ground crews with enhanced health and usage monitoring. This would minimise the overheads associated with HUMS and allow such aircraft to fly for more hours before human intervention is required.

2.4.2 Smart Materials in Civil Engineering Applications

However, ‘sensual structures’ need not be restricted to hi-tech applications such as aircraft. They could be used in the monitoring of civil engineering structures to assess durability. Monitoring of the current and long term behaviour of a bridge would lead to enhanced safety during its life since it would provide early warning of structural problems at a stage where minor repairs would enhance durability, and when used in conjunction with structural rehabilitation could be used to safety monitor the structure beyond its original design life. This would influence the life costs of such structures by reducing upfront construction costs (since smart structures would allow reduced safety factors in initial design), and by extending the safe life of the structure. ‘Sensual’ materials and structures also have a wide range of potential domestic applications, as in food packaging for monitoring safe storage and cooking.

The above examples address only ‘sensual’ structures. However, smart materials and structures offer the possibility of structures which not only sense but also adapt to their environment. Such adaptive materials and structures benefit from the sensual aspects highlighted earlier, but in addition have the capability to move, vibrate, and exhibit a multitude of other real time responses.

Potential applications of such adaptive materials and structures range from the ability to control the aeroelastic form of an aircraft wing, thus minimising drag and improving operational efficiency, to vibration control of lightweight structures such as satellites, and power pick-up pantographs on trains. The domestic environment is also a potential market for such materials and structures, with the possibility of touch sensitive materials for seating, domestic appliances, and other products. These concepts may seem ‘blue sky’, but some may be nearing commercial readiness as you read this.

2.5 Mechatronics

Approaches vary from the use of mechatronics (essentially hybrid mechanical/electronic systems) to the development of truly smart materials, where sensing and actuation occurs at the atomic or molecular level. The mechatronic approach is familiar from systems already in existence such as ABS and active ride control in road vehicles, and such an approach has already been employed in the vibration control of high rise Japanese buildings. However, in truly smart structures the integration of sensing and actuation is generally greater than that in pure mechatronic systems, with the required function integrated within the structural material itself. Such structures have been compared to Frankenstein's monster since separate sensors and actuators are integrated (or bolted) together into a structural material, but without the materials themselves being smart. Examples include sensual structures containing optical fibre sensors for monitoring load history and damage accumulation in bridges, dams and aircraft and adaptive structures containing novel piezoceramic, electrostrictive, magnetostrictive and shape memory actuators, for real time vibration and shape control.

2.6 Ken Materials

‘Mechatronic’ smart structures have demonstrated the capability of this technology, but raise the important issue of the complexity of the resulting system. These smart structures contain a multitude of different materials, and in the case of sensual structures will generate large amounts of data. This increase in complexity has been described by Hiroaki Yanagida as the ‘spaghetti syndrome’, and has led to the proposal for an alternative type of smart structure based on the concept of ken materials (the Chinese characters meaning wisdom, structure, monitoring, integration and benignity being pronounced ken in the Japanese language). Such structures would move functional integration into the constituent engineering materials themselves.

Few practical examples of ken materials exist at present, although a structural composite based on this concept has been developed in Japan. This is a carbon and glass fibre reinforced concrete which is able to monitor concrete structures using only the structural reinforcing fibres, thus reducing the complexity of the system.

2.7 At the Atomic Level

The ultimate integration is a level beyond ken materials where functionality occurs at the microstructural or atomic and molecular scale. This produces what is commonly known as a ‘smart material’. Few examples of true smart materials exist at present, although the function of such a material can be illustrated by the familiar photochromic glass. Such glasses have inbuilt sensing and response but have only one response to the one stimulus.

2.8 The Future

The development of true smart materials at the atomic scale is still some way off, although the enabling technologies are under development. These require novel aspects of nanotechnology (technologies associated with materials and processes at the nanometre scale, 10^{-9}m) and the newly developing science of shape chemistry.

Worldwide, considerable effort is being deployed to develop smart materials and structures. The technological benefits of such systems have begun to be identified and, demonstrators are under construction for a wide range of applications from space and aerospace, to civil engineering and domestic products. In many of these applications, the cost benefit analyses of such systems have yet to be fully demonstrated.

The concept of engineering materials and structures which respond to their environment, including their human owners, is a somewhat alien concept. It is therefore not only important that the technological and financial implications of these materials and structures are addressed, but also issues associated with public understanding and acceptance.

The core of Yanagida’s philosophy of ken materials is such a concept. This is ‘techno-democracy’ where the general public understand and ‘own’ the technology. Techno-democracy can come about only through education and exposure of the general public to these technologies. However, such general acceptance of smart materials and structures may in fact be more difficult than some of the technological hurdles associated with their development.

The following chapter will illustrate with some examples some of the ideas discussed above. It is worth pointing out that describe the multifunctional materials may not be new to the world but may not have been used within the construction sector. It is thus essential to examine the properties of the materials from a construction sector’s point of view with

the sector's special constraints and needs in mind. The ECTP Material Vision document[3] presents the background, present situation and future challenges of new materials and improved traditional materials. They summarise the need of R&D as follows:
New design and the development and application of new materials in both new and existing construction with a view to:

- Enable easy installation, maintenance and moitoring in new constructions
- Minimize environmental impact as well as disruption of activities and cost, to maximize speed of application and performance in existing constructions subjected to upgraiding
- Maximize the durability and the lifecycle of both new and existing structures
- Reduce consumption of natural resources.

The materials of the "future" should have distinct characteristics such as the following:

- High performance combined with tolerance and robustness
- Sensing coapabilities
- Multifunctionality

They should be the outcome of an optimisation process at the materials level.

For the evaluation of the overall performance of new materials, it is useful to keep in mind the criteria stated by the ECTP Material vision document (www.ectp.org).

[3] Materials, Vision 2030 & Strategic Reserach Agenda, Focus Area Materials, Version 1, Sept 02, 2005, European Construction Technology Platform (ECTP)

3 Smartness in the thinking

3.1 Learning from other industries

Building manufacturing puts new demands on the building materials that traditional building materials do not have the answer to. A big technology leap has to be made in order to introduce the new opportunities described in this report, but how is this to be done? What does the construction industry need to make this happen?
All but a few revolutionary innovations through history have taken shape when someone has taken ideas, objects and/or people surrounding existing technologies and exported them to new technology fields. There are a number of tangible examples of this (see for example Hargadon, 2003[4]). For example, Henry Ford got the idea of his assembly line from the meatpacking industry and that the tubing and pump in Reebok's Air Pump shoe was exported from the medical tools industry.
This ability to move between different industries and create bonds between them is introduced in the book as *technology brokering*. How to benefit from technology brokering in a good fashion varies depending on which knowledge the company has and in which area it exists. There are examples of companies that are fully dedicated to technology brokering through acting in several business areas with thin walls between each section as well as multiple examples where companies by accident discovered that its knowledge brought something new to unexpected markets. The problem in the latter case is that most company organisations aren't built to embrace ideas that target other areas than the company's core activities. Most of the time, people who discover potential bonds with markets distant to their company aren't in leading positions in that company. Also, their local managers don't have anything to win on exploiting opportunities outside the focus of their section. This means that, unless the people with the ideas find their own ways to anchor them with the company management, the opportunity is lost for the company.

3.2 Using technology brokering

For the development of building manufacturing systems, it seems like technology brokering is a valuable approach to make the technology leap discussed above. This is also valid for other needs then materials; connections for example. Snap-locks from the electronics industry, bayonet mounts from the camera industry and zippers from the textile industry all have features that are closer to the fast, clean and ergonomic assembly wanted from tomorrow's connections than any connection method of today. Existing objects like these could be scaled up and developed into well-functional, flexible, connections for the industrial building system.

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[4] Hargadon, A. (2003): *How breakthroughs happen: the surprising truth about how companies innovate*. Harvard business school press, Boston, 254 pp.

In order for the construction industry to obtain the advantages of technology brokering when adopting new materials, this report suggests a couple of possible arrangements:

- *Joint efforts*: Bring in skilled engineers from other interesting markets at an early, brainstorming stage of the development of building manufacturing systems. The difficulties with this approach is that it can be hard to find the interesting markets and even harder to find the right, open-minded people within these companies. A solution to this problem could be to hire people with documented design knowledge in different areas from companies that act in multiple markets, companies like for instance Caran, Ove Arup, Umbilical design. Even better would be to hire people from companies whose business strategies rely on combining their skills from different sectors, companies like IDEO or Design Continuum. If people from other business areas are to be invited to a group designing building connections, it is of essence that the requirements on the connection is clearly described so it is possible to understand for anyone.

- *Advertisement*: The probability of someone realising that an idea or object from their area of knowledge could be used in the construction industry will increase with the number of people knowing that the construction industry looks for radically new ways to connect prefabricated elements. Therefore, it should be an important concern for many organisations to spread this information together with lists of companies and contact persons who are interested in such ideas. This also helps the person who sees the connection between what his/her company is doing and what the construction industry needs to anchor the idea with the company management. It should be far easier to convince the management that your idea is worthwhile if you have a client for your idea, rather than if your idea means that your company has to sell it to companies in markets where your company has little authority.

- *Training*: It can be assumed that technology brokering in its purest form is impossible to obtain through theoretical training since successful technology brokers rely on their relationships between different industries. However, an awareness that it is possible to look at other businesses for inspiration should be possible to pass on to the developers through lectures in technology brokering. These lectures could be given by persons from technology brokering companies or other persons with knowledge of the phenomenon. This will likely spark ideas among the design team, and open their minds to a new method of working.

3.3 Structuring materials wisely

In the EU project ManuBuild (www.manubuild.org), key priorities for an open manufactured building concept have been structured into value-adding product design values based on the Vitruvian *Beauty*, *Functionality* and *Durability*, linking product development to customer requirements. Materials could be structured in the same manner, from the viewpoint of what value they add to the product. This is addressed in this section.

Designers are frequently looking for a material to fulfil a number of different requirements; strenght, fire, sound insulation and so on. The specifics of the materials we choose from have often been given in tables, where the materials are classified for easy accessibility and predicability. Traditionally, materials are classified according first to their origin and only secondly to their performance. We are used to discussing concrete, steel and timber of a certain strength class. When we make the technology leap of adopting the new materials, this approach will be very cumbersome for the situations when we are looking for materials for specific functions. When we look in tables of concrete (to take an example) strength classes, are we not often really looking for a certain sound insulation, strength, fire resistance and so on? Because of the large number of other materials possible to choose the opportunity is lost to choose something different than concrete. For low-maintenance balcony fronts, do I start looking in the tables of Biomimetic materials, Ken materials or Mechatronics?

We suggest a complete reversal of the structure that materials are given by; *Requirement* (or Performance) before *Solution*, as opposed to today's of Solution before Performance.

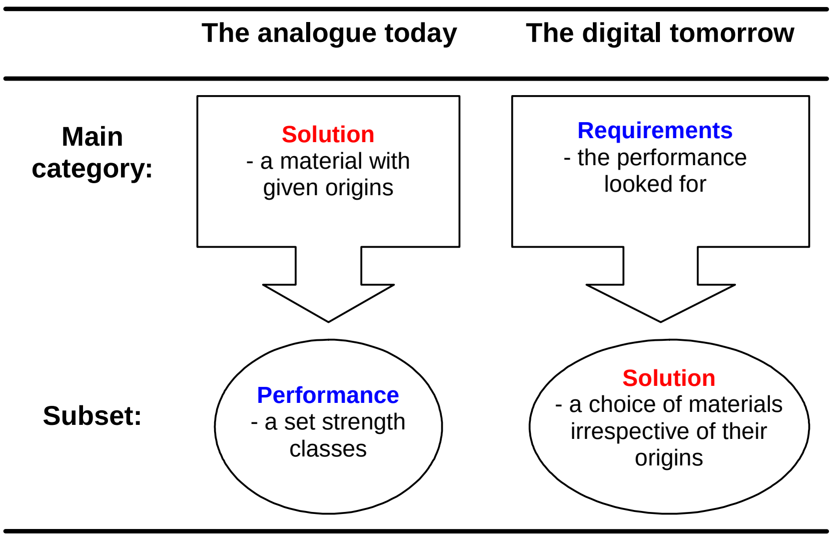

Figure 2 A suggestion for a new classification structure for materials in construction

A typical example of today's classification would be that the main category is timber, the subset is a number of strength classes. The question, essentially, is: *What can timber do for me here*? If the answer is unsatisfactory, the question is rephrased: *What can concrete do for me here?* And so on for additional materials.
A typical example of tomorrow's classification is that the main category is a set of requirements and the subset is a choice of materials. For the main category of requirements long-durability, non-combustibility, UV resistance, directionally translucency, the subset includes Panelite IGU (www.e-panelite.com). The question then becomes: *With this specific set of simultaneous performance requirements, which materials will do service for me?*

3.4 An interactive database for new materials

This approach requires an intelligent databank of materials and their specifics, which can be accessed through an iteractive menu of choices. I give the performance, the database comes up with the anwers. When it comes to ICT, such functionalities are commonplace. When it comes to the working methodology for building designers, it would be nothing short of revolutionary.
There are a number of possible sources for new materials, a few of which are given below, but none of them provide the proper interactivity that makes it possible for me as designer to combine a set of requirements and get a choice of suitable materials.
Resources on the WWW include:

- **Interactive Architecture dot Org**
  http://www.interactivearchitecture.org
  Interactive Architecture dot Org is a weblog about the emerging practice within architecture that aims to merge the digital virtual with tangible and physical spatial experience. Instead of defining a fixed architectural product it is architecture in constant flux best suited to prototyping and semi-permanent installations.

- **Transstudio**
  http://www.transstudio.com
  Transstudio is a weblog featuring new materials that redefine our physical environment; a forum for the major environmental, social, and economic issues that are transforming our physical world. "By adopting the art of the long view and sharing ideas, we can design a better future. " Blaine E. Brownell is an architect, researcher of materials, and a sustainable building advisor with NBBJ in Seattle. He is an advocate of harnessing the latest materials expertise to transform the way we make buildings and products.

  Blaine also edits a weekly electronic journal about innovative materials, and is the author of Transmaterial (Princeton Architectural Press), where he has compiled

200 of the most innovative materials that have appeared on the site to date.

- **Materials Connexion**
http://www.materialconnexion.com
Material ConneXion is the largest global resource of new materials. Their Library houses over 2,000 new and innovative materials representing eight categories: polymers, glass, ceramics, carbon-based materials, cement-based materials, metals, natural materials and natural material derivatives. Complete Library information is accessible via the Internet, using Material ConneXion's database. Materials Connexion boast that they "feature truly cutting-edge materials and applications". Surprisingly, the structure is still according to the old methodology , where origins (cement-based, metals) come before the service they are expected to perform.

  From this website, it is possible to download pdf files without charge. For registered members, there is more information on the materials, which facilitates their use in projects. Their office is in New York, but Material ConneXion opened in Milan in 2003, and in Cologne and Bangkok in 2005.

- **Innovathéque**
http://www.innovathequectba.com
Innovathéque is a commercial materials library which is owed and run by the French wood and furniture industry, and by a government version of it; CTBA. It opened in Paris in January 2001. The focal points are new materials and its target audience is architects and designers. The materials collection is in part shown in thematic exhibitions. The library also gives workshops and conferences. Individually tailored smaller material sample selections are for sale.

- **MaTech**
http://www.matech.com
MaTech is a commercial materials library that is sponsored by materials manufacturers and has a specialized staff of engineers and technicians. It is owned by Galileo Science and Technology Park and opened in Padova, Italien, in the spring of 2001.

- **MatériO**
http://www.materio.com
MatériO is a privately owned commercial materials library which opened for a 6-month test run in 2002 and then permanently in 2003. The company was founded in 2002 and has two employees. Situated in Paris, the library has a showroom of

100 sqm with self-service products and material samples, over 500 specifications form anufacturers, 137 metres of shelfs and 12 work stations. Their web site includes a searechable data base which covers the whole selection of materials. This library hosts workshops, conferences, courses and so on.

Reference material libraries

Projects
www.designinsite.dk
www.inventables.com
www.materia.nl
www.materialworks.com
www.progettomateria.com
www.thematerialpoint.se

Commercial materials libraries
Kommersiella materialbibliotek
www.hellefors.se/formenshus
www.innovathequectba.com
www.materio.com
www.matech.com
www.materialconnexion.com
www.materialbiblioteket.se
www.nordicinnovatheque.com
www.ravara.se
www.raumprobe.de

Materials libraries supported by academia
www.csm.linst.ac.uk
www.dh.umu.se
www.designkuopio.fi
www.ebb.ar.tum.de
www.ensad.fr
www.ensci.com
www.konstfack.se

Data bases
www.matdata.net
www.materialatlas.com
www.materialsgate.de

World Wide Web
www.ideo.com

3.5 The new structure without the interactivity

3.5.1 Categorising by architectural features

In the absence of interactive databases to suggest materials, there is the opportunity to define the main categories according to the main architectural feature of the materials in the subset. In a project sponsored by EMVS, this is being done. As reported by Arroy et al (2005)[5], the main categories are: *Shape Performance*, *Optical Performance*, *Sustainable Performance*, *Integrated Performance*, *Responsive Performance* and *Process Technique* respectively. Below is given indications what these categories mean and examples of materials which might be found under each category. Ion order to give an overview, in Appendix 1, a number of these materials are structured in their context.

[5] Arroy, S. P., Kebel, I. And Atena, R. (2005): Emerging Technologies and Housing Prototypes. Berlage Institute, Postgraduate Laboratory of Architecture.

3.5.2 Shape Performance

"Materials that are able to assume mechanical resistance due to a specific three-dimensional conformation."

This order of materials include honeycomb structures; a technology from the aeronautics industry. They are highly efficient on the mechanical level; low weight for performance and shape stability under stress. Their potential lies in their techno / aesthetic / functional characteristics. For example, they are thermally insulating and their aesthetic characteristics range from opaque to transparent. Combined with a coating, honeycomb structures can be used for almost any surface, horizontal or vertical, planar or curved, indoor or outdoor.

Materials include: *Flexible honeycomb* (flexible honeycomb polymer, www.supracor.com), *Parabeam* (3-glass fabric, www.parabeam3d.com), *Formetal* (punched sheet metal, www.formetal.de), *X-Tend* (stainless steel cable net, www.carlstahl.com), *Pressload* (energy absorptive panels, www.cellbond.co.uk), *Woven Wire Mesh* (metallic mesh, www.gkd.de), *Superform aluminium* (aluminium plastically former sheet and plate, www.superform-aluminium.com) and so on.

3.5.3 Optical Performance

"Materials that are able to perform in specific environmental conditions to produce optical effects: visual aspects are related to behaviours in order to disclose, to sign, to merge, to overlap and/or to add texture to the produced image."

Material transparency, texture and translucency have been used by architects for a very long time to invoke relationships between the building and its users. Materials in this category are open to different, subjective perceptions of their character by the viewer. Of special interest is the ability to modify the optical performance of the materials in order to create sensations of immateriality.

Materials include: *Crinkly Glass* (glass panels, www.galaxycustom.com), *Glass Cylinders* (technical glass cylinders, www.schott.com), *Shimmer* (metallic fabric, www.gkd.de), *Lexan* (polycarbonate resin, www.geplastics.com), *Birdwing Panel* (thermoplastic panel, www.benocre.it), *Light-emitting polymers* (polymers-LEP, www.olight.com), *Panelite IGU* (tubular polycarbonate honeycomb core sandwiched between clear tempered glass facings, www.e-panelite.com) and so on.

3.5.4 Sustainable Performance

"Materials that concern, first, one and more life cycles of the product, and second, for any quality such as production, workability, use, dissemblance and reuse, and show qualities of sustainability and environmental preservation."

Materials in this category refer are: produced with low environmental impact mainly by local, lightweight and strong raw materials which are easily renewable and biodegradable, and with a closed life cycle. Of special interest for sustainability is the ability to design low-weight and strong, low-maintenance materials to meet specific performance requirements.

Materials include: *Tennage* (flexible wood sheets, www.onlyone-pro.com), *3D-veneer* (formable veneer in three dimensions, www.reholz.de), *Foamglas* (cellular glass, www.foamglas.com), *Aerogel* (hydrophobic silica particles, www.cabot-corp.com), *Alusion Aluminium Foam* (stabilized aluminium foam, www.alusion.com) , *Insolcore* (transparent insulation acrylic or polyethylene, www.advancedglazings.com) and so on.

3.5.5 Integrated Performance

"High-tech composite materials that integrate technologies that give additional value from a performance perspective."

When it comes to multi-functionality, these materials are perhaps the most interesting ones. They are capable of performing multiple functions simultaneously. Generally, they are extremely thin and use layering systems on nano-level. They are typically textiles, fabrics or fibres, because the performance of such materials can be managed both on the micro-mechanical level (fibre disposition) and on the macro-mechanical level (directions of fibres). Having fibres of processed carbon. Glass, ceramic and so on, they have high tensile strength combined with light weight. More than one fibre type can be combined to engineer specific properties. Coating the surface make it possible to transmit electronic input by the touch of a hand, to set off alarms, control on-/off signals, to convert mechanical energy to electric signals and so on.

Materials include: *Enkardin* (subsurface drainage matting, www.colbond.com), *Euro-St Screen System* (polyurethane, www.eurogomma.net), *Cuben Fiber* (textile, www.cubenfiber.com), *DIAX-LSP* (high performance laminates, www.bainbridgeint.com), *Carbon-Glass* (carbon/glass fibric, www.pidigi.com), *B-Clear Glass* (glass-aluminium honeycomb panel, www.cellbond.co.uk) *SIBU Multi-Style* (metal composite, www.sibu.at) and so on.

3.5.6 Responsive Performance

"Materials with the built-in ability to evolve while interacting with users or external input, hence becoming an interface that reacts to stimulus that changes the material's physical state."

Materials in this category include *thermo-chromatic materials*, which react to UV-light and temperature by modifying their colour, *orthodromic materials* which react similarly but under magnetic fields and *memory shape materials*, which have the ability to interact with human actions. These materials can be made to change their elasticity should they suddenly need to withstand an earthquake. This category also includes nanotechnologies such as *thermo-regulator materials* that have the ability to uniformly appropriate, maintain and give back heat, and *materials with biological characteristics*, which have the ability to process impulses and react by adapting to changes.

Materials include: *Aquaclean* (self-cleaning glass, www.saint-gobain-glass.com), *Technogel* (polyurethane-based gel, www.technogel.it), *Lumisty* (view control film, www.madico.com), *Tempur* (the visco-elastic material in the famous mattress, www.tempur.co.uk), *Luminex* (woven optical fibres, www.luminex.it), *Re Liquid Crystal Sheet* (liquid crystals, www.lcr-uk.com), *Shape Memory Textile* (fabric, www.marielleleenders.com), *Glass Sound* (sound system integrated on transparent glazing, www.glas-platz.de) and so on.

4 New multifunctional materials

This chapter will give a few examples of multifunctional materials, some commercially available, others still at the research stage. The aim is to give more information on some of the materials emerging.

4.1 Steel

Steel is one of the most important construction materials. Almost half of the steel produced is used for construction purposes. New applications for steel can be found through the development of new grades, building components and systems, composite structures, and construction technologies.

4.1.1 SPS - a steel solid polyurethane sandwich panel

Sandwich Plate System (SPS) is a technology created by UK-based Intelligent Engineering Ltd in which two metal plates are bonded to a solid polyurethane elastomer core. The elastomer, as a two part liquid, is injected into closed cavities formed by the steel faceplates and perimeter bars. The elastomer provides continuous support to the plates and stops local plate buckling, eliminating the need for stiffeners. The steel components are either shop fabricated (with obvious advantages) and assembled in the field or field fabricated and assembled. The steel cavities or units are fabricated using standard shop welding practices and assembled with welds and slip resistant bolted connections for dynamically loaded structures.
Other advantages of SPS include its high strength-to-weight ratio, high energy-absorption capacity, good thermal and acoustic insulation properties and inherent fire resistance. SPS structures such as ships, bridges, sport stadiums, floor systems and blast walls can be designed and produced using industry standard techniques.

More information can be found at: http://www.ie-sps.com/

4.2 Concrete

4.2.1 SCC - Self-compacting concrete

<u>Introduction</u>

Being more expensive than traditional concrete but providing added process values, self-compacting concrete is the perfect example of a new material that will reach its full potential in building manufacturing.

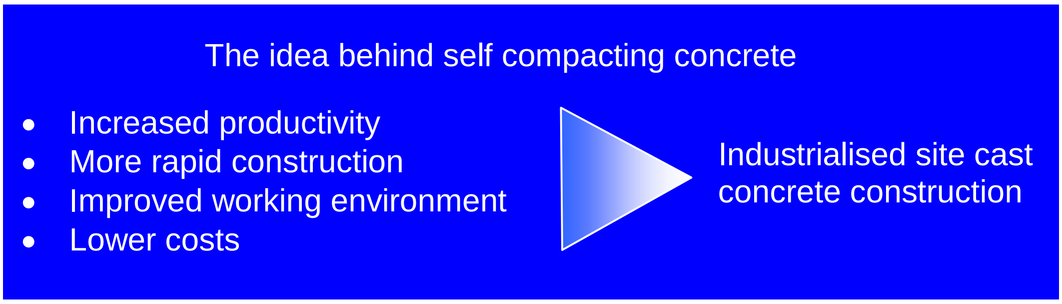

Figure 3 SCC is inherently beneficial for industrialisation

Why self-compacting concrete? Nearly all concrete currently used in building and civil engineering construction requires compaction to achieve the required strength and durability. The main method for compaction is vibration of the freshly placed concrete. However, vibration generates delays and overcosts in projects. Moreover, it is a serious health hazard on and around construction sites.

Self-compacting concrete can be used for all types of construction. The self-compacting concrete displays not only good flowability properties but also good confinement around densely spaced reinforcement bars and fills the formwork even when large recesses are present. On a number of construction sites in Sweden, both housing and civil engineering projects, NCC has tested, documented and followed-up the use of self-compacting concrete. The results obtained from these full-scale tests have given us valuable experiences and a greater understanding of self-compacting concrete has been obtained. NCC can now offer its clients knowledge of the whole chain, from design to production of the self-compacting concrete.

4.2.2 Advantages of using self-compacting concrete

The elimination of the compaction process opens, finally, the way to an effective introduction of automation into the concrete construction processes, both in-situ and in precasting. Major benefits include:

- Shortened concrete construction time, increased turnover in pre-casting,
- Improved health and safety on concrete construction site and reduced environmental load (noise) on the surrounding area by elimination of vibrators,
- Improved quality of concrete,
- Overall decrease of concrete construction costs.


*Figure 4 Which technology would you prefer for casting a slab?
Choose SCC (left) or a situation you might land in with traditional concrete (right).*

When a good self-compacting concrete is used, better quality surfaces with less pores that requires less repair and finishing, are possible. The honeycombs that often appear in the lower parts of walls and columns when conventional concrete is used can completely be avoided when self-compacting concrete is used. The self-compacting concrete shows good confinement of the reinforcement bars. The concrete confines large recesses well and sharp edges are usually obtained. There seems to be less leakage from the forms compared with when using conventionally vibrated concrete.
In reality, no matter how good a product may seem on the paper, if the workforce does not like it you may as well forget it. Fortunately, the experience on the construction sites of the self-compacting concrete has been in general positive. In fact, some of the concrete workers would prefer not having ever to work with conventional vibrated concrete.

Figure 5 A SCC bridge over a railway outside Motala, Sweden.

One of the first full-scale trials done by NCC where SCC was used was in a bridge over a railway outside Motala, Sweden. “One of the striking things was the silence. Usually there is a lot noise. This time ear protection was hardly needed,” says Anders Sörberg who has been a concrete worker for 15 years. “I have nothing but good experience. It provides physical relieves and it was very easy to cast. It is definitely the future.” Modern self-compacting concrete is here and its technical and commercial benefits are already being exploited. Its spread into general, all-purpose concrete construction is on the near horizon and knowledge of self-compacting concrete technology will soon become essential for all construction professionals.

Working environment

The prevailing method of compacting concrete today is by vibration. The task of vibrating concrete cannot be seen as anything other than an exhausting, dangerous and low-skill activity. Heavy, noisy vibrating equipment must be manhandled and operated often in precarious circumstances on top of high temporary formwork. These primitive methods of vibration/compaction lead to early "burn out" of workers and sometimes to the recognised 'white finger syndrome' and other health problems. In fact, most of the concrete workers have to stop working before reaching retiring age due to health problems. It is today very difficult to recruit young people to become concrete workers as the working environment is very tough and many concrete workers have work related health problems already at an age between 30 and 40 years. Back problems, deafness and “white hands” are very common problems among relative young concrete workers.

Noise

Sound-levels have been monitored on employees casting with traditional vibrated or self-compacting concrete. The monitoring equipment was sound dosimeters Brüel & Kjaer 4428 and each person carried them, with the microphone attached to the collar. Measurements were performed at three occasions: wall-casting with traditional vibrated and self-compacting concrete and floor-casting with self-compacting concrete. Presuming that the background sounds are on a low level, the use of self-compacting concrete means that the involved personnel is exposed to sound levels that are approximately one tenth of the levels produced when using traditional vibrated concrete.

Emissions of VOCe

From experience it is known that high moisture content in concrete slabs at the time when the floor coverings are laid often increases the emission of volatile organic compounds (VOC) from the floor. A chemical breakdown starts in the adhesive and in the PVC-flooring due to moisture- and alkali content in the concrete, and mainly two compounds, n-butanol and 2-etylhexanol, are emitted from the floor construction.
An office building was constructed by NCC. In order to obtain more information about the materials in the floor constructions NCC decided to measure the emission from floor systems/specimens. The decision to study the combination of materials in the floor

systems was due to that the slabs were cast with self-compacting concrete, and no measurements of emission have previously been carried out on systems with self-compacting concrete.
The results from the measurements of emission show negligible amounts of breaking down products. These results correspond with similar studies for traditional vibrated concrete.

Ergonomy
A survey on physical strain when casting with self-compacting concrete compared to casting with traditional vibrated concrete was carried out at NCCs construction site Startboxen in Stockholm. The subject of the study were all the concrete workers in the work force, in all seven persons. The control group consisted of seven concrete workers from another construction site with similar tasks but using traditional vibrated concrete. The workers rated their physical strain according to the Borg RPE scale for ten different operations, using self-compacting concrete and traditional vibrated concrete. The control group rated their strain only for traditional vibrated concrete.
The study shows that when casting with self-compacting concrete the concrete workers are exposed to less strain compared to casting with traditional vibrated concrete. This is mainly due to the fact that the operations with vibrating tools are eliminated. Also racking and screeding are rated lower when using self-compacting concrete. The conclusion is that casting with self-compacting concrete can be recommended from an ergonomic point of view.

Economy
Using data obtained in case studies and simulations, the advantages offered by SCC has been quantified in a global approach. The SCC figures were compared with costs for conventional concrete regarding:

- extra cost of concrete (mix),
- placing labour cost,
- equipment cost: type of formwork (stiffness), vibration equipment, ...
- concrete production (mixing time)
- concrete transport (from plant to site, on site),
- global construction time (production time)
- social impact: safety (costs for absence and injuries), ...
- environmental impact: elimination of vibration, ...

The balance for the 12 m^3 wall used as an example on the next page was that the time needed for all tasks decreased from 27.5 hours by a net gain of 2.3 hours per m^3. The total cost decreased from 70.1 euro/ m^2 to 40.9 euro/ m^2. The same trend was visible in other building parts.
In typical applications, the extra-cost of SCC was easily outweighed by the savings in the cost of labour or the duration of construction. This requires a holistic view – in traditional construction, it is easy to focus on the material price per m^3 of concrete. When it comes to

building manufacturing, sub-optimisation is a problem easily handled. In addition, in building manufacturing, casting is an even more critical cost-driver, and requirements for a speedy and healthy process will quickly overtake the increase in price per cubic metre.

Table 1 Sample from a study on overall economy for casting walls in self-compacting concrete.

Site : Solna
Structure type : Walls (Casting no. 9)

		Data for Ordinary concrete	Data for SCC	oc/scc
Concrete mix design		Cement: 310 kg/m3 Fine aggregate (0-8 mm): 970 kg/m3 Coarse aggregate (8-32 mm): 950 kg/m3 800 SEK/m3	Cement: 330 kg/m3 Filler Myanit: 125 kg/m3 Fine aggregate (0-8 mm): 1031 kg/m3 Coarse aggregate (8-18 mm): 688 kg/m3 Viscocrete 3 6.5 kg/m3 900 SEK/m3	+
Concrete production	Mixing time	90 seconds	260 seconds	+
Concrete transport	From plant to site	Truck mixer 5 m3 Time transport 45 minutes	Truck mixer 5 m3 Time transport 45 minutes	0 0
	On site	Bucket	Bucket	*
Formwork	Pressure Additional formwork	tonnes/m2 m2	tonnes/m2 m2	
Vibration equipment	external vibrators pocket vibrators	diameter = 38 mm number = 2		-
Reinforcement	Materials Placing	kg/m3 h/tonnes	kg/m3 h/tonnes	
Concrete placing	Volume	11 m3	11 m3	
	Speed	1.5 hours	1.5 hours	0
	Number of workers	number = 4	number = 2	-
Production time	Cycle time Global labour time	days hours	days Hours	

* time transport : from batching plant to site
SCC = Self Compacting Concrete; OC = Ordinary Concrete

+ : increase in cost for SCC
- : decrease in cost for SCC
0 : same value for SC and for OC
* : no data

	OC	SCC
Work	154 SEK/m³	77 SEK/m³
Concrete	800 SEK/m³	900 SEK/m³
Other costs (machines, ...)	24 SEK/m³	11 SEK/m³
SUM	978 SEK/m³	988 SEK/m³
Δ =	+ 10 SEK/m³	

4.3 Other types of concrete

4.3.1 Litracon

LiTraCon™ offers the phenomena of light transmitting concrete in form of a widely applicable new building material. It can be used for interior or exterior walls, illuminated pavements or even in art or design objects. LiTraCon™ is a combination of optical fibres and fine concrete and can be produced as prefabricated building blocks and panels. Thousands of optical glass fibres form a matrix and run parallel to each other between the two main surfaces of every block.

The proportion of the fibres is small, at 4% of the total volume. Because of their size, they become a structural component in the concrete. The surface of the blocks therefore remains similar to homogeneous concrete. In this manner, the result is not only having two materials - glass in concrete - mixed, but a third, new material which is homogeneous in its inner structure and on its main surfaces as well. The glass fibres lead light through the two sides of the concrete. Because of their parallel position the lighting on the brighter side of such a wall appears unchanged on the darker side. Shadows are displayed on the opposing side of the wall and the colour of the light remains the same. Load-bearing structures can also be built using these blocks, as glass fibres do not have a significant negative effect on the high compressive strength of concrete. The blocks can be produced in various sizes and also include embedded heat-isolation.

More information can be found at: http://www.litracon.hu/

4.3.2 Ductal

Ductal® is an innovative technology which covers a family of ultra-high performance concretes with exceptional characteristics in terms of mechanical resistance (compressive strengths up to 200 MPa, flexural tensile strength beyond 40 MPa), durability, abrasion resistance, and resistance against chemical and environmental attack (freeze and thaw, salt water, etc.).

This new technology permits the development of innovative solutions which are competitive, offer faster construction, require less maintenance, and have a reduced impact on the environment.

More information can be found at: www.ductal.com

4.3.3 Agilia®

Lafarge's Agilia® is the ultimate ready-mix concrete that is self-compacting, self-leveling and flows easily through high congested forms. Agilia® is highly flowable and can move into place under its own weight and achieve good consolidation without internal or external vibration and without exhibiting defects due to segregation and bleeding.

Agilia represents a significant leap in technology from standard concrete. It has the properties of a fluid during placement, yet the properties of traditional concrete after setting. It has a very good surface finish (P-1, per ASCC index) with uniform distribution of aggregates. Long term performance is comparable, yet placement is far simpler and less costly.

More information can be found at: http://www.lafargenorthamerica.com

4.3.4 TX Active®

TX Active® is a photo catalytic principle for cement products which can reduce organic and inorganic pollutants that are present in the air. Its effectiveness has been thoroughly tested and thus certified by important independent research centers (CNR, ARPA, Ispra Research Center). Its formulation is the result of 10 years of research, tests and applications carried out by CTG (*Centro Tecnico di Gruppo*, a company in the Italcementi Group) which has led to the final formulation of the active principle. Italcementi will make this material available to the whole construction sector which will thus be able to offer products with high quality standards under the "TX Active®" brand.

More information can be found at: http://www.italcementigroup.com

4.4 Wood

4.4.1 Massive Timber Plates

There are rational, technical and architectural gains to be made from interactively developed architectural and structural utilisation of massive timber plates. This product type is relatively new. It is a timber-based product type, which has been refined through an industrial process that provides the product with a set of characteristics, static features and potential utility, which distinguishes it from other timber-based products. These characteristics also make structures possible that are not achievable in any other material, considering e.g. weight to stiffness ratio, thermal inertia and adaptability. The glued cross-laminated timber-plate is of primary interest. Compared to other timber-based products, because of its character of double load-carrying directions, it opens possibilities for diaphragm and plate action. This makes new timber architecture possible. Its function can be that of several materials that are included in a traditional stud-frame system. Insulation can be limited, moisture barriers and gypsum boards removed and so on. There are also other kinds of laminated build-ups, as well as structural elements with hollow box-sections.

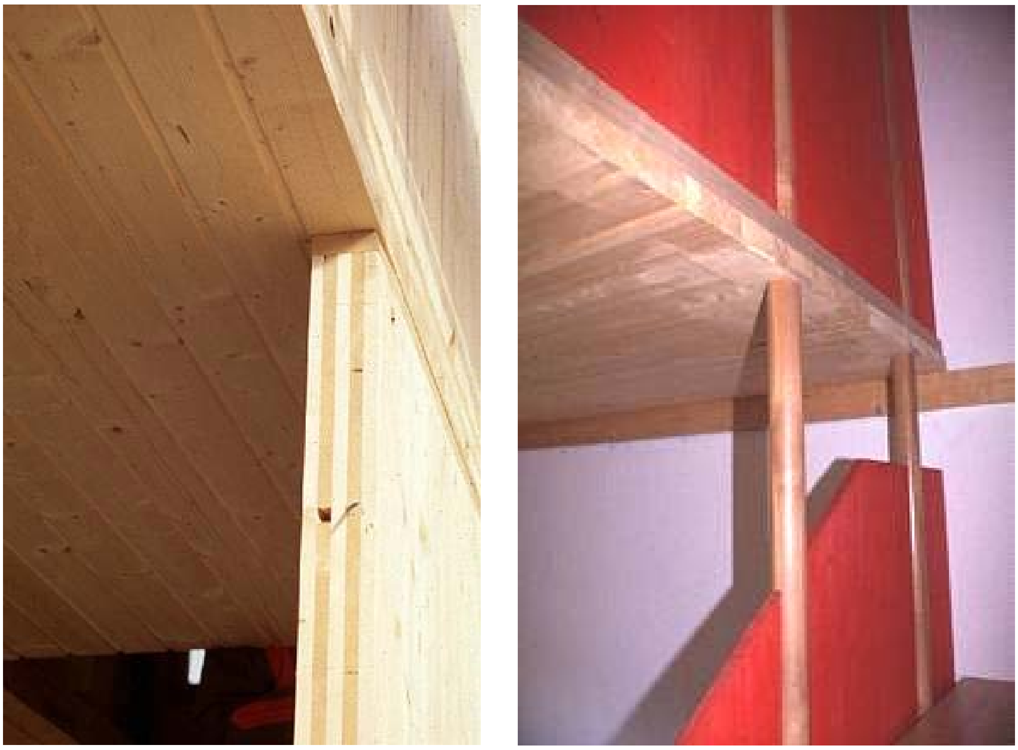

Figure 6 Massive timber plates: Diaphragm action and plate action allows for new architectural timber-based expressions and multi-functionality in a single element.

4.5 Composite materials

Many people refer to fibre reinforced polymers, FRP, as composites. One very interesting development within ManuBuild is the FPR (Fibre Reinforced Polymers) infill wall elements, its use currently being developed by the Polish contractor Mostostal (www.mostostal.pl). Generally, a composite is a material formed from two or more separate parts with a distinguished phase between them. Consequently, there are plenty of composites around us. Fibre reinforced polymers is a composite where a polymer matrix is reinforced with many relatively thin and long fibers. These composites are to be found in sports equipment, the sailing industry, aircraft, and the spacecraft industry. Although composites have been used for some time in the building industry, the usage and the material itself can be considered as new within building industry perspectives. The construction sector is still taking its first steps on the research and development to apply these materials, and the development of structural and non-structural applications designed and constructed in these materials.

Figure 7 Carbon-fibre Reinforced Polymer sheet (left)
Glass fibre Reinforced Polymer sheet (right)

The two main application areas of these materials in construction are new structures or building components and reinforcement of existing wood, steel or concrete structures. Arguably, when it comes to new structures and components, composites materials can turn into a revolution on the construction methodologies, opening large future possibilities.
Composites materials present clear advantages against conventional materials, such as presenting stable and waterproof character, turning these materials into the ideal material to be used in corrosive or wet environments. +Additionally, components which are manufactured using these materials have a very low maintenance or are even maintenance-free.
Composites' reduced weight facilitates on site handling, reducing the construction times and the need of logistic means. This is an essential factor in building construction, where setting up the building interiors, especially the partition walls, can suppose up to the 30% of the construction time.
Composites can be used indoors or outdoors, both as structural and non-structural component, as well as ornamental component. The use of composites materials as partitions walls in building construction would make of this construction a pioneer at an international level and with a worldwide impact, setting a precedent for future constructions using these materials, and as a high-tech and high-innovative building construction.

4.5.1 Fibre Reinforced Polymers

Fibre Reinforced Polymers (FRPs) combine light weight and high corrosion resistance, making life cycle costs lower than conventional materials such as steel. The composite structure can last much longer than conventional materials and may also have reduced maintenance costs. The fibre reinforcement in civil engineering applications are often carbon, aramid or glass fibre, with a matrix of polyester, epoxy, vinyl ester, or phenol.

Fibre optic monitoring facilities may be included. When the fibre and the matrix are combined into a new material it becomes a composite.

Fibres
The most commonly used fibre types are carbon, glass and aramid, while main matrices types are polyester, vynilester, phenolics and epoxi. Most of these materials present an elastic behaviour. However, it is possible to design a ductile structure.
Carbon fibre is made from a precurson fibre, usually PAN (polyacrylonitrile), which is subjected to different transformation procedures: stretching (orientation), oxidizing, carbonization and graphitization. In general, there are two different types of fibres: HR (high resistance) and HM (high modulus).
In particular, HM fibres have a specific modulus 70 times higher than aluminium alloys. Besides, they have a low expansion coefficient, which gives high dimensional stability to the structures and a high thermal conductivity. These fibres also have a high tensile and compression strength, and they are not affected by corrosive or acid environments.
Glass fibre have the following advantages as compared to traditional materials: mechanical strength, good electrical properties, non-combustibility (unflammable, non-ignitable), thermal insulating even on small thickness, good dielectric permeability, permeable to electromagnetic waves.

Matrices
Regarding the **matrices**, the most commonly used in construction are polyester, vynilester, phenolics and epoxi. Their main function is to keep the fibres that make of the composite embedded and transfer the stresses among them.
The properties of composites materials depend on the type of materials that make of the final system, as well as the fibres and the resins, only an appropriate combination will result on a suitable product for each specific application.
Composites materials are made of a laminate. One composites laminate consists on a number of carbon/glass fibre plies, impregnated in epoxi resin to make a high-strength stiff plate. These plies can be made of different types of fabrics and may have different orientation.
Their main advantages are their high strength and structural stiffness, low weigh, easily mouldable to make any desired form, high resistance against external pollutants and easy installation. They also offer safe, economical and functional structures, therefore satisfying the society needs, and improving the quality of life of the people.
Besides the structural and logistics advantages, there are other architectural advantages, such as the possibility of choosing the colour of the structure among a wide range of colours, or choosing the surface texture (smooth, undulating, rough, etc.).
The performance of these materials in cyclic strengths has been proven in the subjected tests and the existing bibliography. One example of this is also shown by the WTG blades, which are made of glass or carbon fibre, depending on their length.

Benefits

The fibres are all much more expensive than traditional material (mainly steel). However, Table 1 lists some of their benefits.

Table 2 Benefits of three types of fibres.

Glass (GFRP)	Carbon (CFRP)	Aramid (AFRP)
• *Has the longest ultimate elongation*	• *Medium density*	• *Lowest density*
• *Non-corrosive, impervious to chloride ion and chemical exposure.*	• *Smallest ultimate elongation*	• *Very lightweight, 1/6 the weight of standard steel*
• *Highest density*	• *Highest tensile strength*	• *Medium tensile strength*
• *Lowest tensile strength*	• *Semi-conductive (thermal, electrical and RF energy.)*	• *Medium ultimate elongation*
• *1/4 the weight of standard steel*	• *1/5th the weight of standard steel*	• *Excellent abrasion resistance*
• *Transparent to magnetic fields or radio frequencies.*	• *Modulus of elasticity close to steel*	• *Good thermal isolation*
• *Non-condutive, non-magnetic*	• *Impervious to chloride ion and other chemical exposure.*	• *UV exposure can cause degredation of aramid fibres*

Manufacturing processes

The manufacturing processes have also developed in tandem with the material developments to further exploit their advantages.

One of the developments of fibreglass, 20 years ago, was as moulded flat sheets (SMC - Sheet Moulding Compound) which, when cured under great pressure, (2 000 tonnes) produces an extremely realistic looking panelled and wood grained door skin.

This is then applied to both sides of an internal perimeter frame structure and filled with polyurethane foam under pressure to produce an exceptionally strong and robust external door, known today as 'composite' doors.

Composite doors have surpassed most other door materials in social housing, where the highest durability is essential. However, builders should ensure that the skins are GRP fibreglass, not thermoplastic – and on both sides of the door, not just one side.

Whilst flat pressing had become common-place in the mid-1990s, another challenge was being addressed. This was the development of fibreglass in long continuous lineal lengths

for window profiles.
Requiring multiple strands of glass fibre rovings and continuous matt to pass through a die together with the viscous thermosetting polyester resin, PVCU window profile is formed by pushing the liquid thermoplastic out through a die in a process known as 'extrusion'.
With fibreglass, however, the strands can only be pulled through from the other side. As a result, the process is known as pultrusion - which, therefore, applies only to FRPs.
The resultant end product of pultrusion has represented the cutting edge of plastics technology in external building components, since the late 1990s in the USA and Canada) – and since the early 2000s in the UK.
For over 25 years, there has been little change in fenestration materials with timber, PVCU and aluminium dominating all market sectors and fulfilling most applications, whether housing or commercial, new build or refurbishment. However, climate change, environmental concerns and the consequences of global warming are causing a major re-think by leading specifiers, architects and designers. Initiatives by international governments to reduce fossil fuel burning and the generation of greenhouse gases, through improved thermal insulation, are also making the entire building industry re-evaluate the products being used today in order to improve thermal performance and longevity.

Costs
New technology products invariably cost more in order to help recoup some of the extensive R&D initial development costs that created them.
However, it is reasonable to expect that there will also be some practical advantages to offset this higher cost.

- A formal Whole Life Cost study undertaken by BRE has shown that the longer life expectancy of a leading pultruded fibreglass over PVCU makes it better value over the 30 year period of the study, even though the initial capital cost is higher. (Environmental considerations, whilst important, do not affect the cost effectiveness).

- Despite the performance, environmental and thermal advantages of over aluminium, the FRP material can actually offer a reduction of the initial cost over most like for like aluminium window designs, thus making it especially compelling in those cases.

The key restricting factors in the application of composites are higher initial costs due to raw materials and also inefficient conventional moulding processes. These higher costs are derived from the following factors:

- Fluctuation in the oil cost, basic constituent in the production of the raw materials.

- Dependence on the quantities purchased of the materials: low introduction involves that the quantity purchased suppose a higher cost than purchasing large amounts.
- Acquisition from other industries: aircraft industry monopolizes the acquisition of the raw materials, and therefore, the introduction of these materials at the construction industry has to be done at higher initial costs.
- Low industrialised manufacturing processes in the construction industry: higher industrialization would reduce the cost to manufacture FRP components for construction.

From a general point of view, there are several cost categories that have to be considered for analysis, beyond the higher initial cost of the materials. These include construction costs, life-cycle costs, future cost estimates, and indirect or intangible costs. However, construction costs are those which reflect the largest costs in most cases and are appropriate for a majority of the applications. These include material, component manufacturing, fabrication, assembly, shipment, installation, and testing. Lifecycle costs also have to be analyzed, because they reflect factors such as maintenance, inspection, repair, disposal, and replacement, which reflect clear advantages over conventional materials.

One approach to perform the FRP components cost analysis is the application of the learning curve theory to FRP components, where the costs can be segregated into two general groups: processes and materials. The first includes the manufacturing processes, quality control processes, design for manufacturability, design for assembly, transport methods, assembly methods, and equipment to manufacture, transport, and assemble the components. These are expected to improve greatly as learning occurs, since so little experience exists in these areas. The learning curve reduction for the material costs can be segregated into two cost drivers. The first cost driver is the improvement in costs due to better application of materials and reduction in scrap, which should be evident as the learning occurs. The second cost driver is the cost of the material itself. However, since these materials have been utilized for years in other industries it has little room for cost reductions, except for the case of purchasing large amounts of materials (due to higher consumption needs), which would reduce, although not too significantly, the raw cost of the material.

Designing composites materials and their products

The development of the advanced composite technology is an engineer's dream for innovative design and application. The characteristics of a composite can be tailored and designed to meet any desired specifications. Most of the information and design data available on composites are in the aerospace applications, but they are protected under the guise of proprietary systems and/or military classified documents. Unlike conventional isotropic materials of steel and concrete, there are no readily available design charts and guidelines to help the structural engineer. When it comes to working with composites as opposed to conventional materials, the difference can be as dramatic as night and day.

The challenge in applying composites is for one to understand the behaviour of not only the constituents in the composites but also the completed end product in the way they respond to an applied load. Since a separate design specification for composites structures is not readily available, existing design guidelines may have to be used with some caution.

The service limit states dictate the level of deformation and crack width under normal service conditions for a structure to perform satisfactorily during its service life. The ultimate limit states are to ensure that both the global and local strength and stability are provided to resist the significant load combinations as experienced by a structure during its design life. Some overstress and structural damage may be inevitable, but the overall integrity of the structure will not be compromised.

The development of a composite is a complex process that requires the simultaneous consideration of various parameters such as component geometry, production volume, reinforcement and matrix types and relative volumes, tooling requirements, process and market economics, etc. Every decision made during the product development process is intricately related to a set of three interacting decision areas (i.e., materials, processing, and configuration).

Composite materials consist of two or more distinct physical phases, one of which, the fibrous, is dispersed in a continuous matrix phase. Composites offer the designer a combination of properties not available in traditional materials (concrete, steel and wood), with higher properties and some of them unique in a specific aspect compared to the individual components.

Composites materials consist on two main elements: fibres and matrix. The right combination of these components gives way to improved materials than individual components. Besides the fibres and the matrices, there are other components, like additives, which provide special characteristics for different manufacturing and application processes.

The fibre is the resistant component of the composites. Fibres contribute with mechanical resistance, stiffness and hardness, and it is essential to obtain the composites’ mechanical properties. The most relevant characteristics of the fibres are the specific strength and its high modulus.

With the inherent low section modulus of a composite structural member and critical high stress demand in structural applications, a designer should consider the following features carefully in his design:

- Avoid abrupt thickness change in components
- Take advantage of geometrical shapes
- Take advantage of hybrid systems

- Use bonded assemblies and joints
- Provide good details for connected joints

Avoid abrupt thickness change in components
In steel or concrete design, an increase in the plate or flange thickness will usually keep the stresses under control. Although this concept also works for composites, it is inefficient for a composite member to follow suit by increasing its overall part thickness. Because composites are viscoelastic materials, it is undesirable to create high stress risers. An understanding in the stress flow of a structural member will help a designer tailor the parts' thicknesses locally and avoid abrupt changes in its geometry.

Take advantage of geometrical shapes
In most design using composites, the stress level is very low. An optimal design in composites balances the stress, deflection, and stability with the use of flanges, ribs, stiffeners, honeycomb or box-cells, or tubes to maximize the stiffness of the section. By placing flanges farther apart at the top and bottom of a hollow core, the section modulus can be designed to span longer structures. By proportioning and orienting the cells adequately, local buckling can be eliminated and material stiffness can be increased.

Take advantage of hybrid systems
By taking advantage of the high stiffness in concrete and the high strength in composites, concrete filled carbon composite tubes for piles and main superstructure members in bridges are found to be very cost effective. Structural timber beams reinforced with composites in strategic locations have demonstrated an increase in the beam capacity. Pultruded carbon FRP composite laminates bonded to steel beams and concrete slabs are being considered for strengthening of bridges. Composite fibreglass rods replacing reinforcing bars in concrete bridge decks are being studied in West Virginia. With any of these hybrid systems, the designer should account for the difference in the strains of each material affecting the compatibility of the total unit.

Use bonded assemblies and joints
Much work needs to be done in developing good joints to assemble the composite members. Mostostal are working on this in T2.6. The successful use of the epoxy adhesive technology from the aerospace industry has been transferred to many recent civil structural applications, and can be transferred to housing as well. The concept of using epoxied shear transfer toggle strips has been demonstrated in two composite bridges in the United Kingdom. Plate bonding using epoxy adhesive on thin laminates to strengthen civil structures is seen as a promising application. The column wrapped with carbon tows (sheets) will be as strong as the epoxy bonded overlapping splice. The ability to advance the composite technology in structures will depend on the integrity and durability of these joints.

Provide good details for connected joints
Discontinuities within a structural system can be a designer's nightmare. Special attention must be given to the local stress flow, overall load path, and joint lines that create weak links or porosity introduced during the manufacturing process. Other irregularities introduced during the cutting/drilling and fit up process must be evaluated. It is important to select proper fasteners. Certain composites with high flexural modulus are very brittle and have a tendency to granulate; they would not be suitable with screws. The ability to connect the components into a structural system will enable composites to go far in civil applications. It needs a technological breakthrough from the current thinking of using nuts and bolts to connect its members.

Risk assessment on the use of composites materials
Risks derived from the use of composites materials in construction are on the one hand those associated to the construction itself. These risks, as are common in construction, such as handling of components, are no further mentioned hereby. However, we must consider as a positive factor that the use of lighter components, such as those made of FRP, makes possible the use of not-as-heavy machinery and construction cranes, and therefore reduces the risks derived from this.
Other risks are those specific of the materials usage and processing, that is, potential risk to the workers health for exposure to composites materials. The following table shows the activity/risk matrix for activities which give rise to specific risks:

Table 3 Risks with FPR.

Type of risk / *Activity*	*Inhalation risks*		
	Solvents	*Glue vapours*	*Soap oils*
Bonding		*x*	
Component processing	*x*		*x*
Material cleaning	*x*	*x*	

The information in the table is not sufficient to evaluate the risks, as it would be necessary to identify the harmful agent and its effect on the respiratory system and the other organs of the worker. Therefore, specific health&safety plans have to be performed, depending on the component to be manufactured, and the materials involved in the manufacturing process.
Following, we provide much in general terms, some general rules that need to be followed when using composites materials, regarding the risks of use of composites.
In closed environments localised ventilation plants which directly remove the harmful vapours emitted are not installed, as the quantities involved are modest. There are only ventilation systems which guarantee the necessary change of air and limit the accumulation of harmful substances in the environment. In specific cases it must be analysed the installation of these localised ventilation plants.
Individual means of protection (IMP) must be used. These include suitable clothing and footwear, gloves goggles, headwear, masks, earplugs and headphones.
The need to use particular IMPs such as masks, earplugs and headphones to protect the eardrums is evaluated by means of readings carried out in the work environment.
Protection against injuries and fire must be in accordance with law and is not included in this study.

4.5.2 Polymeric Composite Materials and Processes for airplane applications

The application of polymeric composites has been an evolutionary process, with increased use as materials and processing technology matured and program needs dictated their use. Glass-reinforced composites, in the form of thin face sheet honeycomb sandwich constructions, have been in general use for secondary structures (i.e., wing-to-body fairings, fixed-wing and empennage cover panels, and secondary control surfaces) on commercial transport aircraft since the mid-1960s.

During the 1970s, the commercial availability of carbon and aramid fibers and the uncertainty in fuel supply and costs provided an impetus for the development and application of structural composites for airframe applications. NASA conducted technology development and flight-service programs to encourage the use of composites in commercial production applications. Carbon/epoxy, aramid/epoxy, and aramid-carbon/epoxy and glass-carbon/epoxy hybrid composites were first used on a production scale in the early 1980s for the generation of aircraft that included Boeing 757, 767, and 737-300; Airbus A310 and A320; and McDonnell Douglas MD-80 series. Applications included secondary structures such as fairings, fixed-wing and empennage cover panels, and engine cowlings, as well as primary flight controls such as ailerons, elevators, rudders, and spoilers. The materials used for these components included largely unmodified amine-cured epoxy resins (e.g., TGMDA/DDS) reinforced with aramid (Kevlar® 49), carbon (e.g., Toray/Amoco T-300, Hercules AS-4), and E-glass fibers. Constructions were generally facesheets co-cured or secondarily bonded to composite honeycomb core.

The first production application of composites on primary structure was in the late 1980s on Airbus A320 empennage components. The construction used was an integrally stiffened carbon/epoxy laminate skin fabricated from materials similar to the first-generation materials previously used for secondary structure and primary flight controls. The further development of carbon fibers with improved strength and modulus (e.g., Hercules IM7 and Toray T-800H) and high-performance and toughened matrix polymers has led to application on the Boeing 777 empennage to expand the primary structural applications.

The factors currently driving new materials applications on commercial aircraft will place added emphasis on design simplification, low-cost processing, and durability and maintainability, very much similar to those of the construction sector.

4.5.3 Trends in processing

Although high costs for raw materials have been blamed for the slow growth of composites in the marketplace, material costs actually account for only 8–10 percent of the overall cost of composite components. In fact, manufacturing costs are the single largest contributor to overall costs. While the development of composites for aerospace applications has traditionally been driven by performance, cost has assumed increasing importance during the past several years. Thus, a primary criterion in the development of manufacturing processes for the next generation of commercial transports has been the potential for low-cost production of components. The National Materials Advisory Board committee[6] believes that the trend to develop low-cost production processes such as resin

[6] http://www7.nationalacademies.org/nmab/

transfer molding, resin film infusion, diaphragm forming, pultrusion, advanced tow placement, and nonautoclave processing will be continued for the foreseeable future.

4.6 Phase changing materials

4.6.1 Micronal® PCM & SmartBoard™

Construction materials which have been modified by means of Micronal® PCM phase change materials acquire an active temperature compensation mechanism which ensures ideal room conditions, particularly in summer. Provided certain general conditions are met, this new form of construction material may save you from having to run an air-conditioning system altogether.
Micronal® PCM can also be used in other construction materials such as plasterboard, textured finishes, and finishing systems and compounds. Construction materials containing BASF phase change materials are impervious to grinding, drilling and cutting. Thanks to their robustness, the microcapsules are virtually indestructible. This means that Micronal® PCM-modified building materials retain their functionality for decades without having to be renewed.
SmartBoard™ plasterboard has a thickness of only 1,5 cm, yet its thermal storage capacity equals that of a 9 cm-thick concrete wall or a 12 cm-thick brick wall. Micronal® PCM SmartBoard™ contains 3 kg of microencapsulated phase-change material per square metre. By using this gypsum wallboard as a dry building material, builders and renovators are now able for the first time to enhance the room climate.
More information can be found at: http://www.functionalpolymers.basf.com

4.7 Pultruded glass reinforced polyester

4.7.1 Startlink

Pultuded GRP is an energy efficient low cost, structurally competent building material available for construction use. Startlink is a modular building system of great elegance and simplicity. The combination of these two elements offers the possibility of constructing energy efficient rural buildings quickly and cost effectively.

- Pultruded GRP has almost twice the strength-to-weight ratio of mild steel which, in itself, has excellent strength and stiffness. It has almost five times the strength-to-weight ratio of reinforced concrete.
- Pultusion optimises the fibre-matrix ratio, which has the effect of stiffening the composite. With a polyester matrix, the value for Young's Modulus can be as high as 39GPa (or kN/mm2). The comparable figure for conventional GRP is between 7 and 10GPa. Softwood suitable for structural applications in buildings has a figure of between 7 and 11GPa.
- The values for tensile and compressive strength are impressive, as can be inferred from the table below, because the composite starts to exhibit the mechanical

properties of the E glass fibres, which have a tensile strength of up to 2,000MPa (N/mm^2).

- The preponderance of glass in the composite that is achieved by pultrusion improves the performance in relation to thermally induced movement, so that it behaves much more like glass than plastic. The linear coefficient of thermal expansion is about 5x10-6/unit length/degree Celcius, which is slightly less than half that of reinforced concrete or mild steel.
- Pultruded GRP is electrically insulating; it is intrinsically good as a thermal insulator; it is acoustically absorbent and attenuates the passage of structure-borne sound; it is mostly impermeable both to liquid water and to vapour (although there is some absorption by the matrix); it is resistant to 'freeze thaw'; it is acid resistant and alkali resistant up to a ph of 13 (vinyl ester rather than polyester would have to be used as matrix material for excessively alkaline environments); it is stable and chemically inert, so that it does not release VOCs while it is present in a building and, finally, it has better performance in a fire than either steel or timber, because the surface of the composite tends to 'char', which protects the core of the structural section against further burning.
- Provided that the correct production techniques are adopted, it can be made to be entirely resistant to the destructive effects of the uv components in sunlight.
- It can be confidently asserted that pultruded GRP is a highly competent engineering material, which is eminently capable of being specified for a large number of building construction applications, not least components for house building in rural areas.

More information can be found at: http://www.startlink.co.uk/

4.8 Insulation

4.8.1 Ultimate

Saint-Gobain Isover has developed a new generation glass wool insulation. S.G. Isover ULTIMATE is a glass wool with the same properties as standard Isover glass wool in terms of insulation, ease-of-use, environmental benefits and value for money. The major difference is Isover Ultimate resistance to high temperatures, making it exceptionally capable of withstanding fire, a quality which can be attributed to its patented chemical composition.
More information can be found at: www.isover.com

4.8.2 Neopor

BASF developed a new EPS insulation with better thermal performances. Because of this better thermal performance the use of raw materials can be less to reach the same thermal performance.
More information can be found at: www.basf.de

4.9 Glass

4.9.1 Saint-Gobain Glass Bioclean

SGG BIOCLEAN is an easy-to-clean glass manufactured by depositing a special transparent layer of photo catalytic and hydrophilic mineral material onto clear glass offering self cleaning properties. The mechanical, thermal and acoustical properties of SGG BIOCLEAN are identical to normal glass.

• Less frequent cleaning allows you more free time.
• Much easier cleaning: less dirt and grime adheres to the surface.
• The cost of window cleaning is reduced.
• Clear vision through your windows even when it is raining.
• Neutrality and transparency is the same for normal glass.
• Less frequent use of detergents helping to protect the environment.

SGG BIOCLEAN works by harnessing the power of UV rays and (rain) water to efficiently remove accumulated dirt and grime (dried water marks, atmospheric pollutants, dust, resin and insect residues) from the external surface of the glass.

More information can be found at: www.saint-gobain-glass.com

4.10 Paints & coatings

4.10.1 COL.9®

COL.9® is a high-tech product combining inorganic and organic chemistry. In the COL.9® binders, inorganic nanoparticles are homogeneously incorporated into organic polymer particles of water-based dispersions. The resulting nanocomposite dispersions combine the benefits of inorganic binders – such as hardness and permeability – with those of organic binders – such as elasticity and water resistance.

More information can be found at: www.functionalpolymers.basf.com

4.10.2 Sto Lotusan®

The Lotusan® exterior coating possesses a highly water-repellent surface similar to that of the lotus leaf. Its microstructure has been modeled on the lotus plant to minimize the contact area for water and dirt. The surface additionally offers enhanced hydrophobic properties. Water and dirt flow off immediately. The façade remains dry and attractive.

More information can be found at: www.stocorp.com/

4.11 Technical textiles

The term 'technical' textile refers to the development of new textiles and applications that have absolutely no connection with traditional clothing, bed and interior fabrics. New combinations of fibres and fibre materials and manufacturing technologies offer a number of new products and improved product performance. Examples are semi-manufactured products or textile components for car and aircraft interiors, the cable strap and conveyor belts, healthcare textiles, sports gear, paper, carpets and packaging, construction, even road building and hydraulics.

4.11.1 Smart textiles

A unique development in the textile branch is 'smart textiles'. Smart textiles can be divided into textiles with dynamic features and textiles combined with electronics. Dynamic textiles are, for instance, textiles for active thermoregulation (www.outlast.com), the controlled release of encapsulated substances (www.devan.net), and active bactericidal textile (www.x-static.com). The combination of textile and electronics will give an entirely new dimension to the concept of multifunctionality. Textile not only protects but also communicates with its surroundings. It enables people to monitor vital body functions continuously. Smart textiles will lead to new entrants to the textiles market. Philips is a major player in this area and is leading a large scale European research project in this field: MyHeart (http://www.hitech-projects.com/euprojects/myheart/). Smart textiles are intelligent products that provide for increased level of customer convenience, improved product performance and improved user performance.

4.12 Biomimetics material

Many environmentalists and researchers claim that millions of years of evolution have often created the most efficient and environmentally friendly ways to do things. Around the world, researchers are looking to nature for solutions to all sorts of problems.

What makes a material tough? The giant pink queen conch, for instance, has a beautiful shell that's extremely strong and hard to break. This mollusk's shell is made almost entirely aragonite—a form of calcium carbonate. Yet the conch shell is hundreds of times stronger than the mineral by itself.

Figure 8 A giant pink queen conch
(Case Western Reserve University Photography Laboratory)

It turns out that the shell owes it strength to protein molecules. These proteins form a web that surrounds the mineral crystals and holds them together. When you hit a conch shell, it doesn't split. Instead, the shell develops tiny cracks that spread the impact throughout the material. This keeps the shell from breaking. The scientists at Case Western Reserve University in Cleveland who made this discovery a few years ago and other researchers hope to use this information in their laboratories to make lightweight materials that are just as difficult to break.

The above is just one example, there is much more to learn, copy and apply.

5 Concluding remarks

In this report, multifunctional materials in general have been discussed mainly based on design and performance benefits. We have pointed out some interesting trends that are worth considering in the development of new components or products. We have also suggested a new way of classifying materials in order to facilitate new materials introduction into construction.
Traditionally in construction, we have basically used one material for one purpose. In order to be resource efficient, especially in building manufacturing, it is essential that the material in question is a multi-performing material. This means that we must be able to reduce part counts through the introduction of the new multifunctional material. This thought can be illustrated by a simple example, a composite column. A composite column consists of a steel tube filled with concrete. This basically means that the steel tube will carry the bending loads while the concrete carries the compressive loads. However, due to the composite action, a higher structural capacity can be achieved. But this is not enough. To become a high-performer, excelling in strength is not sufficient. Thus, we have to take into account other advantages. One such advantage is removing the need for fire protection. Normally, a steel column needs to be protected either by gypsum plates or by fire proof painting. Correctly done, there is no need for such precautions when using a composite column. Thus, we have been able to remove parts and many benefits are achieved regarding cost, production time, safety and health.

Appendix: Summary table

MATERIAL PROFILE	PRODUCT	MANUFACTURER	MATERIAL CATEGORISATION			
			SHAPE PERFORMANCE	OPTICAL PERFORMANCE	SUSTAINABLE PERFORMANCE	INTEGRATED PERFORMANCE
NATURAL MATERIALS	flexible wood sheet	www.onlyone-pro.com	TENNAGE		TENNAGE	
	formable veneer in 3D	www.reholz.de	3D-VENEER		3D-VENEER	
GLASS	3D glass fabric	www.parabeam3d.com	PARABEAM	PARABEAM		
	glass panel	www.galaxycustom.com	CRINKLE GLASS	CRINKLE GLASS		
	technical glass cylinder	www.scott.com	GLASS CYLINDERS	GLASS CYLINDERS		
	cellular glass	www.foamglass.com			FOAM GLASS	
	hydrophobic silica particle	www.cabot-corp.com		AEROGEL	AEROGEL	
	self-cleaning glass	www.saint-gobain-glass.com		AQUACLEAR		AQUACLEAR
	self-cleaning glass	www.saint-gobain-glass.com		SGG BIOCLEAN		SGG BIOCLEAN
CERAMIC	Macro- & micro-cellular p	www.msm.cam.ac.uk/gor	POROUS CERAMICS		POROUS CERAMICS	
	Ultra-high performance c	www.ductal.com			DUCTAL	DUCTAL
	Self-compacting concrete	www.lafargenorthamerica.com				AGILIA®
	Reducing organic & inorga	www.italcementigroup.com				TX ACTIVE®
METALS AND ALLOYS	punched sheet metal	www.formetal.de	FORMETAL®	FORMETAL®		
	stabilized aluminium foam	www.alusion.com	ALUSION AL. FOAM		ALUSION AL. FOAM	
	stainless steel cable	www.carlstahl.com	X-TEND	X-TEND	X-TEND	
	energy absorptive panels	www.cellbond.co.uk	PRESSLOAD		PRESSLOAD	
	metallic mesh	www.gkd.de	WOVEN WIRE MESH	WOVEN WIRE MESH		
	aluminum plate	www.fielitz.de	WEB PLATES		WEB PLATES	
	stainless steel plate	www.fielitz.de	STRUCTURAL PLATE		STRUCTURAL PLATE	
	aluminum superplastically	www.superform-aluminiun	SUPERFORM ALUMINUM		SUPERFORM ALUMINUM	
	metallic fabric	www.gkd.de	SHIMMER	SHIMMER		
	steel solid polyurethane s	www.ie-sps.com				SPS
POLYMERS	flexible honeycomb polym	www.supracor.com	FLEXIBLE HONEYCOMB	FLEXIBLE HONEYCOMB	FLEXIBLE HONEYCOMB	
	Honeycomb ship insulatio	www.nida-core.com/englis	NIDA-CORE STRUCTURAL HONEYCOMB		NIDA-CORE STRUCTURAL HC	NIDA-CORE STRUCTURAL HC
	flexible, reflective color fil	www.3M.com/about3M/technologies		3D RADIANT COLOR FILM		
	membrane	www.buitink-technology.com		PVC		
	polycarbonate resin	www.geplastics.com/resin	LEXAN	LEXAN		
	thermoplastic panel	www.bencore.it	BIRDWING® PANEL	BIRDWING® PANEL		
	polymers-LEP	www.olight.com		LIGHT EMITTING PANEL		
	transparent insulation, acr	www.advancedglazings.com		INSOLCORE™	INSOLCORE™	
	light diffusing & insulating	www.okalux.de		OKALUX	OKALUX	OKALUX
	membrane	www.buitink-technology.com		ETFE MEMBRANE	ETFE MEMBRANE	
	optical light film	www.3M.com/about3M/technologies		3M OPTICAL LIGHT	3M OPTICAL LIGHT	3M OPTICAL LIGHT
	subsurface drainage matt	www.colbond.com	ENKARDIN®			ENKARDIN®
	polyurethane	www.eurogomma.net			EURO-ST SCREEN SYSTEM	EURO-ST SCREEN SYSTEM
	polyurethane-based gel	www.technogel.it		TECHNOGEL		
	view control film	www.madico.com		LUMISTY		
	visco-elastic material	www.tempur.com				
	New wax-filled heat-storage	www.basf.com/corporate/(	MICRONAL® PCM		MICRONAL® PCM	MICRONAL® PCM

FIBRES	3D net sheets	www.mayser.de	3D-TEX®	3D-TEX®		3D-TEX®
	nonwoven spunbonded te	www.reemay.com		REEMAY® SPUNBONDED		REEMAY® SPUNBONDED
	continuous fiber aluminum	www.3M.com/about3M/technologies			CFAMC	
	textile	www.cubenfiber.com		CUBEN FIBER	CUBEN FIBER	CUBEN FIBER
	high performance lamina	www.bainbridgeint.com		DIAX-LSP	DIAX-LSP	DIAX-LSP
	carbon fiber fabric	**na**		TRIAXIAL FABRIC	TRIAXIAL FABRIC	TRIAXIAL FABRIC
	carbon\glass fabric	www.pidgi.com			CARBON\GLASS	CARBON\GLASS
COMPOSITES	sandwich element	www.mtm.kuleuven.ac.be	FOLDHEX HONEYCOMB		FOLDHEX HONEYCOMB	
	mouldable honeycomb sh	www.nuovopovero.com	YST	YST		
	laminate panels	www.e-panelite.com		MICA LAMINATES		
	tubular polycarbonate hon	www.e-panelite.com	PANELITE IGU	PANELITE IGU		
	light transmitting concrete	www.litracon.com		LITRACON		LITRACON
	glass-aluminium honeyco	www.cellbond.co.uk	B-CLEAR GLASS	B-CLEAR GLASS		B-CLEAR GLASS
	metal composite	www.sibu.at				SIBU MULTI-STYLE
	fiber-reinforced composite	www.fyfeco.com			TYFO FIBRWRAP	TYFO FIBRWRAP
	fiber-reinforced plastics, c	www.spsystem.com	FRP		FRP	FRP
	composite of aluminium tr	www.dupont.com/corian				CORIAN
	woven optical fiber	www.luminex.it		LUMINEX		
	liquid crystals	www.lcr-uk.com		RE LIQUID CRYSTAL SHEET		
	fabric (NiTi wires)	www.marielleleenders.cor	SHAPE MEMORY TEXTILE			
	sound system integrated (	www.glas-platz.de/index.html		GLASS SOUND		GLASS SOUND
	display system integrated	www.glas-platz.de/index.html				GLASS DISPLAY
	LED system inegrated on	www.glas-platz.de/index.html		POWER GLASS		POWER GLASS
	phase changing materials	www.outlast.com			OUTLAST	
	Plasterboard	www.functionalpolymers.basf.com				