MATERIALS

Vision 2030 & Strategic Research Agenda
Focus Area Materials
Version 1

September 02, 2005

European Construction Technology Platform (ECTP)
www.ectp.org
# TABLE OF CONTENTS

1 EXECUTIVE SUMMARY ................................................................. 4
2 INTRODUCTION ................................................................................. 5
3 VISION ............................................................................................... 7
4 BACKGROUND, PRESENT SITUATION & FUTURE CHALLENGES .............................................................................................................. 8
  4.1 Production of building materials ........................................................ 15
  4.2 Application of building materials ......................................................... 17
  4.3 Use phase ......................................................................................... 18
    4.3.1 Structural function ....................................................................... 18
    4.3.2 Aesthetic function ....................................................................... 19
    4.3.3 Resource efficiency ...................................................................... 20
    4.3.4 Health, hygiene and safety ............................................................. 21
  4.4 Demolition, re-use & recycling .......................................................... 22
  4.5 New advanced functionalities ............................................................ 23
5 STRATEGIC RESEARCH AGENDA ....................................................... 24
  5.1 Reduce the environmental impact of building material production and demolition ............................................................................................................. 24
    5.1.1 Introduction .................................................................................. 24
    5.1.2 Research areas ............................................................................. 24
    5.1.3 Targets for 2030 and Key Performance Indicators ......................... 25
  5.2 Improve predictability and efficiency of building material production processes ............................................................................................................. 25
    5.2.1 Introduction .................................................................................. 25
    5.2.2 Research areas ............................................................................. 26
    5.2.3 Targets for 2030 and Key Performance Indicators ......................... 26
  5.3 Improve resource efficiency of buildings and infrastructure in use through improved materials ............................................................................................................. 27
    5.3.1 Introduction .................................................................................. 27
    5.3.2 Research areas ............................................................................. 27
    5.3.3 Targets for 2030 and Key Performance Indicators ......................... 27
  5.4 Reduce lifecycle costs of building materials ........................................ 28
    5.4.1 Introduction .................................................................................. 28
    5.4.2 Research areas ............................................................................. 29
    5.4.3 Targets for 2030 and Key Performance Indicators ......................... 29
  5.5 Improve comfort of living (health, hygiene & aesthetics) ..................... 30
    5.5.1 Introduction .................................................................................. 30
    5.5.2 Research areas ............................................................................. 30
    5.5.3 Targets for 2030 and Key Performance Indicators ......................... 31
5.6 Improve working conditions in production and construction (ease of application and maintenance, workers safety) ........................................... 32
  5.6.1 Introduction ............................................................................................................... 32
  5.6.2 Research areas .......................................................................................................... 32
  5.6.3 Targets for 2030 and Key Performance Indicators .................................................... 33
5.7 Develop new, multi-functional knowledge-based materials and construction systems adjusted to customer needs ........................................... 33
  5.7.1 Introduction ............................................................................................................... 33
  5.7.2 Research areas .......................................................................................................... 34
  5.7.3 Targets for 2030 and Key Performance Indicators .................................................... 34
6 ORGANISATION .................................................................................................................. 35
  6.1 Organisation chart of the Focus Area Materials ............................................................ 35
  6.2 Leadership .................................................................................................................... 35
  6.3 Core team ..................................................................................................................... 35
  6.4 Working groups ............................................................................................................ 36
    6.4.1 Ceramics .................................................................................................................... 36
    6.4.2 Composites .............................................................................................................. 36
    6.4.3 Cementitious ............................................................................................................. 37
    6.4.4 Natural Stone .......................................................................................................... 37
    6.4.5 Wood Products ........................................................................................................ 37
    6.4.6 Other materials ....................................................................................................... 37
  6.5 Membership (all colleagues not mentioned in WGs or as contact persons) ....................... 38
7 IMPLEMENTATION PLAN ........................................................................................................ 40
  7.1 Actions ............................................................................................................................ 40
  7.2 Calendar .......................................................................................................................... 40
  7.3 Financial aspects ............................................................................................................. 40
1 EXECUTIVE SUMMARY

Building materials form the basis of any kind of construction. They determine the foundation, the structural strength and aesthetic expression of constructions and thus provide safety and comfort for all members of society. Due to the volumes needed, the construction sector is the largest raw material consuming industry. In Europe, the volume of building materials used exceeds two billion tons per year. At the same time, the properties and combinations of materials also determine the energy demand of buildings, thus further increasing their environmental significance. This demonstrates that even small improvements in the environmental performance of building materials would have a huge overall beneficial impact.

Today about 50 % of all construction costs are devoted to maintenance, repair and rehabilitation. Improvements in functional durability would therefore have significant economical relevance.

Against this background this paper describes the main challenges and opportunities the European building materials sector faces. Successful answers to these challenges will help the industry to maintain and strengthen its leading position in the global market place.

The current situation and main challenges are systematically analysed according to the life cycle of building materials: ranging from the production phase (energy and raw material demand, emissions), application (automation, safety) and the use phase (structural and aesthetic function, comfort, resource efficiency) through to the demolition phase, material recovery and/or safe disposal.

Based on this analysis, the following Vision 2030 has been developed:

*European building materials producers are recognized worldwide as innovative and competitive companies. They develop knowledge-based materials and applications with predictable and multi-functional characteristics. Their tailor-made products create a comfortable living environment and serve the customers’ needs while minimizing environmental impact throughout their entire lifecycle. The result is a leading position of European building materials producers and the construction sector on the global market place and an industry that attracts and employs well-educated people.*

To live up to this Vision, the group of important producers that gathered in this initiative developed a common set of main objectives addressing the main challenges and opportunities. Based on these objectives, clear targets are defined and a Strategic Research Agenda is proposed.

To achieve the targets and objectives, considerable efforts in R&D are required. Today, R&D expenditure of building materials producers typically ranges from 0.5 % to 1.5 % of turnover, thus being far from the European Council target of 3 % (Barcelona 2002). Increasing this figure in joint initiatives to overcome the fragmentation of industry and research leveraged by public support on EU and national level is therefore necessary to achieve the Vision and strengthen the competitiveness of the European construction industry.
2 INTRODUCTION

For any kind of construction, building materials are needed. The total amount of materials required 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.

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.

Building materials also have a major economic impact on society because of the large investments in buildings, structures and infrastructure and because they need to be maintained and repaired. Thus the construction industry accounts for approximately 10 % of EU GDP. Wear and durability issues necessitating repair of roads, buildings, water networks etc. cause major disruption with large associated costs. Today, some 40 – 60 % of the costs of construction go on repairs and maintenance. Over the long-term, knowledge generation and better use of building materials can impact beneficially on all these 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.

Thus, any strategy to achieve economic, ecological and social objectives within Europe must include measures to improve functionality, durability and efficiency of materials used for construction.

The European building materials industry includes many innovative companies, which, in many cases, control a large part of the world production and are the leading companies in the global market place. This underlines the high competitiveness of the European building materials industry. On the other hand, there are many locally based small and medium sized companies where the R&D capacities are relatively small.

In general, the resources spent on R&D are relatively small. There is an urgent need to raise R&D budgets in order to keep Europe’s leading role in this field and not to fall behind the challenging competition of other economic regions (e.g. China and Japan) making great efforts in building material research. There is also a need to increase competitiveness and innovation in Europe’s many small and medium sized companies.
The potential of creating technical breakthroughs to the benefit of the construction industry and society and to increase competitiveness of the industry is huge. In addition, it is expected that new, innovative companies will start up.

It is essential that R&D is invested in a fundamental understanding of traditional materials in order to be able to exploit their opportunities and to develop new materials. Interdisciplinary, generic research which can be applied for several building materials involving technology traditionally related to other fields, such as nano-technology, biotechnology, information technology and vision technology, will increase the chances for innovative breakthroughs.

The scope of the FA Materials has been intensively discussed to avoid duplication of work carried out in the vertical FAs. It should thus support the activities in the vertical FAs and fulfil their material related R&D needs. The development of material applications on the other hand should be dealt with in the vertical Focus Areas. Therefore, a good integration into the other FAs is mandatory to ensure a good flow of information.
3 VISION

European building materials producers are recognized worldwide as innovative and competitive companies. They develop knowledge-based materials and applications with predictable and multi-functional characteristics. Their tailor-made products create a comfortable living environment and serve the customers’ needs while minimizing environmental impact throughout their entire lifecycle. The result is a leading position of European building materials producers and the construction sector on the global market place and an industry that attracts and employs well-educated people.

To live up to this Vision, the following main objectives need to be accomplished:

– Reduce the environmental impact of building material production and of demolition
– Improve the predictability and efficiency of building material production processes
– Improve the resource efficiency of buildings and infrastructure in use through improved materials, tailored to the specific application
– Reduce lifecycle costs for building materials
– Improve comfort of living (health, hygiene, safety and aesthetics)
– Improve working conditions in production and construction (ease of application and maintenance, workers’ safety)
– Develop new, multi-functional, knowledge-based materials and construction systems adjusted to customer needs.
4 BACKGROUND, PRESENT SITUATION & FUTURE CHALLENGES

Development of new materials and improvement of traditional materials is one of the key aspects to achieve new developments in the construction sector.

Improvements in construction materials are needed to respond to the increasing demands of society. According to Den Dover, MEP (E-CORE Brussels Conference): “Overall European citizens want better services and products (for them and society in general) along with improved sustainability”. Better products will require materials with enhanced durability and performance with lower maintenance.

A second driver for change is the “Göteborg Objective” (2001). It puts sustainable development at the top of the agenda of all EU activities. This objective has multiple implications. On the one hand, it will need more efficient processes in terms of resource consumption (energy, water and raw materials). On the other hand, a better performance, in terms of property to mass ratio, will lead to a de-materialisation of some construction components, resulting in a reduction of materials use. Another contribution to sustainability will be the result of the increased durability of materials and their specific design for service conditions or purpose, avoiding early replacement and associated costs.

The third driver is the “Lisbon Objective” (2000), that is “to help Europe become the most dynamic and most competitive knowledge-based economy within 10 years”. The full development of multi-scale modelling, feed-back monitoring systems and simulation will play a key role on the achievement of new intelligent “demand oriented” materials and will be the way to achieve full computational materials design. The processing and synthesis of materials could be deeply transformed through the new knowledge application. Materials would be tested with new analytical tools, precision and control instruments. The new situation on materials design, production and integration on construction systems and components will be a major change from an intensive resources consumption activity towards a knowledge-based one.

A wide variety of materials are used in the construction sector. Most of them are represented in this initiative either via direct participation (ceramics, cement, aggregates, concrete, composites, natural stone) or through contact points to other Focus Areas and ETPs (wood, steel, glass).

Before discussing the status, challenges and opportunities of building materials throughout their lifecycle, this introductory part highlights the economic relevance and global competitiveness of European producers.
Ceramic products

Ceramic tiles are the most important ceramic product in terms of production and turnover. The European Union is the worldwide leader in ceramic tile products manufacturing in terms of design, quality, internationalisation, and added value of the products, while China is world leader in production volume with almost 2.000 million m² produced in 2003. The Italian and Spanish companies are also world leaders in ceramic products manufacturing with 1.200 million m², but there are excellent representatives in other European countries too. It is estimated that, in the year 2003, world production reached around 64.000 million m².

In order to have a better perspective on the economic importance of this sector, it is worth pointing out that the EU market value of ceramic products is estimated at approximately 10.000 M€ for the year 2003. The above figures clearly show the importance of this market in the EU, which accounts for 52 % of total world turnover. On the other hand, the projected figures for the year 2015 point to a more pessimistic overall situation with Europe’s share dropping dramatically to less than 40 %.

The existing dynamism of the world economy could upset the favourable position of European ceramic companies facing the threat of Asian competitors, which have broken strongly into the global market, due to their lower cost of workers or to their less strict environmental laws. These unfair trade advantages may at times be seen as dishonest competition. Countries like China or even Brazil or Mexico are, or will be, in this situation.

In order to maintain leadership in the future, particularly given the ever growing competition from China, it is necessary that ceramic products come to incorporate completely new features. In this way, by the year 2015, a completely novel ceramic product concept should be ready for introduction into homes on a large scale. This concept should also become the better option from the perspective of the integrated constructive solution.

Ceramic products also include bricks, roofing tiles and sanitary ware.

The brick and roofing tile industry enjoys a special status within the ceramic sector: its markets are regionally limited. The price per ton of the product prohibits long transport distances, so that export or import figures are usually marginal. The main markets are governed mostly by climatic factors, but also by tradition. As a consequence, Europe still occupies the world leader position with a production around 11 billion Euro (about 45 % of the world market), with Italy, Spain and Germany in top positions. For roofing tiles, the total production from Europe is around 200 million m².

The sanitary ware industry doubled turnover between 1990 and 2002. However, worldwide profits of 8 billion Euro only make up 6.3 % of the entire turnover in ceramics, which means that the sanitary ware sector is the sector with the least turnover volume. Europe produces around 30 % of the world production, while China alone covers more than 20 %.
**Composite materials**

Composite materials are the combination of high-strength and -stiffness structural fibres with light-weight and environmentally resistant polymers. This type of material has much better mechanical and durability properties than either of the constituents alone.

The use of composite materials in construction is a market with a great potential in the next 10 years, where growth rates of more than 500 % with respect to the current market are expected. The worldwide market value is expected to grow from 268 million US dollar to 1.4 billion by 2010. These composites are typically combinations of high-strength fibres and resin matrices, offering significant benefits in terms of strength, stiffness, weight and service life performance. Glass fibres will see the greatest growth followed by carbon fibres. Unsaturated polyester (UPR), vinyl ester and epoxy resin will be big winners, too. Composite materials are also able to meet diverse design requirements with high strength-to-weight ratios.

In the global composite materials market, construction constitutes:

- the second largest use sector in the USA and Japan,
- the fourth largest use sector in Europe.

In the year 2000, the construction sector in the USA used 720 tons of composite materials, 280 tons in the rehabilitation of buildings and infrastructure (36 M€) and 120 tons in industrial structures (14 M€). In Europe, the total was 240 tons, with 80 tons (9.5 M€) in rehabilitation and 20 tons in industrial structures (2.4 M€).

Due to the increase in research and the success of demonstrative projects realized in the last years, composites are now achieving wider acceptance in the construction industry around the world.

Whereas research on the use of advanced composites in construction has demonstrated an enormous potential, there is a distinct gap between the available expertise and the industrial implementation. This lack of integration is a drawback for both the construction and composites industry, which both consist, to a large extent, of SMEs, a driving force of the European market. Moreover, given the available expertise, European competition in the global market in this innovative field is lagging far behind.

“The future is in composites” is the realization of many decades of high-technology progress towards different materials and parts assembled and combined as monolithic units that would provide a combination of versatility, strength and other properties.
Cement-based materials

Concrete and other cementitious materials are also composite materials, however, due to their market importance and the applied volumes, they are treated separately in this focus area.

The term “cement” can be traced back to the Romans, who used a concrete-like brickwork containing burned lime and called it “opus caementitium”. Later on, cement was known as a mixture of burned lime and brick meal or volcanic tuff, which formed a hydraulic binder. This means an inorganic, non-metallic, finely ground material, which is self-hardening after mixing with water and remains solid under exposure to air as well as under water. The development of modern cements started in the 19th century in England, France and Germany. Their further modification and the potential for industrial production consequently resulted in an incomparable success story of cement as well as of the building material concrete produced from it, which made it the most used building material in the world.

Yearly production worldwide is currently around 1.9 billion tons of cement per year, of which about 250 million tons per year is produced in Europe. These are used to produce around 750 million m³ of concrete, equivalent to a yearly consumption of around 1.7 m³ concrete or around 4 tons per EU citizen.

Concrete and cement are indispensable building materials for domestic construction and infrastructure. The essential push for this development was essentially the work of European researchers. This resulted in a continuous improvement of the classical Portland cement quality, the development of numerous other cement types having special properties and, last but not least, in the optimisation of the production process.

Cement is the most important raw material for producing concrete. However, aggregates account for about 70% of the total volume in concrete and is, by volume, an important raw material. Aggregates are used for a range of different application fields and are by far the most used material worldwide, second only to water. There is a constant need for aggregates, both for repair of existing structures and for new construction work. In the past, aggregates have been quarried from natural resources, however an increasing amount is coming from crushed rock and from secondary raw material, demolition waste and material recovered during road repairs. The industry is facing large challenges. It produces noise and dust, sites are often unsightly, changes to land are non-reversible and high volumes of lorry traffic are associated with the industry. New quarry applications are rejected on the grounds of various environmental issues and in some countries existing quarries only get a few years permit at a time.

The leading role in product development and production efficiency also led to a dominant role for European companies. While the EU only accounts for around 12% of the 1.9 billion tons of cement produced worldwide, European companies control about one third of world production. 4 out of 5 of the leading cement producers in the world are based in Europe.
Steel

The European steel industry produces approximately 160 million tons of crude steel, i.e. about 16% of world steel production, and employs 260,000 people. Global consumption of steel in construction is estimated at 300 million tons per year, i.e. equivalent to an average of 44 kg per capita. The construction sector is the largest single market for most European steel companies, providing between 25 and 40% of sales volume, and growth is expected to approach 5% per annum over the next decade. Construction is however highly fragmented and there is a need for much closer cooperation between leading suppliers and major construction companies. A key aspect of the steel industry strategic plan over the coming 30 years is therefore to work more closely with customers seeking technical and commercial alliances. Ability to re-use or recycle at the end of service life is another important issue. Steel is 100% recyclable and because of its unique magnetic properties can it be easily separated from other materials.

Aluminium

The European aluminium industry annually produces some 5 million tonnes of primary aluminium and recycles close to 4 million tonnes.

The construction sector is the largest market for rolled and extruded semi-products and the second largest market for aluminium products in general, totalling around 2.5 million tonnes per annum. The use of aluminium in buildings and construction has kept growing over last years in spite of the decline of the sector as a whole. Due to its high intrinsic scrap value, both from a technical and economical point of view, aluminium is collected with a documented rate exceeding 90% from end-of life buildings, and is then fully recycled. Recycled aluminium retains the properties of the primary metal and saves 95% of the energy required for the production of the same amount of primary aluminium.

Glass

Glass is one of the oldest manmade materials. The European glass industry produces approximately 30 million tons and employs more than 200,000 people. Glass is actually used in construction as flat glass (e.g. double glazed units), reinforcement fibreglass for composites and glass wool insulation material. Main world manufacturers are European and export is an important part of the activity. Innovation and research are necessary to add new, multifunctional properties to the basic material in order to maintain the leading position of the industry.

Natural stone

Natural stones are extensively used for both construction and decoration purposes, significantly contributing to the improvement of human life quality, culture and prosperity. Due to their superior technical and aesthetic properties there is a steadily increasing market demand for high-quality stone construction and decorative materials.

The world stone production increased by 218% since 1986, rising from 275 million m² to 880 million m² that is today. Stone market statistics estimate an increase of about 100% in the market demand of finished stone products until 2015, which corresponds to 1.6 billion m², while the increase will reach 400% until 2025.
A considerable part (approximately 35 %) of the total world stone production is attributed to the EU countries, representing a market of about 20 billion €. Italy, Greece, Spain and Portugal hold 81 % of the EU stone production. Nowadays, more than 60.000 companies, mainly SMEs, are linked to the stone sector in Europe, employing more than 500.000 people. Moreover, the European stone equipment sector has a leading position in the world market (66 %).

However, recent figures of the world stone trade show that the market share of the EU countries is decreasing steadily in favour of relatively new stone producing countries (China, Brazil, Turkey, India, etc.) and it may decrease from 35 % that is today to 7 % in 2025 if no action is taken. The consequence is that EU will lose an income of about 8 to 11 billion € annually and even more because the consumption of natural stone is expected to increase in the future.

The European stone sector is a technologically underdeveloped sector requiring strong modernisation. The SMEs are widely dispersed all over Europe with difficult access to recent technological developments. Due to the nature of the stone sector certain activities of the production are characterised by a high accident rate and increased problems associated with working conditions (noise, vibrations).

The main challenges include the very low efficiency and productivity, the huge amount of waste produced and disposed in the environment and the significant fluctuations in the quality and performance during application in construction of the final stone products.

**Wood**

The forestry and the forest industry are important sectors for many EU countries. Forests cover about one third of Europe’s land area with big variations between countries from 71 % in Finland and 1 % in Cyprus. The enlargement of the EU is of specific importance to the forest-based sector. The forests in the new member states amount to around one quarter of the forests in Europe.

The forest-based industry is one of the biggest industrial sectors in Europe with an annual production value in the EU 25 of some 550.00 to 600.000 M€, accounting for approximately 8 % of the total value added in Europe. Together with forest resources management the forest-based sector provides up to 4 million jobs in Europe, to a large extent in rural areas and SMEs.

The woodworking industry is an important business sector accounting for almost 150.000 M€ in sales and employing 1.6 million people in Europe in 2001. The most prominent sub-sector is the furniture industry followed by building components (e.g. windows, doors, flooring, trusses, etc.), sawing, planning and impregnating, wood-based panels and packaging. A very significant share, roughly 25 %, of the European forest-based raw material ends up in the construction industry. Of all saw mill production 70 to 80 % is used in building construction or related end uses.

The research for this part of the sector is mainly organised and run at universities and institutes, financed partly by the industry and partly by national public programmes or EU Framework Programmes. InnovaWood is a network of 85 organisations from institutes and universities in 20 European countries involved in education and training, research and knowledge transfer.
**Need of R&D**

To defend the leading role of the European building materials sector against strongly growing competition (mainly China, Japan, America) huge efforts in R&D and productivity are required. And there are many possibilities for improvement.

Several of these possibilities are common to all materials. Among them are new design and the development and application of new materials in both new and existing constructions, with a view to:

- Enable easy installation, maintenance and monitoring 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 upgrading (e.g. repair/strengthening).
- 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 (e.g. self-compacting concrete tolerant to mix design adjustments, new forms of composites by combining organic fibres with inorganic, e.g. cement-based matrices, customised long span steel systems with high strength and stiffness and inherent fire resistance).
- Sensing capabilities.
- Multi-functionality, e.g. self-curing and self-repair concrete, composites combined with optical fibres, new advanced coatings for e.g. steel products.

They should be the outcome of an optimisation process at the materials level (materials by combination to maximize performance).

The critical aspects to consider in materials developments are described below. The challenge is to obtain high performance materials for each and also highly balanced materials in most of the aspects considered since they are closely related.

Apart from the use of the above-mentioned “basic materials” on their own or in rather conventional combinations (e.g. cement with aggregates), a variety of material combinations is possible (e.g. cement may be combined with polymers, advanced fibres may be included in a cementitious matrix etc.). The optimal combination of materials in construction and the proper understanding of properties in products where materials are used in combination with each other remains a challenge. However, the potential to develop new materials that meet these requirements is well worth the effort.

In the following background information, including the present situation and future challenges are described under five different sub-titles indicating different life cycle phases of building materials. The descriptions are general and valid for all building materials, however attention must be paid to the fact that the situation/relevance of the various aspects might differ from material to material and so do the research needs.
4.1 Production of building materials

The production process of most building materials, such as glass, steel, cement, composite materials and ceramics, requires high amounts of energy and, together with that, gives rise to CO₂ and other emissions. The reduction of raw material consumption, energy demand and emissions in the production of building materials is thus of primary importance. Simultaneously, the product performance and economic efficiency of the production process needs to be improved.

A lot of progress has already been made by optimising processes and utilizing alternative raw materials and fuels. As an example, the EU cement industry today utilizes more than 31 million tons of secondary raw materials and fuels. However, due to the high volume of material produced (e.g. cement production today is accountable for around 5 % of the anthropogenic CO₂ emissions) the cement and concrete industry still faces a number of environmental challenges. Even slight progress in production processes means significant steps in improving environmental impact.

Despite the considerable progress, there is still a big potential for further enhancing the environmentally beneficial properties of concrete, e.g. by increasingly replacing Portland cement clinker with substitution products such as slag, fly ash or limestone. However, significant research activities are still required to optimise such substitution to achieve similar or even better performance.

On the other hand, the production process for aggregates, natural stone and concrete has not developed for many years. There is a large potential if labour-intensive manual lay-up can be changed to automated manufacturing methods including the use of intelligent feedback monitoring systems and robotic technology. Innovations such as automated lay-up of reinforcement in contoured tools with close conformance have reduced manual labour by about 70 %. Developments in automated integration of the pre-form fabrication and moulding make already available technologies more desirable from the standpoint of economics and productivity. Furthermore, this will lead to possibilities of producing individually designed building components to the benefit of more interesting architecture.

The production of composite materials has to be improved. High-performance composite processing is still done by hand. To achieve a complete inclusion of these materials to develop structural functions it is needed to process composite parts into a mass market, which requires highly automated processing methods with high productivity and cost reductions.
Steel productivity, in terms of tons produced per person, has improved continuously year on year. Indeed over the past twenty years productivity has increased by a factor of three. The industry in Europe ranks among the best in the world in terms of manufacturing excellence and product quality.

Innovations envisaged over the coming years stem from a very strong focus on even lower production costs coupled with product and system innovations, so creating greater value for our customers in the construction sector. Fully integrated (in terms of services and inherent fire resistance) building systems will be developed that offer huge benefits in terms of construction depth and spanning capability. Highly innovative facades and roof systems using new insulation technologies and smart construction processes including extensive prefabrication will be developed and tailored to all building types.

New processes will be required that offer greater integration and flexibility than existing methods. Process lines that are more compact with short response times and extended capability are currently being investigated. The new EU REACH regulation is also considered to have an impact on the innovation in the production of building materials.

Innovations are also foreseen in the preparation of a site for building. When succeeding in adapting the properties of the local soil, and to fit them with the requirements of the construction, then no removal of soil and replenishment with other material is needed. Recent advances in nano-technology, bio-technology, modelling, analytical techniques and other technologies have shown the potential of creating such a breakthrough.

Although production of timber for construction needs very little (external) energy, the processes can still be enhanced from an energy point of view. For the development of new wood-based composites it is very important not to increase the total use of energy, i.e. more energy for production has to be regained during lifetime use.

Due to the continuous drive for optimisation of efficiency and energy consumption in the production process a strong equipment supplier industry has also developed in Europe. In many areas (cement, ceramics, steel, composites etc.) European equipment suppliers for production technology are in world leading positions. For example, most machinery manufacturers for any kind of ceramic product are European; they act worldwide with almost no competition at present, thanks to the technological synergy with European ceramic manufacturers.

During recent years, machinery manufacturers have played an important role in the innovation of ceramic products, by bringing important modifications from the point of view of the production process, decorating technologies and finishing technologies. Innovative measurement and control systems will be of great importance for future manufacturing; in principle, industry expects to further reduce man power for production, using it instead for product design; digital technologies will be very helpful in this respect. Therefore, the combined research performed by ceramic producers and machinery suppliers is an opportunity to generate cost-effective breakthrough innovations in the sector, thereby drastically modifying the production processes in terms of efficiency, energy consumption and the potential of obtaining completely new functions and properties. The same certainly also applies to other building materials such as cement.
Strengthening the close cooperation between the equipment supplier industry and the materials producers therefore presents the opportunity of maintaining and further developing Europe’s leading role in the production technology of building materials.

4.2 Application of building materials

Many of the traditional building materials currently used are not optimal in terms of applicability in that specific design, manufacturing, installation, and recycling criteria limit the wider use of these materials. In addition, health and safety issues are of increasing importance and have to be taken into consideration during the whole life cycle of building materials.

Efficiency of the construction process is of major concern to the industry. Indeed significant improvements in this area are necessary before many new, innovative technologies can be taken up and implemented within construction in a cost effective way. Factory production of elements, components and complete building systems (e.g. prefabricated beams, wall and floor panels, modules and other volumetrics) is therefore considered to be vitally important to the future of the sector.

One of the root causes for not fully exploiting the potential of building materials is that the design process is not focused enough on such aspects as multiple use, ease of use, ergonomics, safety, and the dismantling or demolition processes. Standards and building codes in many cases hamper innovation and the introduction of new materials and construction processes. A change towards a performance-based concept is expected to overcome these barriers.

Many of these aspects are not adequately and proactively dealt with in the construction industry, which creates the perception of the construction industry being “low-tech” and not able to meet state-of-the-art standards of other sectors and industries, e.g. consumer industry (electronics, cars etc).

The fabrication of composite structures and products including concrete and aggregates is evolving from labour intensive manual lay-up to automated manufacturing methods, including use of intelligent feedback monitoring systems and robotic technology. Innovations such as automated lay up of reinforcement in contoured tools with close conformance have reduced manual labour by about 70 %. Developments in automated integration of the pre-form fabrication and moulding make already available technologies more desirable from the standpoint of economics and productivity.

Ease of application and use must be considered in a broad sense respecting the interests of all stakeholders in order to cover topics related to materials design, production and integration of components into construction systems. This process needs to have a strong focus on end user demands, as it will be decisive for the selection of one material or another for a particular function.
Applicability and ease of use are therefore essential prerequisites to increase acceptance and improve the overall life cycle of a building. It is a major challenge to increase significantly the current possibilities of application and use of building materials and apply the concept along the whole value chain of the construction industry eventually improving quality of life of all stakeholders. In addition also new technologies for inspecting materials in situ with no intrusivity should be developed for quality control.

In other words, new materials developed should simplify application and use in such a way that they do not increase the complexity of above-mentioned processes but simplify the life of the end user who will live, work and travel in buildings made with such materials.

Also safety is a serious concern for the construction industry where work-related injuries and deaths are significantly greater than in most other industries. It is estimated that moving 80 % of outdoor construction site activities into controlled factory environments would result in a radical reduction in the number of workers seriously injured or killed by a factor of 10 and 20 respectively. A much greater use of off-site factory production techniques is therefore envisaged over the coming years. Improved chemical and physical properties of building materials and minimization/avoidance of hazardous substances in the materials flow chain can also contribute to a healthier and safer working environment.

4.3 Use phase

4.3.1 Structural function

The structural function is usually the prime function of construction materials, but many challenges are still to be faced to optimise the structural performances in combination with other functions. Developed regions including the EU must enhance their infrastructure and also renew and repair under-performing structures. Being subject to wear necessitates repair and maintenance of roads, buildings, water network etc. and causes major disruption with large costs associated. Over the long-term, knowledge generation and better use of building materials can impact beneficially all these areas of our daily life. Today some 40 – 60 % of the costs of construction are for repairs and maintenance. The cost of failures in soil, road and hydraulic engineering and in commercial and industrial building amounts to about 25 % of the total costs. Half of it is related to the subsoil. Therefore, soil as an industrial material will have an impact on cost reduction. A pronounced example is the circumstances in areas where thick layers of peat and soft clays are present. The strength of these soils is sometimes too low to even bear the road materials. Such areas are common in regions like the Po area in Italy, the Donau area in Central Europe, the deltaic area of the rivers Meuse and Rhine in Belgium and the Netherlands and the deltaic area of the river Elbe in Germany.

Recent advances in nano-technology, bio-technology, modelling, analytical techniques and other technologies have the potential of creating breakthroughs in production processes and in adapting the properties of building materials to the requirements of the construction.
Therefore the most important structural functions to be optimised are:

- Economic and environmental impact in use and through improved durability
- Materials tailor-made for their specified structural function including producing low quality materials when this is required
- More cost effective safety of structures
- To improve durability of structural function
- New materials (and new combinations of improved materials) matching new structural requirements (e.g. compromise between weight and structural resistance)
- New monitoring and measurement techniques for structural diagnostics in place
- In composite materials, careful selection of individual materials enables finished product characteristics to be tailored to almost any specific engineering requirement. Current design in the construction sector however is a hurdle to the optimal use of the capacity of composite materials.

### 4.3.2 Aesthetic function

For thousands of years, architecture has combined artistic expression with functionality, as seen in our cultural heritage. The material's visual appearance, its tactile properties and its ability to be formed into desired structures are the key parameters affecting choice of materials, design possibilities and quality of the built environment for the user. The importance of the material's aesthetic properties cannot be overestimated as a design factor even though it is a subjective design criterion.

An important way of improving the built environment for the user, and hence improve quality of life, is to create aesthetically pleasing buildings and structures in a cost-effective and durable manner. As a result the coating of manufactured products is a high value-added process enhancing the aesthetic appeal of colour and finish as well as contributing to wear resistance and durability. Coatings can be deposited by a variety of techniques (thermal spraying, CVD, PVD, …) depending on the material and application of interest. The main objective is the characterisation of structural, physical and mechanical properties of the coatings, and the relationship of these with substrate surface treatments and deposition conditions. The deposited coatings are used as reaction barriers, overlay coatings and as adhesion layers for subsequent coatings applied by other means.

In order to achieve this, materials with new aesthetic properties and combinations of materials, such as composite materials, coatings and finishes have to be developed. This could be innovation leading to new, durable surface textures or new possibilities of shaping bold structures or construction elements. Industrialised construction methods must be developed to enable high-quality structures to be constructed in a cost-effective manner. It could also lead to materials which interact with their surroundings, e.g. by changing colour, form or texture. It could also lead to materials that retain their aesthetic properties throughout the life through, for example, resistance to UV degradation or to saltwater exposure.
While physical durability and ways to improve and maintain this has been a natural part of the building materials sector development for years, the aesthetic durability aspect has only recently come into focus in the building community.

Typically, aesthetic durability was seen as a matter for the building owner to consider. Some owners however do not want to use resources on aesthetic maintenance, with the effect that the building appearance is allowed to degrade.

Recently, individual materials groups have begun developing materials with improved aesthetic properties, like self-cleaning glass, ceramics and paint products, or concrete and masonry products with hydrophobic treatments. Even so, the aesthetic aspect is still only a secondary issue in the planning of most building projects.

The resulting situation is that, for most constructions, the appearance is either left to deteriorate or excessive resources must be employed in the maintenance during the service life period.

4.3.3 Resource efficiency

World resources are limited and materials for construction should limit their impact on them. In the next decades, an answer is needed on the shortage of water, energy, and of many raw materials resources; e.g. around 42 % of all energy used is needed for the heating and lighting of buildings.

New products and systems are therefore required that actively and passively reduce energy consumption of buildings including air and water cooling/heating technologies, integrated solar-thermal systems, intelligent building envelopes (facades and roofs) and super-insulated cladding systems.

New assessment and predictive tools are needed to accurately model/simulate building environments, predict energy performance and so enable innovative and cost effective solutions to be specified.

The actual situation, different for each material, is that the issue of available resources has really started to be a priority. Optimization of resource efficiency should consider the whole life of the product. For example, higher energy consumption during production can lead to energy savings during use.

The main resources to be considered are energy and water. However, other natural resources like stone production are in focus. Huge amounts of waste are produced and disposed, only 7 % overall production efficiency is the current status.

The thermal properties of a lot of materials and products are commonly used to save energy during the lifetime of the buildings. Thermal insulation products, windows, heat accumulators, etc. make real contributions to fulfilling the objectives of a more sustainable world for new buildings. At the same time, drinking water is used for many applications in which it is not really required. A strategy of use of water from more restrictive application (human ingestion) to less restrictive applications can save a great percentage of water used.
The positive development of utilizing residual products, e.g. for raw materials for cement and concrete production, will continue to develop and will result in further improvements of resource consumption and CO₂ reduction. Another important solution to achieve resource efficiency is to use local materials, e.g. local aggregates for road construction, which will significantly save transport and thereby energy. New scientific knowledge and radically new technologies are necessary in order to effectively address the inherent inefficiencies in the physical and mechanical properties of natural stone and other materials and the technical limitations of the current materials used for processing.

4.3.4 Health, hygiene and safety

The provision of healthy buildings in which to live, work and play is a crucially important issue for the construction sector in the coming years. Much of this relates to the quality of indoor air and ventilation particularly in offices and residential buildings. The development of functional coatings, e.g. self-cleaning or with microbiological action for healthcare buildings, is now a reality and significant further innovations in this area are expected over the coming decades.

Another aspect, which indirectly has influence on health and hygiene, is release to soil from building materials of substances harmful to health. Considering the impact of materials on environment and health, up to now major efforts have been channelled into the reduction of possible influence of hazardous substances and into the reduction of environmental impacts. In addition to these efforts, which are of fundamental importance for the built environment of the future, innovative and improved functionalities can be developed which will open new possibilities in the interaction of materials with citizens and nature. Additionally, this will be supported by considering hazardous substances already in the production phase through characterizing, tracking and reducing them in the production of building materials and finally by studying their further health, safety and environmental impact on the living environment.

Developments in nano-technology offer new opportunities for traditional and new building materials. The development of new functionalities of materials, such as self-cleaning properties, heat storage, surface active materials, self-healing capacities, sensor technologies, etc. are still in their infancy. Their further development can play a key role in the issues of improved sustainability, environmental aspects (outdoor and indoor environment), and also security of the built environment (industrial hazards, natural hazards, terrorism, etc.).
4.4 Demolition, re-use & recycling

The amount of construction and demolition waste (C&DW) is of great importance. It is estimated that roughly 180 million tonnes C&DW are produced annually in Europe according to the European Commission. Furthermore, it is estimated that these 180 million tonnes will almost double by 2010.

Authorities in several countries in Europe are considering or have already imposed taxes on primary aggregates, partly in order to promote secondary aggregates.

Most countries use the European Waste Catalogue for categorizing C&DW. The amount of C&DW, which is recovered between < 20 % (Spain) and 96 % (UK). This span clearly demonstrates the huge potential that improved recycling technologies can offer.

In recent years the implementation of the EU’s Construction Products Directive and its implications for the re-use and recycling of building products have initiated extensive research into the environmental impact aspects of the different products. Missing knowledge on the material properties in regard to this impact, the difficulty to define adequate performance indicators and environmental product figures as well as a limited availability of recycling technologies are limitations, which have to be addressed by innovative approaches. Increased knowledge on materials properties in this respect, clear and adequate environmental impacts indicators derived from life cycle studies and new recycling possibilities will facilitate the development of decision systems regarding materials choice and new systems for waste recycling, including required technology and logistic systems.

The waste from building materials originates mainly from demolition, while deconstruction and demounting of materials could facilitate the reuse not only of materials, but also of the products derived from these materials as construction components.

The demolition works will be easier with lighter materials as these will also reduce the heavy machinery in the process with inherent increase in worker’s safety.

The combined need to improve the safety of the demolition process and minimise waste will lead in future to an extensive re-assessment of demolition practices. In the same way that the electronics & automotive industries have reviewed product design in the context of end-of-life it will be necessary for the construction industry to do the same. The concept of design for deconstruction will become a reality together with innovative procurement options including leasing. There will be a consequent need for adequate logging and tracking of materials and products through their full life cycle. The ultimate final goal will be a closed-loop system valorising the materials at maximum value.

Although the innovations in building materials and their functionality is directed toward durability and enhanced service-life, the necessity to address this issue becomes more important when taking into account the requirements regarding novel building systems and material functionalities. These innovations will incorporate novel material combinations which incorporate material modifications and incorporations for which the environmental impact is as yet unknown and for which new recycling options have to be defined. The impact of new composites based on renewable resources, the introduction of sensing properties and the use of nano-materials are examples of required innovations. This will lead to materials combinations in which the separation of materials with different environmental impacts may be required to define cost-effective recycling.
On the other hand new materials will be developed especially taking into account the aspect of easy deconstruction and recycling, as in the use of bio-technical systems as building components.

### 4.5 New advanced functionalities

Materials for construction are usually considered and classified as having traditional functionalities (structural, covering, etc.) and, as a consequence, they are used by builders only in a traditional way. This poses limitations to the development of new ideas and concepts in the building, cities, construction and networks of the future.

The European industry as a whole needs to move from resource-based towards knowledge-based, more environment-friendly approaches, from quantity to quality, from mass produced single-use products to manufactured-on-demand multi-use, upgradeable product-services; from "material and tangible" to "intangible" value-added products, processes and services. Successful technological solutions have to be sought increasingly further upstream in the design and production processes; new materials and **nano-technologies** have a crucial role to play as drivers of innovation.

The possibility of having materials with new and improved functionalities opens up new opportunities in the way constructions are conceived from the design stage up to the final use. For example, important innovations could be achieved in indoor quality and in comfort by using smart, sensing, “active” or ergonomic materials, which could be integrated into our daily life. Furthermore, new functionalities could also bring innovation in the construction processes.

Materials with new properties and functionalities are being studied and developed in many different advanced fields (bio-medical, aerospace, electronics etc.). The construction sector must look at these in order to bring real innovation. The material functionalities must be adapted to the new requirements of citizens and constructors, in such a way as to offer new possibilities and solutions in the broadest possible way.

The main challenges in this process are to develop:

- **new functionalities** which are potentially sustainable and which can guarantee an important socio-economic impact;
- **tools** to simulate, design and measure (from the basic phenomena) the materials with the new improved functionalities;
- **cost-effective processes** for the production, use and maintenance of these materials in the buildings of the future while respecting health and safety expectations of workers and users.
5 STRATEGIC RESEARCH AGENDA

In the present chapter the strategic research agenda is presented in seven different themes. The research areas are to a large extent general and valid for all building materials. However, attention has to be paid to the fact that the situation/relevance for the various aspects might differ from material to material and so do the research needs.

5.1 Reduce the environmental impact of building material production and demolition

5.1.1 Introduction

The production of building materials accounts for some 50 % of all materials extracted from the earth crust. Their production often requires enormous amounts of fuels and electrical energy and gives rise to considerable amounts of emissions and greenhouse gases and other pollutants. At the same time construction and demolition waste accounts for 22 % of all waste generated and is only partly re-used. Land use for quarrying is also an important environmental challenge. Improvements in raw material and energy consumption, utilization of construction and demolition waste and other waste therefore offer a huge potential to minimize the environmental burden of the construction industry.

5.1.2 Research areas

Medium term

- Creation of knowledge based environmental performance indicators and performance rating systems for materials and buildings
- Use of large quantities of residual products and waste as raw materials in building materials production
- New selective design and deconstruction technologies
- Improved treatment technology for construction waste
- Logistics tools to facilitate cycling
- Alternative energy sources efficiently integrated in production plants
- Adapting production processes minimizing the need of energy and water through an understanding and control of reaction mechanisms
- Use of renewable raw materials, e.g. natural fibres, which do not form any residues and soy-based resins – cheaper, lighter and potentially bio-degradable
- Buildings optimised for deconstruction via use of dismountable products
- New recycling technologies for novel building materials and material combinations
Long term

- New logistic concepts and manufacturing technologies for full utilization of construction demolition waste
- Eliminate substances harmful to health and safety
- Development of concepts for long term land use planning
- New life cycle designs, concepts and building components
- Combination of different materials and the full recyclability of all their components tending to a zero waste construction technique.

5.1.3 Targets for 2030 and Key Performance Indicators

- 30 % specific reduction of the natural raw materials need of building materials production
- 100 % re-utilization of construction and demolition waste
- 30 % specific reduction in CO₂ emission of building materials production

5.2 Improve predictability and efficiency of building material production processes

5.2.1 Introduction

Despite the considerable progress achieved in the production process of building materials significant research activities are still required to reduce environmental impacts, reduce production costs and to improve product performance and manufacturing predictability. There is a large potential in changing labour intensive processes to automated, intelligent feedback systems and thereby achieving high performance materials with reduced environmental impact. Success is dependent on cooperation with the machinery manufacturers and the supplier industry and on using technology not traditionally used in the building industry, e.g. robot technology, sensor technology and nano-technology.
5.2.2 Research areas

Medium term

- Development of measurements and characterization techniques for materials at the early stage of production, e.g. on-line feed-back systems
- New cost-efficient solutions for raw material control
- Development of simulation tools for predictable and multi-functional products and manufacturing processes for reduced production time and cost, e.g. by use of robot technology
- Integrated IST product design and process control to support rapid prototyping
- New manufacturing processes of building materials with high performance and reduced environmental impact through reduced energy and raw material demand
- Innovative manufacturing, control and measurement processes to ensure quality all along the production batch and manufacturing flexibility, exchanging dynamically the applied designs
- New processes with reduced production time
- Processes for functionally graded and multi-functional materials

Long term

- Cost-effective industrial processes for functionally graded and multi-functional materials
- Creation of background knowledge for material transformation, compaction and production
- New digital technologies for enhanced control of the production process
- Synthesis of organic/inorganic nano-materials based on principles similar to bio-mineralisation
- New logistic concepts and manufacturing technologies for full utilization of construction demolition waste

5.2.3 Targets for 2030 and Key Performance Indicators

- Production time and costs reduced by 50 % through innovative, efficient and predictable manufacturing processes
- Improvement of production quality to 100 % of 1st choice products with high flexibility and reduced production batches tailor-made to the markets demands
- Materials suppliers are fully integrated in the construction processes
- New manufacturing processes are able to sustain the production of materials with new functionalities
- Industrialised production which at the same time allows for individual design
5.3 Improve resource efficiency of buildings and infrastructure in use through improved materials

5.3.1 Introduction

Life cycle assessments of buildings and civil structures show that a significant contribution to environmental impacts such as energy and water, stem from the use phase, i.e. energy for transport, energy for heating and cooling and for repair and maintenance. The new EU directive imposes stricter requirements on buildings thus enabling materials to reduce energy consumption and to improve the effects of thermal insulation. There is a need therefore for research in building materials, construction methods and maintenance and repair methods that reduce energy consumption during use.

The correct management of energy usage in production of materials is essential for the optimisation of resources in the sense that commonly higher energy consumption during production can lead to important energy saving when in use and consequently lower maintenance.

5.3.2 Research areas

Medium term

- Expanding the limits of existing materials by understanding chemistry, biology and physics
- New thermal insulation materials with extreme performance
- Typification of existing building and adequate upgrading choices, IST tools for virtual testing
- New systems based on air vector, with heat storage, able to reduce energy and environmental impacts
- Improving and using the most optimal pavement material to reduce fuel for transport
- Protocol development for resource efficiency rating, incl. water use
- New repair materials and technologies with reduced environmental impact
- Understanding and controlling degradation phenomena to improve the service life
- Advanced insulation materials, easy to build external insulation systems.
- New materials with expanded properties by understanding chemistry, biology and physics.
- Occupiers’ personalized lighting active systems
- Optimised use of light and heavy building materials to reduce the need of energy of heating and cooling in buildings
Long term

- Integrated design and manufacturing of customized components for new buildings and for rehabilitation
- Smart materials, the properties of which are able to change with the environment.
- New techniques and new products implemented without delay in ICT education and training tools.
- Smart, active components for energy collection and/or storage, connected to building and/or local energy management systems.
- Active, multi-functional materials which improve energy consumption of buildings by nano, sensor and information technology

5.3.3 Targets for 2030 and Key Performance Indicators

- Insulation and storage (thermal, acoustic, electro-magnetic) capabilities increased by 20 % with respect to current building materials
- Cost-effective materials for energy-positive new buildings
- Energy consumption for transport reduced by 30 % by optimised use of pavement materials
- Total energy consumption and emissions reduced by 50 % during the life cycle of new buildings

5.4 Reduce lifecycle costs of building materials

5.4.1 Introduction

A key factor for maintaining and improving the competitiveness of the European building materials industry is to reduce lifecycle costs of building materials. This includes aspects such as durability, repair and maintenance and aesthetic durability in both new and existing buildings and structures. The research needed includes both improving properties of new and existing building materials, using the materials in an optimum combination and developing new design methods aimed at service life design.
5.4.2 Research areas

Medium term

- The concept of aesthetic durability and life-cycle costs taking aesthetic maintenance cost into consideration are integrated into the building process
- Knowledge on aesthetic ageing rates for Europe based on previous experience and initial research results in a form to be used for cost benefit calculations
- Detecting the important parameters from environment, maintenance activities and physical-chemical characteristics of materials on the ageing process
- Modelling service life behaviour
- Development of “easy to use & install” building materials
- Explore the mechanisms of environmental stress cracking, one of the least-understood problems impacting polymer and common materials “shelf life”
- Integration of mechanical, chemical and biological aspects in service life models
- Develop accelerated test methods to estimate durability, including aesthetic durability
- Improvement and development of durable materials with prolonged and predictable service life under aggressive conditions including self-assessment and innovative non-intrusive in-situ inspection techniques
- Introduction of Non-Destructive Techniques (NDT) for investigation of structural health and integrity in construction; innovative, non-intrusive in-situ inspection techniques

Long term

- Aesthetic maintenance programs prediction for buildings, incl. economic life-cycle evaluation
- Analysis of nano-coatings and other treatment materials to enhance technical and aesthetic durability and to reduce maintenance costs
- Development of wireless sensors, which can function in a harsh environment at or inside buildings materials, which can warn about risk of damage, i.e. measuring moisture.
- Development of virtual design/construction programs based on service-oriented materials that drastically increase the range of utilization (design by the customer)
- Enhancing material resistance against substances that initiate the deterioration process, e.g. chemical modification
- Development of materials with smart and sensing capabilities for self-assessment of integrity, functional control and self-maintenance, improving structural and aesthetic properties
- Optical fibre sensors as non-destructive structural health monitoring devices for infrastructure elements that can also be used in concrete structures
5.4.3 Targets for 2030 and Key Performance Indicators

- Knowledge-based control of properties of building materials (such as porosity, microstructure and behaviour at nano-metric scale) to allow total architectural freedom in selection and combination of building materials, structural design and design of surface appearance
- Total life-cycle costs for buildings and structures are reduced by 30%
- Building materials can be 100% inspected and maintained in-situ with no impact on building functionality

5.5 Improve comfort of living (health, hygiene & aesthetics)

5.5.1 Introduction

Health, hygiene and aesthetics are key words with regard to future generations’ requirements for the buildings and structures we live and work in. The knowledge on these issues is insufficient and research is needed in order to fulfil these requirements. Developments in nano, sensor and information technology offer new opportunities for traditional and new building materials and for the functionality of the buildings and structures.

High levels of indoor safety must be reached to ensure comfort in new buildings and constructions. Buildings and construction must evolve to be safe, attractive and accessible places. Flexibility of buildings is needed to adapt them to eventual changes and owner wishes, which can be achieved by the introduction of modular construction that satisfies the desire for change.

5.5.2 Research areas

Medium term

- Development and application of materials and products with zero emission and zero leaching in relation to risks for human health (including indoor air quality and release to soil)
- Development of materials with drastically improved aesthetic durability by detecting the important mechanisms influencing aesthetic durability spanning from a nano to macro description, e.g. materials which change colour and texture
- Development of materials with drastically improved aesthetic durability by detecting and controlling degradation phenomena from a nano to macro scale description
- Development of self-cleaning and highly hygienic surfaces
- Physical and chemical parameters influencing the aesthetic surface parameters of all building materials identified and verified
- First generation calculation models for predicting development and required maintenance of aesthetic expression
- Development of aesthetic durability standardized tests
- Improved aesthetic durability by new coatings, glazes, coverings etc.
Behaviour of joints between composite materials and concrete structures in seismic events shall be studied

- Development of systems and materials for efficient protection from fire.
- Simple methods for verifying and visualising aesthetic properties
- Optimum use of light and heavy materials to reduce temperature, optimise moisture and lighting conditions, improve acoustical and electromagnetic insulation variations in buildings
- Second generation calculation models for predicting development of aesthetic expression available

**Long term**

- Design to achieve flexibility of the buildings to adapt for changes and offering full mobility for all, e.g. by using flexible modules
- Development of prevention systems to detect the first signs of failure to protect and ensure safety
- Novel materials for mitigation of natural hazards
- Smart materials that can change their physical properties on demand through user demand, e.g. electrical pulse actuation
- Visual 3D simulation program based on third generation models for aesthetic durability developed as design tool for architects and engineers
- Active, multi-functional materials which improve indoor climate by nano-, sensor- and information technology
- Abatement of architectural barriers for new aesthetic concepts and materials

**5.5.3 Targets for 2030 and Key Performance Indicators**

- Tailor-made materials which can fulfil any demand on active response and aesthetics
- Building materials capable to adapt 100 % indoor environmental conditions depending on changing use requirements
- Full understanding of aesthetic durability is used in the design and maintenance strategy of structures
- Improved general well-being of people by creating an “easy-to-use” environment
5.6 Improve working conditions in production and construction (ease of application and maintenance, workers safety)

5.6.1 Introduction

The building industry in general is characterized as an industry where the number of health implications and accidents due to bad working environment is high (heavy weights, repetitive movements, noise, vibrations etc.). Furthermore, it will be increasingly difficult in the future to attract well-educated employees. There is an urgent need therefore to improve the working conditions related to the production and construction of buildings and structures. The research needed includes material design and optimisation, other design processes, industrialisation and developments in repair and maintenance methods.

Many of the risks and accidents associated with construction are related to the management of heavy loads on site. In this sense, advanced materials have a lot to offer due to their high strength/stiffness to weight ratio compared with conventional materials, enabling reduction in the risk of accidents, injury or death during on-site installation.

5.6.2 Research areas

Medium term

- Building materials optimised for easy industrialized prefabrication
- Development of materials for strengthening existing constructions
- Development of new measurement techniques for inspection and monitoring of material integrity which give early warnings
- Development of rapid assembly processes, incl. dismountable elements
- New building materials installation and fixation systems focused to develop new industrialized construction methodologies
- Development of new building materials and optimisation of existing ones to reduce the impact on the working environment during construction, e.g. use of self compacting concrete
- Optimisation of new and conventional fabrication processes, e.g. use of ultraviolet light (UV), curable prepeg providing a nearly infinite shelf life and reduced styrene emissions
- Increasing advanced materials strength/stiffness to mass ratio
- Reduction of risks for workers deriving from exposure to chemical and biological agents in the production process of building materials
Long term

- Development and application of embedded micro- and nano-sensors to be used at the buildings site for preventing accidents
- Materials with embedded monitoring systems are fully integrated in automatic construction procedure and processes
- Integrated design and manufacturing of customized components for new buildings and for rehabilitation, e.g. walls assembled by vacuum
- Application of biological technology in the production of building materials
- Efficient inspection and repair technologies to maintain/upgrade structural function of existing structures

5.6.3 Targets for 2030 and Key Performance Indicators

- Number of days lost through sickness reduced by 50 %
- Number of lost-time injuries in construction industry reduced by 50 %
- Building materials are optimised for industrialised prefabrication

5.7 Develop new, multi-functional knowledge-based materials and construction systems adjusted to customer needs

5.7.1 Introduction

Materials for construction are usually considered and classified as having traditional functionalities (structural, covering etc) and, as a consequence, they are used by builders only in a traditional way. This poses limitations to the development of new ideas and concepts in the buildings, constructions and network of the future. The challenge for the construction industry as a whole is to move towards knowledge-based approaches exploiting the possibility of the materials and constructions to introduce multi-functionality. Technology jumps can only be achieved when seeking inspiration from other, advanced fields (bio-medical, aerospace, electronics etc). The goal for the research can be summarised as “From design for the customer to design by the customer”. Service-oriented materials are therefore needed to drastically increase the range of utilisation.
5.7.2 Research areas

Medium term

- Generate, study and evaluate potential, sustainable new functionalities with high socio-economic impacts
- Creation of background knowledge, e.g. on the nano-scale, about the behaviour and properties of multi-functional materials and/or material combinations, e.g. hybrid nano-composites, nano-structured polymers etc.
- Study and production of new materials with improved properties, e.g. mechanical resistance, corrosion resistance, wear resistance, easy to clean, controlled moisture behaviour, acid attack resistance and improved comfort, e.g. surfaces with “warm-feeling” properties, anti-vibration, acoustic insulation etc.
- Materials and manufacturing technologies allowing the incorporation of different additional functionalities on a cost-effective basis, e.g. anti-static/conductive properties, sensing properties, self curing, self inspection, by embedded bio electronics, active surface properties
- Tougher (more ductile) mineral materials, e.g. organo-mineral composites
- Development of materials to ensure stabilisation of soils and rock, e.g. optimising injection processes, chemical interaction between materials and substrates
- In-situ monitoring of new functionalities

Long term

- Virtual 3D design/construction programs that dispose a wider range of materials for a wider range of uses
- New advanced materials and material combinations with intelligent advanced properties and intelligent functionalities, e.g. detection, regulation, control
- Study and application of new markets, new logistics approaches and new management concepts
- Use of biomaterials and natural processes technologies in material modification
- Integrated design and manufacturing of customized components for new buildings and for rehabilitation, e.g. walls assembled by vacuum, advanced multi-functional façade elements
- Models and codes to allow balancing of different criteria and performances during material design phase

5.7.3 Targets for 2030 and Key Performance Indicators

- New advanced functionality materials are ready, accepted and widely utilized
- New and innovative building materials and production technologies are compatible with the application of IST technologies in the building, e.g. sensoring, monitoring
- New, integrated concepts and networks from material producers to facilitate management suppliers and clients exploiting the full benefit of multi-functional materials
- Tailor-made materials, which can fulfil any demands on durability, strength, active responses etc.
6 ORGANISATION

6.1 Organisation chart of the Focus Area Materials

![Organisation Chart]

6.2 Leadership

Wolfgang Dienemann (HeidelbergCement)
Gian Marco Revel (Universita Politecnica delle Marche)

6.3 Core team

In order to enable productive meetings and progress a core team has been created, made up from the working group leaders and contacts to other FAs and networks. According to the above-mentioned principles, the core team composition is the following:

**Working group leaders:**

- **WG Ceramics**
  - M. A. Bengochea
  - V. Sanz Solana

- **WG Composites**
  - E. Shahidi
  - I. Calvo

- **WG Cementitious**
  - W. Dienemann
  - M. Tschudin

- **WG Natural Stone**
  - I. Paspaliaris

- **WG Wood**
  - J. Lagerström
  - M. Lehtonen

- **FA Materials**
  - Wolfgang Dienemann
  - Gian Marco Revel

**Core Team**

Leader of WGs + contact persons

**Contact Persons**

to other FAs
WG Natural Stone Ioannis Paspaliaris (Technical University of Athens)
WG Wood Jan Lagerström (Swedish Forest Industries Federation)
Markku Lehtonen (Woodfocus)

Contacts to other FAs and platforms:

Cities & Buildings: Norman Blank (Sika)
Roger de Block (Saint-Gobain)
Ilaria Roncarati (Leonardo 1502 Ceramica)
Eugenio Gutierrez (Joint Research Center)
Juan Manuel Mieres (Nesco, Entrecales y Cubiertas)

Underground Construction: Markus Tschudin (Holcim)

Networks: Luigi Cassar (Italcementi)
Thanasis Triantafillou (University of Patras)

Quality of Life: Jesper Sand Damtoft (Aalborg)
Philip Bennett (CEPMC)
Marcel Engels (FGK)

ECOSERVE network Mette Glavind (Danish Teknologisk Institute)

i-Stone network Ioannis Paspaliaris (Technical University of Athens)

Forest Based Industries Platform Jan Lagerström (Swedish Forest Industries Federation)

Steel David Martin (Corus)

6.4 Working groups

6.4.1 Ceramics

Vicente Sanz Solana, Miguel Angel Bengochea, Gonzalo Silva, Marcel Engels, Gian Marco Revel, Bjarte Oye, Ilaria Roncarati, Mr. Laufer, Dr. Bresciani

6.4.2 Composites

Ebby Shahidi, Ignacio Calvo, Thanasis Triantafillou, Gaetano Manfredi, Erick Knudsen, Dr.Borghetti Nazario, Dr. Bianchi Fulvio, Ismail Hakki Hacialioglu, Andrea Barbagelata, Dr. Kimon Alexiou, Rod Martin, Bert Kriekemans, Nello Giamundo, Roko Zarnic, Alfonso Recuero, Peter Thornburrow, Eugenio Gutierrez
6.4.3 Cementitious


6.4.4 Natural Stone

Ioannis Paspaliaris

6.4.5 Wood Products

Jan Lagerström, Markku Lehtonen, Andreas Kleinschmit, Diter Lechner, Marc-André Gonin, Jostein Byhre Baardsen

6.4.6 Other materials

Links to other materials have been established as follows:

- Glass through Roger de Block (Saint-Gobain)
- Steel through David Martin (Corus)
- Insulation through Peter Thornburrow (Saint-Gobain)
- Mortars through C.-G. Nilsson (Maxit)
- Aluminium through Bernard Gilmont (European Aluminium Association)

Whether or not these materials will form their own working groups inside the FA Materials depends on their industries’ participation (some of them have initiated their own ETPs). Anyhow, the FA Materials is open to the participation of other building materials sectors.
6.5 Membership (all colleagues not mentioned in WGs or as contact persons)

Industry

Stefan Bahnmüller (Bayer MaterialScience)
Vlatko Bosiljkov (ZAG)
Pablo Comino (Saint-Gobain)
Stephane Cousin (Saint-Gobain)
Tiziana De Marco (Italcementi)
Manfred Diehl (Umicore)
Daniel Guinard (CTBA)
Pal Francis Hansen (HIFROM)
Antonio Miravete (Sistemas y Procesos Avanzados, SYSRA)
Philippe Paquet (CTBA)
Jesus Rodriguez (Dragados)
Wolf-Rüdiger Wichmann (Züblin)
Tomaz Vuk (Salonit)

Universities

Bruno Daniotti (Politecnico di Milano)
Martha Grossou-Valta (Institute of Geology and Mineral Exploration IGME)
Gerd Hauser (TU München)
Robert Kliger (Chalmers University of Technology)
Cecilio Lopez (Instituto de Ciencias de la Construcción Eduardo Torroja)
Harald Müller (Universität Karlsruhe)
Peter Richner (EMPA – Eidgenössische Materialprüfungs- und Forschungsanstalt)
Santiago Sanchez Beitia (Basque Country University, San Sebastian)
Björn Schouenborg (Swedish National Testing and Research Institute)
Irina Wasserman (Israel Institute of Technology)
Volker Wittwer (Fraunhofer Institut)

Associations

Tumer Akakin (Turkish Ready Mixed Concrete Association)
Silvan Baetzner (VDZ)
Bernard Gilmont (European Aluminium Association)
Antonella Grossi (ICIE)
Christian Leroy (European Aluminium Association)
Holger Ortleb (Bundesverband Baustoffe, Steine & Erden)
Michael Weissenborn (Bundesverband Baustoffe, Steine & Erden)
Engineering/Consulting

Richard Annells (Mineral Industry Research Organisation)
Frans Barends (Geodelft)
Luc Bourdeau (CSTB – centre scientifique et technique du bâtiment)
Robert Cope (CSTB – centre scientifique et technique du bâtiment)
Herve Di Benedetto (ENTPE)
Heikki Kukko (VTT)
Klaus Luig (3L Architekten + Industriedesigner)
Francesco Mirri (Eco Consulting Ingegneria)
Waldo O. Molendijk (Geodelft)
Antonio Porro (Labein Centro Tecnologico)
Daniel Quenard (CSTB – centre scientifique et technique du bâtiment)

Private institutions

Maria José Lopez-Tendero (AIDICO – Instituto Tecnológico de la Construcción)
Livia Pardi (Autostrade)
Jacques Varet (BRGM)
Andrej Zaje (IRMA)
7 IMPLEMENTATION PLAN

7.1 Actions

- Development of Vision 2030 12/2004
- Development of Strategic Research Agenda 06/2005
- Initiation of Integrated Projects / Joint Technology Initiatives 09/2005

7.2 Calendar

1st meeting Oct 14, 2004, Maastricht
- Kick-off meeting
- Scope definition
- Creation of working groups

2nd meeting Nov 11, 2004 at 11:00 a.m. in Brussels (at CEPMC)
- Report from working groups
- Input from other FAs / contact persons
- Preliminary draft of Vision 2030 FA Materials

3rd meeting Dec 02, 2004 at 10:00 a.m. in Lausanne
- Status report task groups
- Report from other FAs / contact persons
- Refinement Vision 2030 FA Materials
- First draft SRA

4th meeting Feb 17, 2005, Brussels
- Revision of Vision 2030 (if required)
- 1st draft of Strategic Research Agenda
- Joint Technology Initiatives

5th meeting Jun 08, 2005, Brussels
- Revision of Strategic Research Agenda (consistency with other FAs)
- Priorization
- Joint Technology Initiatives

7.3 Financial aspects

Initially each participant shall cover his own cost.