“Trends in Construction Materials”

Dr. Joe Mapiravana BSc (UZ); MScTech.(Sheffield); PhD (Leeds); EDP(UNISA-SBL)
Principal Researcher and Construction Materials Research Group Leader, CSIR

ABSTRACT

This paper was motivated by the need to identify trends in building materials research development and application that will significantly reduce building costs, life cycle costs and minimise the lead time for building delivery in South Africa whose low income urban housing backlog now stands at 2.2 million units. The paper reviews objectives, developments and impacts on cost and delivery lead time of building materials research and development programs globally and in South Africa. Comparisons are drawn between the global and South African scenarios. Virtually all developments that arose from building materials research and development impacted positively on reducing building life cost and delivery lead time. Global building materials research and development trends are towards the development of light-weight ultra-high performance concretes, Portland cement replacement, cement matrix and polymer matrix composites, recycling and reuse of waste materials, smart building materials, nanotechnology materials, green energy efficient building materials, reduction of embodied energy, reduction of carbon footprint and the use of renewable bio-based materials. South Africa, while lagging behind the more developed world is closely tracking global developments particularly in cement and concrete, steel and composites research.

Analysis of the building materials market situation in South Africa identified the major building material cost drivers as cement and concrete and steel. For South Africa, research and development focus has been on cement and concrete, composites, waste recycling and reuse and recently nanotechnology materials. To significantly impact on cost reduction and delivery lead time, it is recommended that building materials research and development

priorities in South Africa be cement and concrete, light-weight steel construction, smart tiles and composite materials. Nanotechnology materials should be used for property enhancement. The building materials developed should be modularised and/or panelised for rapid construction, leading to reduction of labour costs.

Keywords: Light-weight, ultra-high performance, concrete, cement replacement, geopolymers, cement matrix, polymer matrix, composites, recycling and reuse, smart building materials, nanotechnology, carbon footprint, renewable, bio-based materials, light-weight steel, modular, toughening, life cycle cost

1 INTRODUCTION

Building materials research and development priorities are discerned from completed and/or ongoing research in a country or countries during a given time-frame and include subject areas that may benefit many countries. This arises from the scattered nature of the building industry and its dependence on different local resources and the technical characteristics of raw materials that are never the same for all countries. This in itself compels countries to conduct research carried out earlier in other countries (with similar raw materials). Such repetition familiarises developing countries with up to-date techniques and prepares them for the introduction of new production methods and products. Building materials research direction is guided by national agenda but may be influenced by common global research trends such as the need for green energy efficient buildings. The trends that are valid for building material research and development are often also valid for the building methods. The prioritisation of building material research areas, which is closely linked to that of the building methods, cannot be done globally, but rather for a given country and timeframe. It requires the (i) identification of potential building materials for research and (ii) a method of comparing and ranking competing building material research themes. It should be borne in ind that research and development of building materials involves two main categories – products and processes.

South Africa’s low income urban housing backlog has ballooned to 2.2 million units. Demand for middle and upper income housing is also firm and buoyant. Demand for other building infrastructure is also increasing due to social and economic demands of the growing economy and population. Despite this huge and increasing demand, traditional building materials and methods in use are increasingly cost prohibitive and sluggish – a scenario that has given rise to the backlog in the supply of building infrastructure.

This paper will review and compare the status of building materials research and development globally and in South Africa to enable identification, prioritisation and scoping of building materials research and development areas that must be explored afresh or further in order to significantly reduce the life cycle cost and delivery lead time of building infrastructure in a sustainable way. The paper also reviews and analyses the trends in building materials globally and locally and finally zeroes in on priority building materials research and development areas in South Africa on the basis of expected impacts on cost reduction and minimisation of delivery lead times for housing and other building infrastructure. Global and local studies, research papers and reports on building materials research and development were analytically reviewed.

Traditional building materials are cement and mortar, concrete products such as hollow building blocks, burnt clay products such as bricks, quarry tiles and pipes, glazed ceramic tiles, facades, ceramic sanitary ware, glass, timber, steel, non-ferrous metal alloys, cast iron, ferro-enamels, minerals and rocks, refractories and plastics such as such as poly vinyl chloride (PVC). Advanced and non-conventional building materials include recycled and re-used waste based materials, composites, nanomaterials and novel materials such as photochromic or chameleon type energy conservation pigments.

2 RESEARCH AND DEVELOPMENT OBJECTIVES FOR BUILDING MATERIALS

Global ongoing and recent overall research and development objectives for all building materials are varied and wide. However, it must be noted that, directly or indirectly, all the objectives seek cost or life cycle cost reduction and/or reduction of the delivery lead time and/or environmental protection. The objectives include the following:

1. use of domestic materials and by-products to save foreign currency and minimise logistical costs; 2. reduction of production and life cycle costs; 3. conservation of resources; 4. reduction of embodied energy; 5. reduction of the carbon footprint; 6. conservation of water; 7. widening the list of natural resources that can be used economically for building purposes e.g. the use of marginal rock and mineral aggregate materials; 8. increasing availability of building materials; 9. increasing productivity of building material manufacture; 10. improving the quality of building; materials e.g. by developing systematic, and detailed procedures and standard codes

11. cleaner production, including reduction of emissions during production; 12. producing materials for green buildings requiring reduced energy consumption for ventilation, heating and air-conditioning; 13. conservation and rehabilitation of the natural environment e.g. by restoration of abandoned quarries; 14. improvement of durability; 15. improvement of fire resistance; 16. increase abrasion resistance; 17. improvement of insulation properties; 18. improvement of acoustic properties; 19. light-weighting to facilitate easy handling and insulation properties; 20. cement replacement or extending to reduce blended cement cost; 21. toughening in concrete geo-textiles or composites; 22. development of ultra-high performance/strength concrete and hence thinning of concrete; 23. process development e.g. quickening strength development of cement and concrete; 24. new product development e.g. self-cleaning and de-polluting glazed ceramic tiles, facades, cement and concrete; 25. development of photovoltaic ceramic tiles and facades; 26. development of lightweight building hollow blocks, modules and/or panels to speed up construction and make it more efficient by elimination of building waste; 27. improving corrosion resistance and protection; 28. replacement of asbestos fibre by synthetic fibres and/or natural fibres in fibre/cement and polymer/fibre composites; 29. use of renewable biomaterials

3 TRENDS BY TYPE OF BUILDING MATERIAL

3.1 Cement and mortar

The partial replacement of Portland cement by various cement extenders has been getting the attention of researchers in both South Africa and the rest of the world. The scope of extenders investigated, developed and used is, however, wider for rest of the world. Over and above extenders investigated and used in South Africa, the rest of the world additionally looked at rice husk ash, maize cob ash, nano-structured zonolite nano clay cement binder (montmorillonite), metakaolin, stronger macro-defect free glycerol plasticised PVA-calcium aluminate (secar 71) and calcium aluminate phenol resin cements. Innovative cement development for total replacement of Portland cement has not occurred in South Africa. UK researchers have discovered new carbon negative magnesium-based cement that absorbs 0.6ton CO_2 per ton of cement on hardening. Rest of the world has also been looking at basic science of pozzolanic materials. SABS cement standards have been reviewed, taking account of numerous blending possibilities.

Geopolymers (Alkali activated binders) has been used outside South Africa as total replacement of ordinary Portland cement in geopolymer concrete. The geopolymers include the alkali activated slag alkali, alkali activated silica and a range of other geopolymeric materials. The advantage of using geopolymers is firstly, drastically reduced CO_2 emissions when compared to ordinary Portland cement, and secondly less material processing.

3.2 Concrete

Concrete research in South Africa has been more on the applied side than basic science. Rest of the world has incorporated both basic and applied science aspects of concrete research. A wider range of concretes have been developed, performance evaluated and applied by rest of the world than in South Africa. One of the world's tallest building (452m high) that is in Kuala Lumpur city centre has used concrete of 100MPa mean strength. Rest of the world has also researched, evaluated and produced concrete toughened by a wider range of reinforcements than in South Africa. De-polluting, self-cleaning and photocatalytic features have also been incorporated into concrete outside South Africa. South Africa has taken lead in textile concrete research to come up with novel geo-textiles for mine tunnel wall and road stabilisation. The country also leads the world in the application of continuously reinforced thin concrete road pavement emplacement and testing and in the production and use of low cost modular concrete block building systems.

3.3 Bricks and blocks

Rest of the world has used advanced characterisation techniques such as mercury intrusion porosimetry for characterisation of porosity in bricks and concrete blocks. Also, use of composite panels rather than bricks in construction is increasing in rest of the world. The recycling and reuse of recycled materials for bricks and concrete blocks occurs on a much smaller scale in South Africa than elsewhere. There have been greater advances made by rest of the world in the use of alternative concrete block production processes such as autoclaving for rapid strength development. Reduction of embodied energy and carbon footprint of bricks is topical.

3.4 Adobe/Earth

In South Africa and elsewhere, research on the use of adobe or earth has included basic science, characterisation and selection of clays for unstabilised and stabilised earth building products. Researchers have also looked at the manufacture of pozzolana for extension of Portland cement from clays using flash calcination of kaolinitic clays and unfired natural fibre reinforcement of mud bricks and their characterisation. Rammed earth construction has been extensively and successfully used and accepted in Australia for 2 to 3 storey buildings but the technology had not made headway in South Africa.

3.5 Timber

Only about 7% of land surface in South Africa is treed and good quality timber has to be imported. There has not been much research on timber and wood in South Africa except the limited evaluation of timber frame built structures in the Sharpeville area, mechanical characterisation of South African pine timber and development of formaldehyde-free polyurethane glues for laminated timber production. Outside South Africa, transgenic trees with decreased or altered lignin content have been genetically engineered to reduce consumption of energy and chemicals for delignification and refining of wood chips. Substitution of chemical preservatives and conventional chemical glues has been achieved through the application of fungal cultures and isolated enzymes as preservatives and adhesion promoters that require less energy to produce than chemicals. Innovative water glass bonded wool wooden fibre composites and bio-glue adhesive-free board materials have been developed. Owing to proper preservation, durability of modern wooden structures now exceeds 25 years and matches that of steel and concrete. Modular, panel and timber frame structures are now industrially manufactured, significantly lowering production cost and delivery lead time.

3.6 Tiles and sanitary ware

There is no ready evidence of research and development activities on ceramic tiles, ceramic sanitary ware, glass and glass ceramics in the public domain in South Africa. Indications are that such research is done abroad and applied in South Africa. In countries like Italy, higher productivity of ceramic tiles and sanitary ware has been achieved by technological advances in processing that introduced fast firing, battery pressure casting and robotic glazing systems. Large 800x800mm ceramic floor tiles are now available on the market thanks to research and development. Photoactive self-cleaning and de-polluting ceramic tiles and façade systems are also available.

3.7 Glass

Glass research outside South Africa came up with strong, durable and insulating structural glass-mica composites, insulating foam glasses and glass ceramics from the recycling of glass cullet, vitrification and devitrification of fly ash and slag waste. The toughening of glass was achieved by molten salt diffusion, lamination with stiffer and stronger interlayer materials being developed. Glass has remained the major substrate for silicon solar panels. Glass fibre research has led to the development of zirconia coated fibres that can reinforce concrete matrices without reacting with the basic cement. Stable, durable glasses and glass fibres that do not devitrify were developed.

3.8 Steel

The development of manufactured high specific strength light-weight steel framed buildings and, with a variety of cladding materials, happened outside and is catching on in South Africa. Outside South Africa, steel encased polymer concrete, steel fibre reinforced concrete, steel fibre reinforced fly ash concrete, steel fibre reinforced metakaolin blended concrete and high strength steel fibre reinforced concrete were developed and characterised. South Africa is following with the step-wise implementation of these developments. In South Africa, research on the recrystallisation behaviour of low carbon hot rolled steel strip has led to the production of stiffer steel strip from cold working of hot rolled strip that originally contains low sulphur levels. Lower Young modulus steel strip was also developed from higher sulphur content hot rolled steel strip. Corrosion resistant nitrogen alloyed stainless steels that offer the best combination of strength and toughness of any material known to date have also been developed in South Africa. Techniques to negate nitrogen losses during welding of stainless steel to retain strength and toughness and stabilise the welding arc and reduce spatter have been developed in South Africa. Basic science evaluations of the effect of concrete strength and reinforcement on toughness of reinforced concrete beams, effect of aspect ratio and volume fraction of steel fibres on mechanical properties of steel fibre reinforced concrete, strength reliability of steelpolypropylene hybrid fibre reinforced concrete, structural performance evaluation of steel fibre reinforced concrete, fatigue of steel cable stayed highway bridges and fatigue and fracture performance of cold drawn wires for prestressed concrete was carried out outside South Africa. By and large, South Africa has reasonably tried to keep pace with steel research and development in rest of the world.

3.9 Non-ferrous metals

New non-ferrous metal products were developed outside South Africa. These include a superplastic Al-Mg-Cu alloy with 700% and 25% elongation at 550oC and 20oC, AlMn alloy sheeting for a helium-cooled thorium high temperature reactor cooling tower and light-weight high specific strength hybrid carbon fibre reinforced plastic (CFRP)- Aluminium laminates. In South Africa, there is preferred use of aluminium alloys to galvanise and epoxy coated mild steel, various grades of stainless steel and PVC. Short and long-term corrosion rate tests on zinc, copper, aluminium, mild steel, stainless steel and corten were carried out at various exposure locations in South Africa. The information obtained is used for long-term planning in terms of material selection, cost of corrosion, corrosion protection, durability, design, maintenance and life cycle cost analysis in South Africa. It should be pointed out that aluminium alloys now face serious competition as construction materials from a range of polymeric composites and glass reinforced plastic materials that have property advantages. All over the world, there is more extensive use of recycled rather than virgin aluminium and copper products.

3.10 Industrial minerals and rocks

There has been increased and wider use of industrial minerals and rocks in South Africa and abroad. A database on “Ceramic raw materials of Southern Africa” and a handbook of South African Natural building stone have been compiled to inform use of these materials. Granite, basalt, basalt tuffs, limestone, dolomite, slate, dolerite, expanded perlite, pumice, exfoliated vermiculite, diatomite, bloating clays, dunite, forsterite, norite etc are being used globally for aggregates, as dimension stone, and for the production of construction materials.

3.11 Refractories

There is no ready evidence of extensive refractories research in the public domain in South Africa. Refractories research work appears to take place exclusively in the private sector. Even then, such research may have been carried out outside of South Africa and only implemented in South Africa. As a relatively big user of refractories, South Africa appears to be keeping pace with developments elsewhere through local developments and licensing agreements. Globally, the use of unshaped monolithic refractories has increased and the high alumina cement content of the castables has been dramatically reduced – to zero in some cases. The trend has also been towards the use of purer higher refractoriness materials. In spite of being the world's largest producer of zirconia, South Africa has not translated this advantage into the production of fused refractories based on zirconia that are imported largely for glass making. South Africa imports high quality magnesite based refractories and makes lower qualities from imported raw materials. The country is the leading supplier of raw andalusite for the manufacture of high alumina refractories to the world market.

3.12 Polymers

In South Africa, plastics contribute only 4% of the cost of building materials that are used in the country. Research on plastics in South Africa has concentrated on the evaluation of the use of various plastics in building and construction applications such as dump proofing by recycled polyethylene sheets, water reticulation and storage, insulation foams and structural uses in window and door frames. South Africa has developed the use of local coals and limestones for the production of poly(vinyl chloride) (PVC) for tiles and sewage reticulation systems. There have also been significant private sector developments leading to the production of resin bonded =geotextiles and geofabrics in South Africa. Table 12 shows that, globally, there is a much wider range of plastics and plastic products that have been developed and are used in building and construction. A lot of research has also gone into improving UV durability and fire resistance properties of plastics, development of biodegradable 107 plastics and production of polymers from renewable biomaterials such as soya beans for building applications. There is increasing interest in the development of polymer matrix composites.

3.13 Glass ceramics

In spite of having the necessary waste materials for the development of glass ceramics, South Africa has fallen behind other countries in the exploitation of these materials for glass ceramics. The country has not made a start on glass ceramics. In other countries, glass ceramics research has made significant advances on basic research and product development. Glass ceramics pilot plants exist in other countries.

3.14 Waste recycling and re-use

Rest of the world lead South Africa in the recycling and reuse of industrial and agricultural waste materials to widen the range of building materials, reduce building product cost, ecological reduction of CO2 footprint, as alternative new pozzolanic binders, as cement replacement, for glass ceramic manufacture and for composite manufacture. The USA and Europe have looked at toxicity challenges associated with the use of wastes like phosphorgypsum, municipal incinerator ashes and some coal combustion ashes. Solutions such as source reduction of toxins, oxidative destruction of persistent organics and reduction of leacheability of toxic elements by pinning them down in glass and glass ceramic matrices have been proffered. Interestingly, even chicken feathers are being used to reinforce biocomposites for structural building applications in the USA.

3.15 Composites

Basic science studies on developing, understanding, testing and applying fundamental principles of reinforcement to fibre/matrix engineering to enhance toughening and strengthening effects between matrix and reinforcement particles and/or fibres have been developed outside South Africa. Fundamental studies of polymer-polymer, polymer-fibre and polymer-particle interfaces have produced plausible theories on interfacial fracture mechanics that are based on thermodynamics. Basic science research on composites in South Africa is more recent and is looking at issues such as developing computational techniques to determine the extent of stress concentration due to dynamic loading, studying the effect of surface treatment of natural fibres on mechanical properties of natural fibre reinforced composites, modelling and measurement of residual stresses in composites due to differential thermal expansion between fibre and matrix, modelling dynamic stress concentration on particulate or discontinuous fibre reinforced composites and modelling of environmental degradation of composites based on chemical link density (degree of entanglement for polymers) and cohesive force variation to predict durability on the basis of short term exposure tests. Applied composite in South Africa research has is looking at the development of biodegradable, renewable, lightweight, natural and man-made fibre reinforced polymer matrix composite panels for structural and non-structural applications such as ballistic applications where impact resistance and tensile strength are major issues. Significant strides have been made in these areas and fire resistance and retarding remain the challenges. Investigations of durability due to alkali-silica reaction in glass fibre reinforced cement composites have led to the development of improved glass reinforced composites. The effect of fibre content on mechanical and thermal characteristics of hemp fibre reinforced 1-pentene/polypropylene copolymer composites has led to the optimisation of the composites in South Africa. Fibre reinforced foamed concrete technology, strain-hardened cement-based composite technology, and foamed polyolefin reinforced natural fibre composite technology was also developed in South Africa. Outside South Africa, product development research produced a plethora of cement/concrete matrix composites, polymer matrix composites and bio-based composites. Monolithic roofs and structural I-beams have been produced in the USA from fibre reinforced resin matrix soya bean based materials. The American concrete institute came up with design guidelines and 108

procedures for applying fibre reinforced composites that take into account lack of ductility by allowing higher safety factors than for steel reinforced concrete design and have environmental exposure reduction factors for various fibre reinforced polymer systems.
South Africa trails in such developments as the large scale use of these composites still has to take off in the country. Product development from recycled optic fibre waste, poly(ethylene terephthalate), polyolephinic polymer wastes (including: polypropylene, polyethylene and polystyrene) have been developed outside South Africa. Ongoing composite projects outside South Africa involve reducing the cost of fibre reinforcement and related technological operations, addressing repairability, fire resistance, durability and environmental concerns associated with composites. It is apparent that there is a lot of interest in composites and several research and development programs on composites are currently going on world wide.
The range of bio-composite construction products that would be typically required in the building includes:
.Insulated roof sheets;..nsulated roof tile; Gutters and downpipes; .Rain water tanks; .Fascia boards; Ceiling boards; Insulated wall panels; Insulated floor panels; Floor finishes (tiles, strips); Boarding for cupboards; Sanitary ware (hand basins, shower bases) etc.

3.16 Nanotechnology materials

Nanotechnology is relatively new to South Africa. Current research focuses on design, modelling, synthesis and characterisation of a range of nanomaterials with specific properties for a range of applications. Nanolayer deposition techniques and technologies for the production of single layer carbon nanotubes are being developed.

Other South African research interests include the purification and functionalisation of carbon nanotubes, the development of polymer nanocomposites for barrier resistance flame retardency and investigating nanostructures and properties of nanocomposites.

Characterisation of nanoparticles takes centre stage. Ultra high performance concrete and rapid strength development concrete repair nanomaterials and high performance biodegradable nanocomposites have been developed. Polymer nanocomposites with good fire properties and wear resistance for ballistic resistance and structural construction panels are expected.

The most widely studied nanomaterial is TiO_2. Basic science on the mechanism of its photocatalytic behaviour have been carried out and are now well understood. The optimal incorporation of TiO_2 into building materials such as window panes, paints, cementitious materials and tiles has led to the development of nano-scale sol-gel coating or painting of carrier substrates such as metals, ceramics, glass, polymers, concrete, wood etc to achieve a few micron thick photoactive layers. Investigations have shown that porosity, concrete aggregate size, cement to aggregate ratio, curing age, TiO_2 content and its degradation affect photocatalytic behaviour in cementitious materials. Carbonation of cement will reduce

photocatalytic activity of TiO_2 containing concrete as the TiO_2 particles are closed from light. Titania solar cells are said to convert sunlight directly into electricity through a process similar to photosynthesis. Unlike silicon-based solar cells, they are said to perform well even in low light/shade and give consistent performance over a wide temperature range. Substrates do not have to be transparent. Thus titania solar cells can be vertically mounted façade panels, power generating windows of integral components of buildings. Such smart building products are under development. World wide, nano silica fume is added to Portland cement based products to enhance strength, abrasion resistance and durability. It is also commonly used for polymer reinforcement and increases hardness, stiffness, weatherability and as fire retardant.

Other nano particles of alumina, titania, fullerenes, carbon nanotubes and nano clay also increase stiffness, strength and toughness of epoxy resin polymers by inducing energy absorbing toughening mechanisms such as crack deflection, plastic deformation of the resin matrix, crack pinning, crack blunting and microcracking of the resin matrix. Global emphasis on nanomaterial manufacturing is currently on titania, fullerenes, nanotubes and fibres. Research is required to quantify any health risks that associated with exposure to nanomaterials.

3.17 Novel/Special materials

Other novel smart materials that are still to be investigated in South Africa include chameleon type/thermochromic building coatings and phase change materials passive energy conservation in buildings. Phase change materials are used in structural sandwich building panels. Microencapsulated thermochromic pigments are blended with ordinary building coatings to obtain coatings that change colours reversibly depending on temperature to maintain thermal comfort of the coated building.

4 RECOMMENDATIONS ON PRIORITISATION OF BUILDING MATERIALS RESEARCH AND DEVELOPMENT FOR SOUTH AFRICA

The relative contributions of the traditional materials to building cost in South Africa

follow the order:

1. cement and reinforced concrete (35%), of which 50% is cement
2. plain carbon steel products (structural steel, tiles, flat and profiled sheets, door frames, window frames and garage doors) (23%)
3. bricks and blocks (12%)
4. Timber and wood (10%)
5. Tiles and sanitary ware (9%)
6. plastics (4%)

7. non-ferrous metals (4%)

8. glass (3%)

Therefore, to significantly reduce building and construction costs in South Africa, research and development efforts must be focused on cement, concrete, light-weight steel construction, smart tiles for modular and façade type construction, and composite material projects to reduce the cost and content of expensive cement clinker in building products and to develop cheaper, durable, and preferably renewable, composite materials that can substitute heavy plain carbon steel products, conventional concrete, bricks, blocks, timber and wood. Nanotechnology should be used to enhance materials properties and/or functionality, where possible. Industrialised or advanced construction that uses panels or modules made from the cheaper and smarter materials developed will reduce the delivery lead time and life cycle cost.

As for cement, projects should focus on its partial to total replacement, research and development of novel binders, cement extenders and cementitious materials such as the recently developed cheaper, carbon negative magnesium based cement, light weighting and property improvement of cement by novel admixtures.

As for concrete, research should focus on alternative reinforcement to the more expensive steel to increase fracture surface energy and fracture toughness, for example by second phase toughening additions or enhancement of interfacial bonding strength, strength enhancement through porosity reduction, and therefore increasing Young modulus, and increasing homogeneity and eliminating or reducing the size of strength limiting flaws. This approach derives from the Griffifth equation and empirical strength-pore fraction and Young modulus-pore fraction relationships. The Griffith equation suggests that the fracture strength (sf) of a body under uniform stress depends on its fracture surface energy, its Young modulus (or stiffness) and the size(c) of strength limiting flaws in it. For polymers, the degree of chain entanglement is an inverse measure of the strength limiting flaw size.

Thinner, lighter and stronger concrete products will derive from research and development activities based on strength enhancement through a fracture mechanics approach – increasing Young modulus by strong bonding and minimising pore fraction, increasing fracture energy by increasing energy absorbing mechanisms and minimising strength limiting flaw size.

Light-weight steel construction and research should focus on the rolling of even thinner and stiffer steel plate and the widening of application of structural light steel sections in building and construction. Intensifying light-weight steel construction will reduce the tonnage and cost of steel used in construction and permit rapid delivery of buildings and structures.

The mass production of glazed ceramic tiles through pressing and extrusion techniques is well developed. Research should focus on making smart tiles that are self-cleaning, kill gems, thermochromic and photovoltaic and can be used to conserve and generate energy for buildings. Further possibilities of using tiles as part of modules and panels for construction should also be explored.

Composite material research offers a wide range of possibilities for research and development of building and construction materials. A fracture mechanics approach to the improvement of strength and toughness is also recommended for composite material development. The development of structural polymer matrix (oil-based and renewable bio-based) and cement matrix composites incorporating toughening nanoparticles, natural and/or man-made fibres, self-cleaning features and other smart functions will be a major step change in the development of construction and building materials and methods in South Africa. Waste recycling and reuse should be incorporated into the research programs.

5 CONCLUSIONS

Prioritisation of building materials research areas cannot be done globally, but rather for a given country and time-frame. Global building materials research and development trends are towards the development of lightweight ultra-high performance concretes, Portland cement replacement, cement matrix and polymer matrix composites, recycling and reuse of waste materials, smart building materials, nanotechnology materials, green building materials, reduction of embodied energy, reduction of carbon footprint and the use of renewable bio-based materials.

For South Africa, research and development focus has been on cement and concrete, composites, waste recycling and reuse and recently nanotechnology materials. To significantly impact on cost reduction and delivery lead time, building materials research and development priorities in South Africa should be cement and concrete, light-weight steel construction, smart tiles and composite materials. Nanotechnology materials should be used for property enhancement. The building materials developed should be modularised and/or panelised for rapid construction. Virtually all developments that arose from building materials research and development impacted positively on reducing building life cost and delivery lead time. South Africa, while lagging behind the developed world is closely tracking global developments particularly in cement and concrete, steel and composites research.

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