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Positioning technology development in the South African construction industry: a technology foresight study

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Internationally infrastructure is ageing rapidly and there is increased utilisation of infrastructure due to urbanisation and globalisation. Significant amounts are invested globally to address this issue, although funding fluctuates from year to year. One response to this situation is to position the construction industry with advanced technological solutions. However, the construction industry is renowned for low levels of innovation and the South African government has also underfunded research into infrastructure. There is a need to stimulate innovation in the construction industry to develop the uniquely South African technological solutions required to provide and maintain economic and social infrastructure. An investment in construction innovation should be based on a review of the current state of construction technology and the industry and an analysis of the drivers and trends that will shape the future construction industry landscape. Technology foresight studies are recognised as one way to determine the future factors that will influence a specific economic sector. This article describes a new approach to conducting a technology foresight study within the South African construction industry. The methodology, as well as initial results from it, is reported. A review is provided of the current state of the construction industry and its potential drivers and trends. Future work will include scenario development and the development of pathways and interventions to take the industry forward from its current position to a desired future state.

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BACKGROUND TO THE STUDY

Investment in the construction industry

In many countries infrastructure is ageing or inadequate, particularly in developing countries where economic growth over the past decade has been significantly higher than the long-term average. The World Bank estimates that the projected funding gap for infrastructure in the USA is a significant US$ 1,6 trillion over a five-year period, while Asia will need an estimated US$ 1 trillion over the same period (ULI 2007). In South Africa there are also significant needs for infrastructure development, as is reflected in the Medium Term Strategic Framework (MTSF 2009) that refers to a "massive programme to build economic and social infrastructure", and by the recent special investment of R600 billion by the South African government into infrastructural development (Van der Merwe 2008).

Factors such as migration, urbanisation and population growth have created the situation where infrastructure is increasingly being overloaded. Consequently, and particularly in developing countries, the rate of increase in service delivery (electricity, water, sanitation, access roads and adequate housing) cannot keep up with demand (Rust *et al* 2008). Governments and the private sector around the world are investing significant amounts in gross fixed capital formation (GFCF), with the result that the construction industry has been growing despite the economic downturn. In South Africa the construction industry has grown by more than 15% per annum over a five-year period (SAFCEC 2008). SAFCEC (2010) also reports that, even though the industry was facing a significant slowdown in 2010, it was still projected to show real growth in the next 10-year period. SAFCEC (2010) states furthermore that this slowdown is not due to the completion of the infrastructure for the 2010 Soccer World Cup, but rather to a lack of national planning coordination.

In addition to the fluid economic situation, the construction industry also faces severe challenges related to skills shortages, increasing emphasis on environmental issues and energy shortages. However, the technology used in construction has aged and not kept up with advances in other sectors of the economy. In a recent survey in the UK, 66% of respondents indicated that the construction industry is not innovative enough (CIOB 2007). In South Africa this is also evident in the low levels of investment

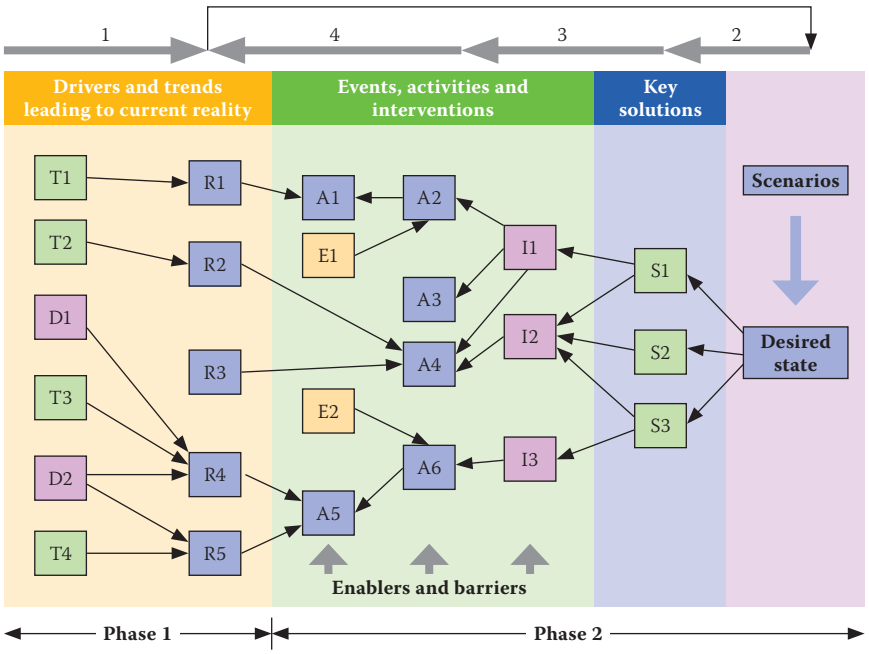

Figure 1 Phased approach to construction foresight study

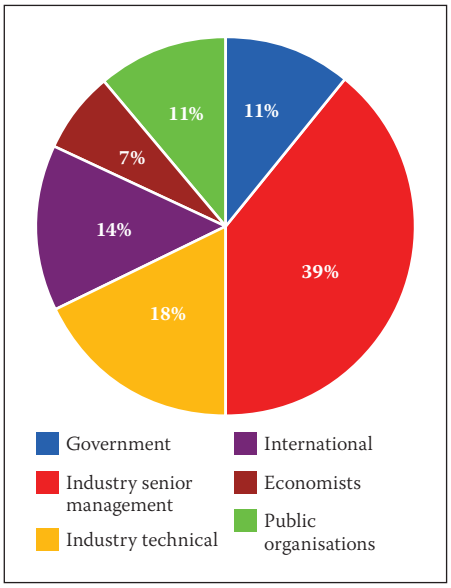

Figure 2 Distribution of thought-leaders interviewed

into research, development and innovation in the industry (Rust *et al* 2008b, HSRC 2006).

Why construction industry foresight?

In view of these challenges faced by the construction industry (be it in times of prosperity or in times of economic downturn), it is opportune to conduct the research, development and innovation (RD&I) projects that will position the industry more appropriately for the future. A rekindled RD&I activity in the South African construction industry will only provide maximum benefit if the appropriate focus for investment is selected. The purpose of a technology foresight study is to provide the information and basis for this investment decision.

Role players and purpose of the study

The Council for Scientific and Industrial Research (CSIR) and Murray & Roberts embarked on a joint project in 2008 to conduct a construction industry foresight study. The purpose of the ongoing work is to:

- understand and anticipate industry and market dynamics
- inform changes in strategic approach
- determine the required competencies to respond to market and industry needs, and
- provide the basis for decision-making in the investment of RD&I funding to develop the key solutions required to address current and future market needs.

Naturally, some of the information emanating from this study is of a confidential nature. Nevertheless, the results of general interest obtained thus far are reported here. The two phases of the study being conducted by the CSIR are indicated below. This article describes the findings of Phase 1.

RESEARCH METHODOLOGY

Approach

The ongoing study is planned in two phases. Phase 1 is aimed at developing a view of the current reality facing the industry in terms of drivers and trends in the industry. This will provide a basis for planning future strategic direction. Phase 2 will be aimed at the development of possible future scenarios for the construction industry in South Africa, which would inform desired key solutions and planning of the interventions and actions required to take the industry from the current reality to a future desired state. Phase 1 of the study has been completed, and this article describes the findings deriving from it.

Figure 1 depicts the overall methodology developed by the authors for this study. It is depicted as a network of drivers, trends, realities, events, actions and future outcomes that are interlinked and interdependent. The phased approach allows the development of a view of current reality in the construction industry and then 'leapfrogs' into the future to develop the potential future scenarios for the industry. From this point a backwards analysis can be conducted to determine the potential paths of interventions and activities that will be required to take the industry forward to the required future outcomes. The elements of the network can be weighted (using ratings from a user group) and a statistical analysis conducted to determine the most likely paths the industry should follow to reach the desired future state.

Methodology

The work done for Phase 1 of this study was mostly of a qualitative nature, combined with some quantitative analysis to support the qualitative findings. The qualitative research started with a desktop study to assess the current state of the construction industry locally and internationally, and the drivers of change in the industry. This work was augmented through 56 interviews with eminent thought-leaders from government, private sector, academia, research organisations and financial institutions. The distribution of the thought-leaders interviewed is shown in Figure 2. These interviews included, for example, the South African Construction Industry Development Board (CIDB) to provide information on the challenges experienced by contractors of all grading levels.

The qualitative analysis of the information gained during the desktop study led to the definition of 12 main drivers of change in the construction industry, as well as 24 trends in the industry. The interviews with the thought-leaders aimed to identify the major drivers, trends and potential disruptive forces or wild cards that could influence the industry in the medium term without sharing the desktop study information with them. The information gained from these interviews was then analysed to assess the importance attached by the thought-leaders to each of the drivers and trends identified in the desktop study. A simple key word count was used to score the importance of the drivers on a normalised five-point scale.

The drivers and trends were then presented to a group of 49 operational managers at middle management level in

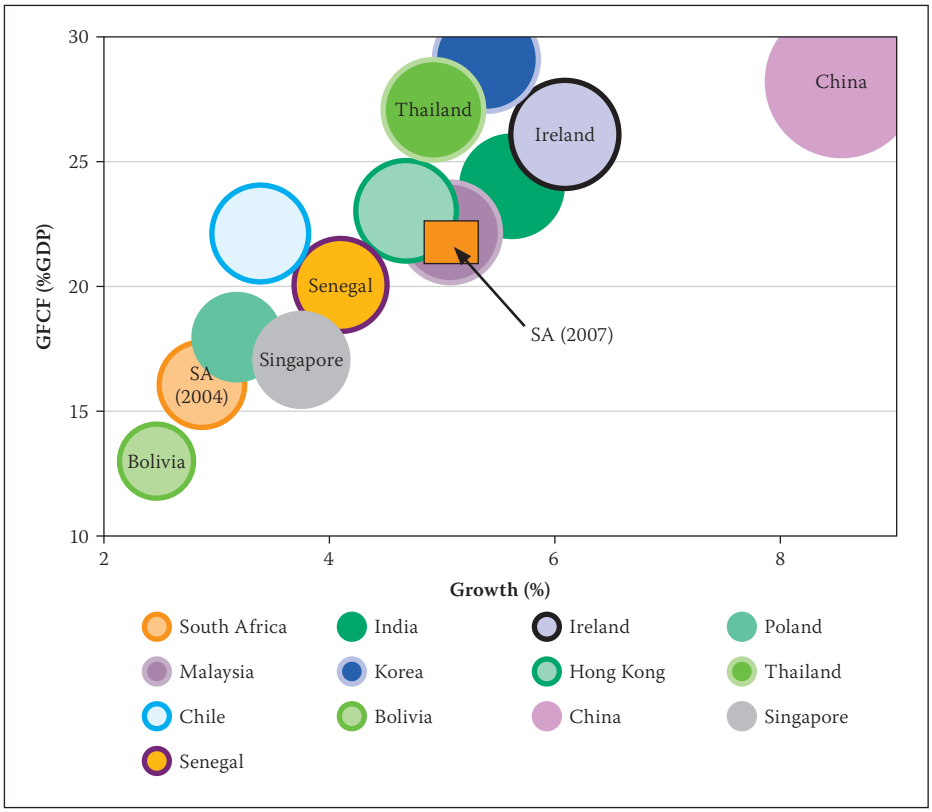

Figure 3 Relationship between GFCF and growth (Investec 2005)

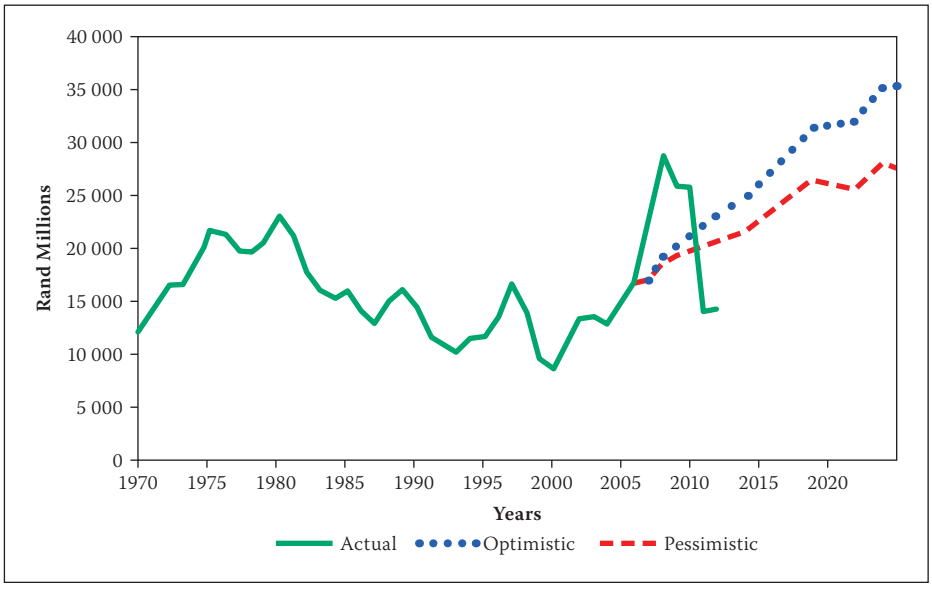

Figure 4 Civil Engineering Turnover: reality, optimistic scenario and pessimistic scenario (SAFCEC 2010)

companies in the Murray & Roberts Group and the participants were asked to evaluate the importance of the drivers and trends to the construction industry, both in the medium and short term. A five-point Likert scale was used (with a score of 5 indicating the highest importance) and the scores were analysed using statistical factor analysis as provided in the SAS version 9 statistical software. Using the results of the factor analysis, the 24 trends were distilled into seven 'mega-trends'.

Finally, the information was analysed to identify the short- to medium-term focus areas where the construction industry should focus its innovation activity.

CURRENT REALITIES FACING THE CONSTRUCTION INDUSTRY

During the desk-top study, various realities influencing the construction industry were identified from local and international publications. These included drivers such as world-wide ageing of infrastructure, fluctuating economies, emphasis on environmental impact and an inherent low level of innovation in the construction industry. These are discussed below.

State of infrastructure

There is concern about the ageing state of infrastructure all over the world. The Urban Land Institute in the USA states that:

> "The United States, in particular, and most of Europe stumble to repair and retool aging roads, plants, and levees that may no longer serve a changing paradigm for how people will live and work in the future." (ULI 2007).

In 2006 the South African Institution of Civil Engineering (SAICE) assessed the state of infrastructure in South Africa and developed an infrastructure report card (SAICE 2006). SAICE reported that, although the South African government had embarked on a programme of increased infrastructure spending, there is still a failure to invest in the maintenance and renewal of infrastructure. According to SAICE, most of the infrastructure in South Africa is in a fair, poor or very poor state.

Industry contribution

The built environment and construction industry play a significant role in sustainable growth and development. The built environment constitutes more than half of gross fixed capital investment in most countries, and construction output, as a global average, represents as much as 10% of global gross national product. Of the estimated US$ 3 000 billion annual global output of the industry, developing countries contribute 23%, while accounting for 75% of total global employment of construction workers (CICA 2002).

The relationship between economic growth and gross fixed capital formation (GFCF) is recognised internationally. Figure 3 shows the relationship for a selection of developed and developing countries (Investec 2005). As an enabler of economic growth, the construction industry stimulates growth by increasing the productive capacity of the economy through the provision of infrastructure to all sectors – both public and private. An established global benchmark is that GFCF should vary between 20% and 30% of GDP and that construction investment should represent between 20% and 30% of GFCF (4% to 9% of GDP), in order to generate a consistent economic growth rate of 5% and more (Murray & Roberts 2008).

Historic fluctuation in construction activity

The trend in construction GFCF in South Africa over the past 50 years is not one of steady and consistent growth. Historic peaks in construction works coincided with the two oil shocks in 1973 and 1978, and the Mossgas project in the late 1980s. In the same period, building activity responded with a similar pattern. From 1975 to 2000, both industry segments were "bumping along the bottom" and the contribution of

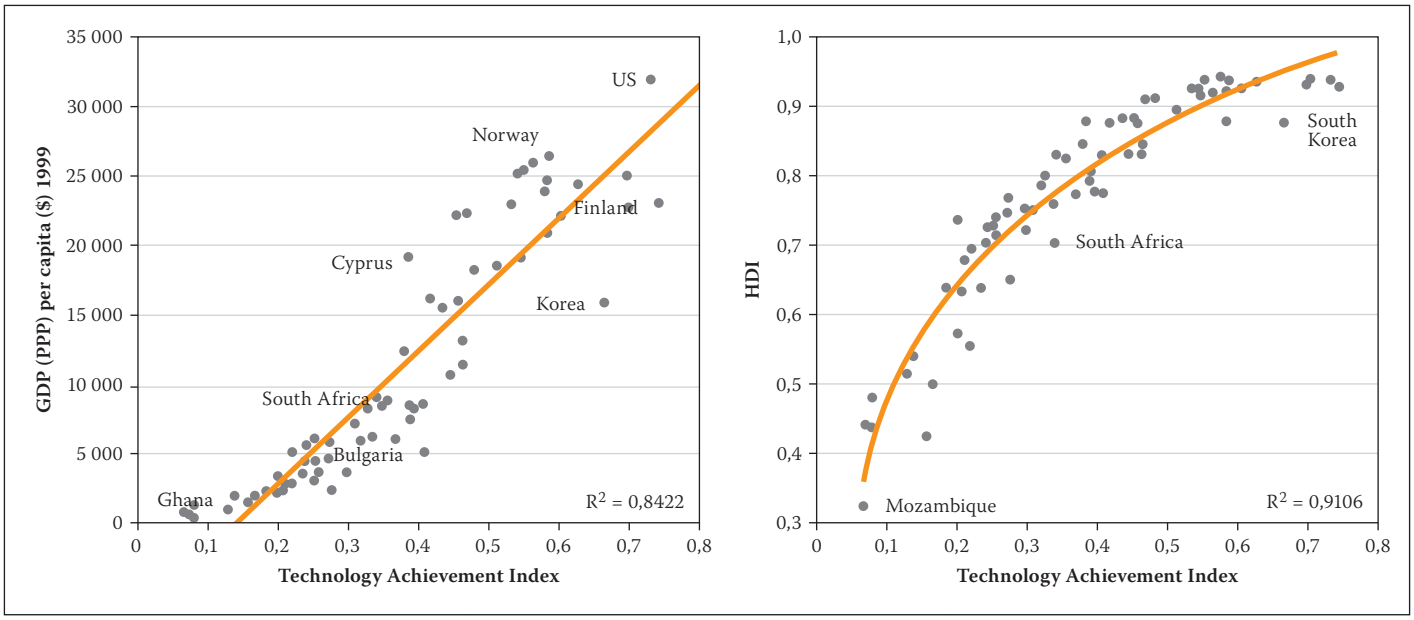

Figure 5 The dependence of wealth and living standards on technology (after United Nations, as reported in: Roux 2007)

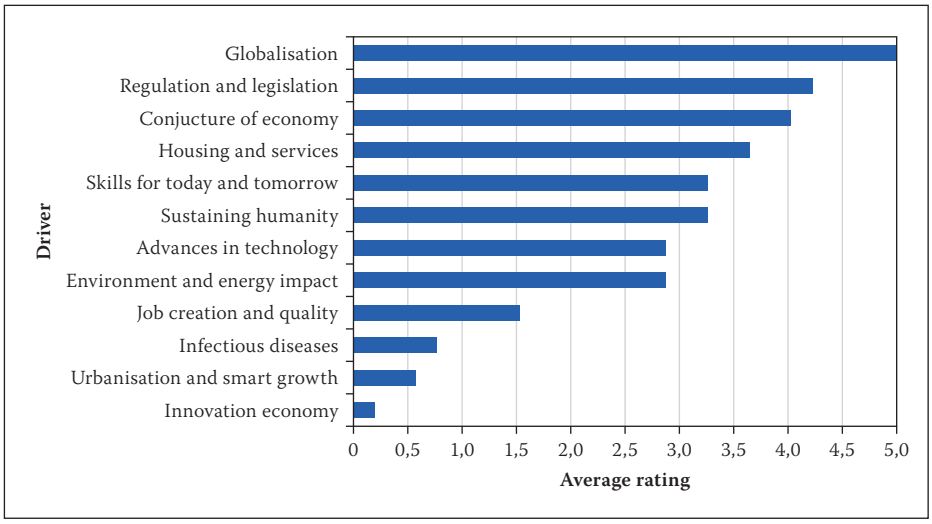

Figure 6 Ranking of the importance of drivers based on thought-leadership interviews

construction to GDP, GFCF and employment halved. Since 2001, however, the industry has experienced dramatic growth (Langenhoven 2007). This is depicted in Figure 4. This growth was tempered in late 2008 and 2009 due to the sub-prime crisis in the USA and the UK, especially in the residential building sector. Due to the recent investment in infrastructure by government, growth continued, but since the middle of 2009 there has been a significant downturn (SAFCEC 2010).

Importance of Science, Engineering and Technology

SET (Science, Engineering and Technology) has a broad impact on society, including the stimulation of economic growth, socio-economic impact and the environment. Kuittinen *et al* (2007) showed that R&D intensity has a significant impact on the financial performance of companies. The role of technology in the development of a country was also highlighted by Roux (2007) who indicated the relationship between the UN Technology Achievement Index (TAI), Gross Domestic Product (GDP) per capita and the Human Development Index (HDI), as illustrated in Figure 5. The data indicates that technology development (and therefore R&D to generate these new technologies) has a significant impact on both economic development and social development. The impact of R&D and SET on the construction industry is wide – for example, the enabling role of information and communication technology (ICT) in construction (Fischer and Kunz 2004), the use of new materials in house construction to reduce environmental impact (Morela *et al* 2000) and the impact of alternative materials in road construction (Rust *et al* 1994) – to name but a few examples.

The construction industry SET base is diverse with gaps in knowledge identified in areas such as local environmental conditions, local construction materials, urban form relating to apartheid legacy and rural development requirements (Rust *et al* 2008). The national R&D strategy has set a target of 1% of GDP to be spent on R&D. In many developed countries this figure is in excess of 2%. Rust *et al* (2008b) have found that investment in construction-related R&D in South Africa by the public sector is very low at about 0,3% of the total budget of the government departments. The National R&D survey found that from 2003 to 2005 less than 0,33% was spent on construction research by the private sector, public sector and universities. Thus technological development in the construction industry has fallen behind many other industries, with the consequent use of ageing technologies (Manseau and Seadon 2001).

CONSTRUCTION INDUSTRY DRIVERS AND TRENDS

Drivers of change

Phase 1 of this study focused on the identification of the drivers of change and trends that could influence the construction industry in the medium- to long-term future. For the purposes of this study, a driver of change is defined as a force external to the industry that influences its behaviour and current situation. The 12 drivers and their key characteristics (obtained from the desktop study) are summarised in Table 1.

The qualitative information gathered from the thought-leadership interviews was analysed by counting the frequency of the use of specific key words relating to each of the drivers by the interviewees. The score for each of the drivers was then normalised to a 5-point scale. This was used to rank the importance of the drivers as seen by the 56 thought-leaders interviewed. The results are shown in Figure 6.

Table 1 Summary of drivers of change and their key statistics

Driver	Description	Key statistics and facts
Globalisation	Geographic distance less important in cross-border economic, political and socio-cultural relations; increased integration and inter-dependency of human activity globally	Increased internationalisation of crime; investors will pay a premium of up to 22% for the shares of well-governed companies; increased importance of governance and international law; diaspora and migration across porous borders is causing changes in demographics and in some instances xenophobia
Conjuncture of the economy	Cyclical nature of the economy; long-term fluctuations of economic activity	Influenced by global trends as well as local economic policy; cyclical nature discussed above
Innovation economy	Economy driven by knowledge and innovation; a digital economy that boosts the productivity of existing industries and creates new industries	Depends on human skills and innovation rather than pure capital investment for economic growth; creates new industries such as biotechnology, nanotechnology and the internet; total R&D expenditure on construction is 0,3% of industry turnover, significantly lower than the South African target of 1%
Regulation and legislation	With associated Acts the driver is important in directing and controlling activity; includes phenomena such as consumer activism, shareholder pressure and corporate liability	In 2006 in the UK 11% of the population were active ethical consumers; shareholder pressure in terms of governance and corporate responsibility increasing; carbon taxes in SA are imminent; SA has a high Gini coefficient: 57,8; regulation on BBBEE and poverty alleviation becoming more important
Sustaining humanity	The need to improve human wellbeing and quality of life for a growing global population through poverty reduction, protection of basic human rights, improved health and food security and delivery of basic services	Globally 1,2 billion people lack access to water (SA 10 mil); 2,5 billion people globally lack access to adequate sanitation (SA 15 mil); 2,5 billion people globally lack access to energy; 900 mil people in rural areas have no reliable roads; 43,2% of SA population lives on income below R3 000 per annum; SA ranks 121st out of 177 countries on the Human Development Index; emphasis on human rights is increasing in private sector governance
Infectious diseases and HIV/AIDS	Infectious diseases include tuberculosis, malaria, polio, cholera, HIV/AIDS, hepatitis C, and other more exotic diseases such as Ebola fever and SARS, all of which have a significant impact on society	95% of deaths from infectious diseases occur in less developed countries; 22 million people in sub-Saharan Africa live with HIV/AIDS; 20% of the adult population of South Africa live with HIV/AIDS (320 000 deaths in 2005 in SA); rate of HIV/AIDS infections has flattened off
Environment and energy impact	The availability and sustainability of ecosystem services that provide food, water, materials, energy (including renewable energy sources) and the ability of the environment to absorb waste products	By 2100 temperatures may be 6°C higher; in 2005 world CO_2 emissions increased to 28 billion tons (17,5 billion in 1990); SA per capita CO_2 emissions 50% higher than global average; Secunda plant the highest single point of CO_2 emissions in the world; 1,930 million tons of CO_2 emissions per annum added by cement manufacturing; global energy demand increasing; 2008 SA budget : 2 c/kWh tax on non-renewable energy; carbon tax to follow; a R3.10 feed-in tariff for concentrated solar energy in SA; SA is classified as a water-stressed country
Urbanisation	Urbanisation occurs when an increasing proportion of a population becomes concentrated in urban areas due to redistribution of people from rural to urban settlements	By 2008 most people were living in cities (will be 60% by 2030); most growth occurring in Asia and Africa; poor countries will have to build a million people city each week for the next 45 years; 60% of all water used goes directly and indirectly to cities; 90% of increase in energy use is in cities; 59,3% of the South African population lived in urban areas in 2005 (global average: 48,7%) – by 2030 the SA figure is predicted to be 71,3%
Housing and services	Current backlogs in housing often lead to city slums and poverty. Urban slums lack adequate access to water, sanitation, security of tenure, structural quality of housing and living space	In 2001, 924 million people lived in slums (estimated to be two billion by 2033); 35 million new housing units are required every year for the next 25 years; in 2003 Africa had 187 million slum dwellers (20% of world total); up to 2008 government built 2,6 million houses, but still a backlog of 2,2 million; SA government aims to eradicate informal settlements by 2014
Skills for today and tomorrow	Scarcity of skills and a shift towards knowledge workers	Ten-fold disadvantage in SA in number of engineers compared with other countries; 95% of the construction industry experiences a critical shortage of skills (SAFCEC 2008); between 1996 and 2006 number of adults with no schooling halved to 6%; number of matriculants increased from 25% to 35%
Job creation and job quality	Need for job creation; changes in the nature of jobs in an innovation economy; job quality expectations of young entrants into the market	Construction not a preferred career option for young people; globalisation requires workers to be increasingly mobile; unemployment in SA is 23% (350 000 jobs per annum needed); generation Z will require the construction industry to be positioned for people who grew up with computers
Advances in technology	Encompasses so-called 'new age' technologies such as nanotechnology and biotechnology; technology trends that influence the construction industry	New construction technology focus areas need to be defined

These drivers can be grouped into three categories: high-order strategic drivers (global issues, regulation and the economy), more locally focused drivers (housing, sustaining humanity, local advances in technology, environmental and energy issues), and a grouping of drivers with lesser importance.

A questionnaire provided to the Murray & Roberts review group of 49 middle (operational) managers was used to rate the importance of the drivers in the medium as well as the long term. The top four drivers ranked by this group in terms of their perceived long-term importance were:

- Advances in technology
- Environment and energy impact
- Skills for today and tomorrow, and
- Job creation and quality.

This indicates that the more operationally-oriented middle-management group rated the technical drivers higher in importance than the industry thought-leaders. They also rated issues pertaining to their operational performance as more important (e.g. skills shortage and job quality). Both these viewpoints should be considered in the development of a balanced portfolio of innovation focus areas that address both short-term and long-term needs.

Trends in the construction industry

The study identified 24 trends in the construction industry, where a trend is defined as the change in the characteristics of a phenomenon over time. The information gained from the thought-leadership interviews was

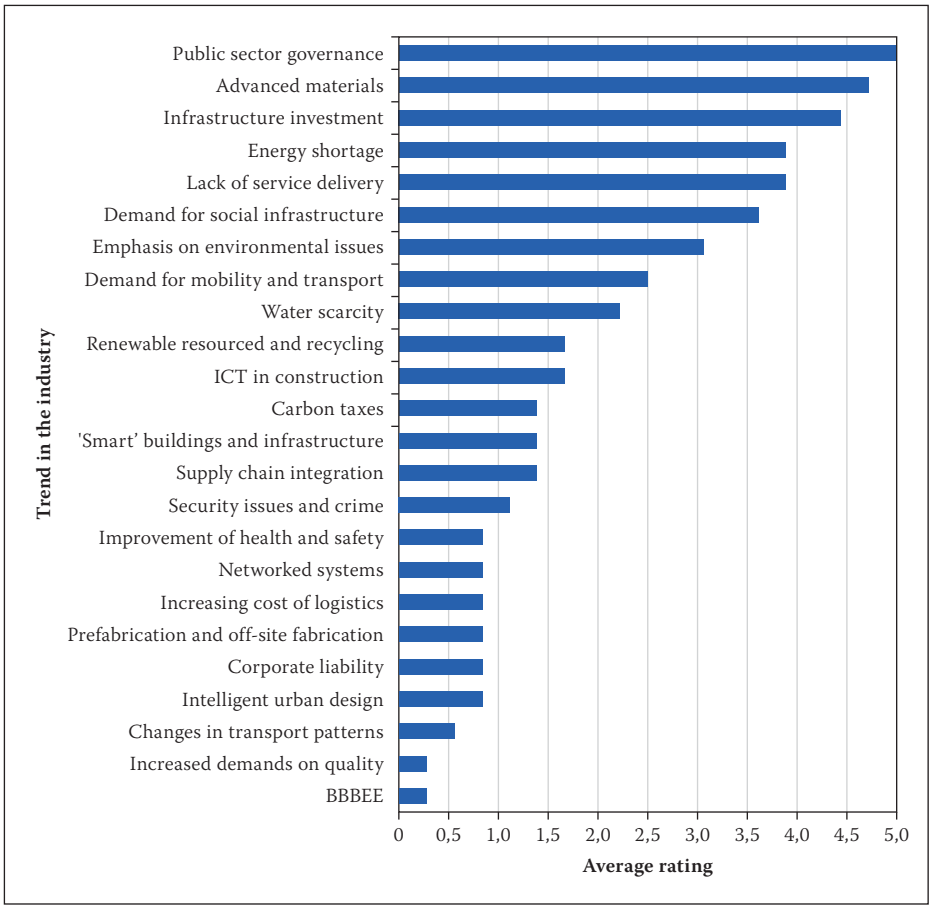

Figure 7 Frequency of mention of trends by thought-leadership group

Table 2 Mega trends derived from statistical analysis

No	Mega trend	Description	Eigenvalue	Proportion*
1	Industry positioning for environmental issues and associated solutions	Carbon taxes, renewable resources, environmentally friendly materials	5,94	46,4%
2	Increased emphasis on corporate responsibility	Safety, quality, BBBEE	1,81	14,2%
3	Enhanced capabilities for smart design of cities and infrastructure	Smart design, supply chain optimisation, smart construction methods, high performance materials	1,42	11,1%
4	Industry positioning for changes in the nature of transport	Increased transport demand, supply chain integration, changes in transport patterns	1,25	9,8%
5	Optimisation of transport operations	Minimisation of cost of logistics, safety and security, crime	0,91	7,1%
6	Focus on governance	Lack of governance and service delivery	0,84	6,5%
7	Information and Communications Technology (ICT) in construction	Improved networked systems, information and communication technologies	0,48	3,8%

* Proportion of the variation explained by each factor

analysed in the same manner as for the case of the drivers to determine the relative importance of the trends as seen by the thought-leaders. The ranking of the trends from this analysis is shown in Figure 7.

The ratings of the trends by the construction industry middle-management group was used to conduct a factor analysis in order to group them into possible 'mega trends' occurring in the construction industry that were viewed as important by the survey respondents. Seven such 'mega trends' were indentified, as shown in Table 2. The table indicates the eigenvalue of each individual factor (or mega trend), as well as the proportion of the variation in the data explained by that factor. The seven mega trends combined explain more than 95% of the variation in the importance ratings received from the participants, indicating that they are representative of the information provided by the respondents.

TECHNOLOGY RESPONSES AND FOCUS AREAS

The information gained from the qualitative and quantitative analyses, as well as further inputs from the thought-leaders and construction industry middle management group, was used to derive a number of technology focus areas and potential technology responses that the construction industry should consider. These focus areas and their link to the drivers and trends are shown in Table 3. The focus areas related to technological development are:

- Advanced materials and products
- ICT and robotics
- Alternative energy systems for the built environment, especially solar power
- Housing and alternative technologies for municipal service delivery
- Clean processes and technologies, and
- Logistics and supply chain optimisation.

The authors view these focus areas as an initial result from Phase 1. Detailed interventions required in each of the focus areas and their associated innovation projects will be determined during Phase 2.

CONCLUDING REMARKS

The construction industry in South Africa is an important contributor to and facilitator of socio-economic development and economic growth. The increasing load on infrastructure, the fact that infrastructure is ageing, and the impact of external drivers on the industry, emphasise the need for the industry as a whole to face its challenges with innovative solutions. However, the construction industry is notorious for low levels of innovation and there is a need in South Africa to enhance and focus innovation efforts in construction and the supporting R&D programmes. The initial results from this study have highlighted twelve drivers external to the construction industry that are expected to influence it in the medium term. The analysis of the ratings from the middle management group also identified seven 'mega trends' in the construction industry that will be shaping its immediate future. The inputs from the middle management group, as well as the analysis of drivers and trends, were also used to define important focus areas for innovation in the construction industry.

Table 3 Technology focus areas and their links to the drivers and trends

Focus area	Description	Drivers	Trends
Advanced materials and products	Light-weight, high-performance materials; smart materials; bitumen replacement; cement replacement; thin section concrete; concrete additives; fibre-reinforced concrete; building panels; advanced adhesives; materials for recycling	Advances in technology; environment and energy impact; housing and services	Advanced materials; carbon taxes; increased demand for social infrastructure; increased demands on quality; increased use of renewable resources and recycling; lack of service delivery; prefabrication and off-site manufacturing; 'smart' buildings and infrastructure
Alternative energy systems for the built environment, especially solar power	Solar and wind energy systems; biogas; biodiesel; integrated energy and water treatment systems	Sustaining humanity; environment and energy impact	Advanced materials; carbon taxes; increased emphasis on environmental issues; energy shortage
Housing and alternative technologies for municipal service delivery	Advanced housing systems and materials; advanced systems and infrastructure for sanitation; ecological water treatment systems; systems for integrated service delivery; use of waste for biogas; low water usage systems and technologies; technologies for rural service delivery	Sustaining humanity; housing; urbanisation	Government investment into infrastructure; increased demand for social infrastructure; lack of institutional capacity; intelligent urban design; lack of service delivery; water scarcity
Clean processes and technologies	Clean manufacturing; carbon footprint reduction; reduction of CO_2 from cement manufacturing; reduction of the use of cement	Regulation and legislation; environment and energy; advances in technology	Carbon taxes; corporate liability; improvement of health and safety; increased emphasis on environmental issues; increased use of renewable resources and recycling
Logistics and supply chain optimisation	Optimisation of logistics to reduce cost, improve productivity and reduce carbon footprint	Environment and energy; urbanisation	Increasing cost of logistics; supply chain integration; ICT in construction; energy shortage; increased demand for mobility and transport
ICT and robotics	Robotics (welding, mine safety); visualisation technologies; tagging technologies; surveillance; intelligent transport systems; data base management and data mining	Innovation economy; advances in technology	Improvement of health and safety; increased demands on quality; ICT in construction; 'smart' buildings and infrastructure; increased demand for mobility and transport
Skills, leadership and capacity development	Interventions to render construction attractive to young people as a career; mentoring programmes; focus on job quality; skills development	Skills for today and tomorrow; sustaining humanity; job creation and job quality	Increased demands on quality; scarcity of engineering skills; Broad Based Black Economic Empowerment (BBBEE); lack of institutional capacity
Health and safety	Zero harm management, mining safety	Regulation and legislation; job creation and job quality	Corporate liability; improvement of health and safety

The industry requires solutions that are specific to South Africa's needs. This implies that R&D and Innovation related to infrastructure should receive a higher priority in South Africa from government and the industry alike to facilitate such development.

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