What are Green Materials and Technologies

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Introduction

The potential impact of climate change and global warming is without doubt one of the most life-threatening challenges that face humanity. Central to this challenge is our dependence on fossil fuels as the primary source of energy – the major contributors of greenhouse gases (GHGs) including carbon dioxide (CO_2) – and the extensive use of non-renewable resources.

It is now widely recognised that the climate systems are warming: there is also medium confidence that other effects of regional climate change on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers. Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70 per cent between 1970 and 2004 . Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change, including severe species loss.

Nevertheless, a wide range of adaptation options is available, although a more progressive rate of adaptation than is currently evident is required. Given an increase in adaptation rates, many impacts can be reduced, delayed or avoided. There is thus a causal relationship between climate change mitigation and sustainable development: sustainable development can reduce vulnerability to climate change by enhancing adaptive capacity and increasing resilience.

The construction and maintenance of the built environment has a fundamental role to play in this challenge: green materials and technologies for new and existing buildings could considerably reduce CO_2 emissions while simultaneously improving indoor and outdoor air quality, social welfare, energy security, and ecological goods and services.

Background

The built environment is where the majority of the world's population now reside: one out of every two people live in a city (UN 1996). Global population has expanded more than six fold since 1800 and the gross world product more than 58-fold since 1820. As a result, the ecological footprint (EF) of humanity exceeds Earth's capacity by about 30 per cent. If we continue on the same development trajectory, by the early 2030s two planets will be required to keep up with humanity's demand for goods and services.

In 2013, the global building stock was 138.2 billion m^2, of which 73 percent was in residential buildings (Bloom & Goldstein 2014:2). It is forecast that the commercial and residential segments will experience compound annual growth rates (CAGRs) in the next 10 years of 2,1 percent and 2,2 percent respectively (Bloom & Goldstein 2014:3). Overall it is projected that the total building stock will grow to 171.3 billion m^2 at a GAGR of 2,2 percent over the next decade (Bloom & Goldstein 2014:3).

Most of the growth is expected to occur in China, where nearly 2.0 billion m² are added to the commercial and residential building stock every year. However, North America and Europe are each likely to make a significant contribution to the total building stock (Bloom & Goldstein 2014).

Interestingly enough, Bloom & Goldstein claim that commercial, residential, and industrial buildings are responsible for 47 percent of global greenhouse gas (GHG) emissions and 49 percent of the world's energy consumption (2014:1).

As stated earlier, the construction industry plays a critical role in the growth of the economy through its creation of immovable fixed assets. Because of this role Government has declared the construction industry a national priority (Cidb 2012:10).

According to StatisticsSA Gross Domestic Product, Quarter 1, 2014 (Statistical release P0441), the construction industry expanded R4 billion to R31 billion from the Q4: 2013 to Q1: 2014 (2014:4). Were this to continue at current rates investments in construction works should reach R124 billion by Q4: 2014.

Gross Fixed Capital Formation (GFCF) for the residential sector fell -2,2 percent year-on-year in Q4: 2011 based on constant 2005 prices, from R24,83bn to R24,29bn. The non-residential sector fell by 1,3 percent year-on-year in Q4: 2011, to R37,08bn from R37,56bn in Q4: 2010. GFCF in construction works rose 2,3 percent year-on-year in Q4: 2011, the highest growth rate over the past seven quarters with investment in construction works increasing to R110,36bn in Q4: 2011 from R107,89bn in Q4: 2010 (Industry Insight 2012:18).

The total economic activity in South Africa amounted to R9,3 trillion: the contribution of the non-residential real-estate totals R61 billion direct impact, R113 billion indirect impact and R173 billion induced impact (SAPOA 2014:49).

The total GDP for South Africa in 2013 was approximately R3,3 trillion of which the non-residential sector contributed 1,41 percent directly, 1,55 percent indirectly, and 2,39 percent induced (SAPOA 2014:51).

During 2013 the real estate sub-sector contributed R1,32 billion to the fixed capital stock of South Africa, while the gross fixed capital formation added R97,856 million to this figure over the same period, representing 20,9 percent and 14,95 percent respectively of the whole economy (SAPOA 2014:15). Of this capital formation, R69,697 million or 71,2 percent, is attributable to non-residential buildings (SAPOA 2014:15).

It is also a significant consumer of resources especially materials, energy and water: globally the construction industry is responsible for about 50% of all materials used, 45% of energy generated to heat, cool and light buildings and a further 5% to construct them, 40% of water used (in construction and operation), and 70% of all timber products that end up in construction (Edwards 2002). In South Africa, buildings account for 23% of electricity used, and a further 5% in the manufacturing of construction products (CIDB 2012).

The construction industry has traditionally been a slow adopter of new technologies in general, mainly due to the perceived associated risks (Woudhuysen and Abley, 2004). The building sector in particular is reluctant to adopt new technologies due to potential buyer resistance (Woudhuysen and Abley, 2004). Thus the sector undertakes most of its work with conventional technologies.

Green technologies really came into consideration with the emergence of the formal green building movement lead by the British Research Establishment (BRE), and Professors' Feist and Adamson in the late 1990s. This saw the publication of green building systems such as British Research Establishment's Environmental Assessment Method (BREEAM), and the Passivhaus concept respectively. Since then a number of new green building systems have emerged, including the Green Star® system as adopted by the Green Building Council of South Africa (GBCSA).

The introduction of these systems has heightened interest in green building, and in the technologies they use. While much of the technology remains conventional, to meet some of the performance requirements green technologies are required.

High Performance Green Building

Because buildings are often used for centuries, the rapid pace of development increasingly means that it is impossible to imagine the demands that future uses will place on buildings. Consequently, products and systems should be chosen that make adaptation easier. While aesthetic appeal will always be a component of building design, the real challenge is to create built environments that are durable and flexible, appropriate in their surroundings and provide high performance with less detrimental impacts.

In response to this challenge, a global initiative launched by the World Business Council for Sustainable Development (WBCSD) and supported by over 40 global companies aims to "transform the way buildings are conceived, constructed, operated and dismantled" to achieve zero energy consumption from external sources and zero net carbon dioxide emissions while being economically viable to construct and operate. Included in the initiative is the identification of the full range of present and future opportunities with regard to "ultra-efficient building materials and equipment". Additionally, this aim is enhanced by using the "cradle to cradle" concept of producing, using and later re-using building materials, a design evolution needed to achieve sustainability for buildings.

The current generation of 'green' buildings already offer significant improvements over conventional buildings inasmuch as they consume less energy, materials, and water; provide demonstrably healthier living and working environments; and greatly enhance the quality of the built environment, including the neighbourhood. However, these improvements are offered through the use of existing materials and products, design approaches, and construction methods. Because of this conventional approach to design and construction, it remains difficult to incorporate truly innovative technologies into current construction practice.

Good design is fundamental to sustainable construction. Decisions made at the initial design stage have the greatest effect on the overall sustainability impact of projects. The issues to be faced by radical high-performance green buildings favours construction products and methods that are flexible, light and durable: it is here that green materials and technologies emerge as a material-driven construction system capable of achieving the prerequisite performance standards.

Prudent use of natural resources results in both greater industry efficiency and a restricted usage of natural materials. Practices such as materials recycling, waste minimisation, local product resourcing, land decontamination, and construction- and demolition-waste disposal make sound business sense and encourage good construction housekeeping. Application of the principles of 'lean construction' and life-cycle analysis are equally important.

The characteristics of high-performance green building as suggested by Fujita Research (2000) include:

1) Optimal environmental and economic performance;
2) Integrated processes, innovative design and increased efficiencies to save energy and resources;
3) Satisfying, healthy, productive, quality indoor spaces;
4) Employing lean construction methodologies and tools to improve waste management and reduce the environmental impact of construction waste;
5) Increasing the emphasis, at R&D stage, of whole-building design, construction and operation over the entire life cycle;
6) Fully integrated approach including teams, processes and systems;
7) Renewal engineering methods;
8) Management and business practices;
9) New standards, open buildings, advance jointing and assembly techniques, process engineering; and
10) Materials and systems: new function integrated building components, durability, repairability, and retrofit-ability of components.

In High Performance construction, the key issue is how the choice of construction products and methods can create scope for reducing burdens.

Green Materials

The market for building materials is predicted to grow steadily into the foreseeable future. The primary driver for growth by sheer volume is the ongoing government investment in new buildings and other physical infrastructure in developing countries such as South Africa. At the same time, the demand for building materials is shifting towards environmentally preferable or "green" materials due to consumer demand; and an ever growing number of mandatory environmental regulations and standards.

Green materials use is predicated on the replacement of future flows of conventional building materials with "green" materials. From an environmental perspective, "green" materials would need to be those materials with the least "embodied effects", where the word embodied refers to attribution or allocation in an accounting sense as opposed to true physical embodiment. In the building community, the tendency is to refer only to "embodied energy" (Trusty and Horst, 2006). However, as implied by the comprehensive list of effect categories (Table 1) typically investigated in a Life Cycle Assessment (LCA) study, all the extractions from and releases to nature are embodied effects, and there are also embodied effects associated with the making and moving of energy itself (known as pre-combustion energy).

Table 1: Embodied effects typically investigated in a Life Cycle Assessment

Inputs (extractions from nature)	Outputs (release to the environment)
Energy	**Acidification**
Land	**Climate change**

Materials **Water**	**Eutrophication** **Eco-toxicity** **Human toxicity** **Photo-chemical oxidant formation** **Stratospheric ozone depletion**

Until the 1970s, the construction industry sector made little attempt to establish objective and comprehensive methods for environmental assessment and improvement of buildings. The concept of Sustainable Construction which is "The creation and operation of a healthy built environment based on ecological principles" (Kibert, 1994) was first mooted in the wake of the 1987 Brundtland Report and the 1992 Rio Accords. Starting with the launch of the Building Research Establishment Environmental Assessment Method (BREEAM) in 1990, a large number of building rating and assessment systems have been developed around the world to provide the basis for putting Sustainable Construction into practice.

However, rating tools are not underpinned by robust science. The environmental improvements suggested are not benchmarked against empirical data (Reijnders and van Roekel, 1999). There is a lack of credits dealing directly with the environmental problems (embodied effects) of concern to society (Zimmerman and Kibert, 2007). These deficiencies are most notable in the case of materials selection which is generally informed by prescriptive easy-to-follow directions, for example, use materials with recycled content (Blom, 2006; Trusty, 2007).

Green Technologies

Green technologies in the building sector can be defined as those technologies which reduce the environmental impact of building on the environment. These technologies would either reduce environmental impact through the development of more environmentally friendly materials and products, or through the generation and/or conservation of resources such as energy and water.

Table 2: A Selection of Green Technologies

Technology	Description	Green characteristics
Advanced cladding systems	High performance building envelopes, generally modular and light-weight	Reduced embodied energy Reduced energy consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production Reduced material mass Self-cleaning Lower maintenance More durable Recyclable Reusable
Chilled beams	Type of convention heating, ventilation and air conditioning system using a heat exchanger to heat or cool space	Reduced energy consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production Greater efficiency

Co-generation and tri-generation	Generation of electricity and heat mainly from gas	Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production
Demand-controlled ventilation	Provides the correct level of heating/cooling for the actual occupancy	Reduces energy consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production Improved efficiency Improves thermal comfort for occupants
Dual-wall facades	Combination of two or more high performance walling systems	Reduces energy consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production Improves thermal comfort for occupants
Heat pumps	Provides heat energy from a source of heat to a destination called a heat sink	Reduces energy consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production
Electrochromic glass	Changes light transmission in response to voltage, light or heat applications thereby controlling the amount of light and heat transmitted	Reduced energy consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production Reduces glare Improves occupant comfort
Fuel cells	Converts chemical energy from a fuel into electricity through a chemical reaction with an oxidising agent	Reduces fossil-fuel derived energy consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production
Geothermal systems	Uses geothermal energy for heating or cooling applications	Reduces fossil-fuel derived energy consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production
Green infrastructure	Includes a range of technologies that mimic natural systems to collect, treat, handle water and sanitation	Uses natural systems and process (e.g. bioretention) Reduced reliance on chemical processes Reduces greenhouse gas emissions Reduced energy consumption Reduces water consumption associated with fossil-fuel derived electricity production Enhances natural processes Enhances ecological goods and services
Innovative Building Technologies	Includes a range of building	Reduced material mass

(IBTs)	systems that are generally lightweight using light steel section frames with insulated core and clad externally and internally	Reduced embodied energy Reduced chemical content Lower toxicity Improved energy efficiency in use Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production
Radiant heating/cooling	Heats and cools surfaces rather than air which then radiate into the occupied space	Reduces energy consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production Improves occupant health Improves occupant comfort
Smart and Intelligent Systems	Uses sensors and actuators to respond to predetermined inputs	Reduces energy consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production Improves occupant health Improves occupant comfort
Solar absorption chillers	Uses solar thermal energy to drive air conditioners	Eliminates fossil fuel consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production
Solar energy	Uses sun energy to either heat a medium (solar water heaters) or to generate electricity (photovoltaic panels)	Reduces fossil-fuel derived energy consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production
Thermal energy storage	Allows excess energy to be collected for later use through mediums such as water, ice, and earth	Reduces fossil-fuel derived energy consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production
Passive ventilation	Uses non-mechanised ventilation systems to ventilate buildings	Reduces energy consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production Improves occupant health Improves occupant comfort
Underfloor air distribution	Relies on air displacement techniques	Reduces energy consumption Reduces greenhouse gas emissions Reduces water consumption associated with fossil-fuel derived electricity production Improves occupant health Improves occupant comfort
Wind turbines	Uses wind energy to generate electricity	Reduces energy consumption Reduces greenhouse gas emissions Reduces water consumption

		associated with fossil-fuel derived electricity production

Conclusion

The construction industry sector is the largest documented user of materials by weight. The market for building materials is predicted to grow steadily into the foreseeable future driven by ongoing investments in built infrastructure and the consumer demand for "green" products. Sustainable materials use is thus predicated on the replacement of future flows of conventional with innovative building materials which have the least embodied effects where the "effects" in question are flows of key natural resources – energy, land, materials and water; and emissions to air, land and water.

The results of previous building-related LCA studies, used here as illustrative examples, and limited mostly to energy cases because of a dearth of other data, suggest that a transition to sustainable materials use would require at least:

i) The integration of LCA-based tools into "green" building material assessment and rating. The literature suggests that this is already happening in the case of LEED (USA), Green Star (Australia) and BREEAM (UK).

ii) Substitution of toxic with environmentally benign building materials. The literature and the results of previous studies indicate that toxic substances are frequently included in the formulation of building materials with devastating consequences for human and ecological health. A step change would entail possibly mandatory provisions in respect of testing, certification and labelling; and a chemical policy – to exclude inherently toxic materials such as PVC.

iii) Design for disassembly or deconstruction to facilitate maximum reuse of discarded building materials, elements and components. This would be the "cornerstone" of the sustainable materials framework, stemming the flows from and to nature and resulting in the avoidance of potential embodied effects associated with those flows. This aspect may need to be supported by mandatory environmental product reporting (EPR).

iv) Design with durability or service life in mind. The results of previous LCA studies emphasis the need for designers to either choose long life interior finishing materials; or to select shorter life materials provided the latter can be led back into EPR scheme. Building designers would need access to a comprehensive service life database on building types and building materials and components to support implementation of this aspect.

References

Blom, I. 2006. "Environmental assessment of buildings: bottlenecks in current practice." In ENHR International Conference, Ljubljana, July 2006.

Bloom, E., and Goldstein, N., 2014. "Global Building Stock Database", Boulder, Colorado, Navigant Consulting, Inc.

Cidb 2012., “Annual Report 2011/12”, Pretoria, Construction Industry Development Board.

Edwards, B., 2002. “Rough guide to sustainability.” London, Royal Institute of British Architects.

Industry Insight 2012. “State of the South African Construction Industry, 2nd Quarter 2012”, Johannesburg, Industry Insight.

UNEP/CIDB 2012. “South African Report on greenhouse gas emission reduction potentials from buildings.” Pretoria, UNEP/SBCI/CIDB.

Fujita Research 2000. “What is sustainable construction?” Accessed www.fujitaresearch.com/

Kibert, C.J., Sendzimar, J. and Guy, B. 2000. “Construction ecology and metabolism: natural system analogues for a sustainable built environment.” *Construction Management and Economics*, 18(2000): 903-916.

Reijnders, L. and Van Roekel, A. 1999. “Comprehensiveness and adequacy of tools for the environmental assessment of buildings.” *Journal of Cleaner Production*, 7(3), 221-225.

SAPOA 2014. “The Economic Impact of the Commercial Real Estate Sector on the South African Economy”, Sandton, South African Property Owners Association.

StatisticsSA 2014. “Gross Domestic Product, Quarter 1, 2014”, Statistical release P0441, Pretoria, Statistics South Africa.

Trusty, W.B. 2007. “Separating process and prescriptive measures from building performance.” Accessed http://www.athenasmi.org/

Trusty, W.B. and Horst, S., 2006. “LCA tools around the world”, Building Design and Construction. Accessed www.bdcnetwork.com/

UN 1996. “Istanbul Declaration on Human Settlements”, New York, United Nations Human Settlements Programme.

Woudhuysen and Abley, 2004. “Why is building so backward?” England, Wiley Academy.

Zimmerman, A. and Kibert, C.J. 2007. “Informing LEED’s next generation with the natural step.” *Building Research and Information* (2007) 35(6), 681-689.