Paper

A framework for the assessment of the structural performance of 21st century buildings

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Synopsis

Standards for buildings have over the centuries reflected the societal values and expectations of the day. Health and safety considerations have dominated the design considerations for the structural systems for building for the past few centuries. Fitness for purpose of such systems is assessed in terms of structural safety, serviceability and durability and, depending upon the design, nature and usage of buildings, fire safety, resistance to moisture penetration and constructibility might also be considered. Societal expectations of the 21st century demand that the structural system for buildings be not only fit for purpose in use but also contribute to sustainable development over life cycle. This paper proposes a performance framework within which the structural system of both new and existing buildings may be assessed in terms of both their fitness for purpose in use and their contribution to sustainable development over life cycle.

Introduction

The built environment comprises the man-made surroundings that provide the setting for human activity. Buildings, which provide shelter for humans, animals, or property of any kind, are central to the built environment and the economy of any country as well as the well being of its inhabitants. Buildings shape and define the environment in which humans live, work and relax.

It is not surprising that building standards have been in place ever since man has been able to capture his thoughts in writing. The earliest known building code is that of Hammurabi (about 1780 BC), the sixth king of Babylon. This code dealt with the two basic issues, namely the fee a builder was to be paid for completing a house and the recourse that an owner had to that builder in the event that the house was not properly constructed. In terms of this performance based code, builders were required, at their own cost, to make stable any walls that appeared to be unstable prior to the completion of the house and to compensate the owner in the event of collapse. Penalties for the collapse of a building were dependent on the deaths or damage that occurred. For example, if the collapse killed the owner, the builder was put to death; if the owner's son died, the builder's son was put to death.

With urbanisation came the scourge of fire and health risks associated with poor sanitation. Over the centuries, many cities were razed to the ground by fire and millions of people died as a result of poor sanitary conditions in highly populated areas. It is not surprising that the 19th century law makers developed building laws to secure proper sanitary conditions and to diminish the outbreaks and disastrous consequences of fires in cities.

Law makers in the 20th century developed minimum standards for the construction and maintenance of buildings designed to protect public health, safety and general welfare. As such they dealt with the issues of structural safety and serviceability, fire safety, health and hygiene, moisture penetration, safety, accessibility and usability. Many of these standards, particularly the earlier ones, were prescriptive in nature and addressed only local or conventional construction techniques and methods.

Standards for buildings reflect societal values and expectations. Building standards for the 21st century need to be developed to address the issues of the day. The Earth's resources are finite. Current growth rate trends indicate that the world's population is set to increase from 6.5bn to 13bn by 2067. To accommodate this growth in a sustainable manner, the built environment of 2067 will need to be very different from what we see today. Law makers have begun to develop minimum standards to protect the environment, e.g. the efficient usage of energy has during the last decade become regulated in many jurisdictions.

This paper establishes a common performance framework for the design and assessment of a structural system for a building which satisfies the two fundamental 21st century requirements, namely fitness for purpose in use and contribution to sustainable development over life cycle. It firstly describes the performance framework currently employed in 'designing for fitness for purpose in use' which is primarily concerned with safety, health and function. It then shows that 'contribution to sustainable development' can also be included in the performance framework by extending the definitions of performance description and parameters.

Designing for fitness for purpose in use

ISO/IEC Guide 2 defines 'fitness for purpose' as an ability of a product, process or service to serve a defined purpose under specific conditions and a 'performance provision' as a provision for fitness for purpose that concerns the behaviour of a product, process or service in or in relation to use[1]. ISO 6707-1 on the other hand, defines 'quality' as the totality of properties that bear on the ability to satisfy specific needs and 'performance' as an ability of a product to fulfill required functions under intended use conditions or behaviour when in use[2].

Fitness for purpose links quality (needs) with performance (stated outcomes in terms of required functions). Accordingly, fitness for purpose in the context of the structural system for a building can be considered to be the ability of the structural system as a whole or any part thereof to fulfill required functions under intended use conditions or behaviour when in use.

The description of performance in relation to fitness for purpose of the structural system for a building can best be described in terms of a hierarchy that starts with an objective followed by a performance description and performance parameters and ends with the means for evaluating solutions for compliance with performance requirements[3] (See Fig 1). The performance description and performance parameters collectively constitute statements of the performance demanded or expected to be fulfilled in response to user requirements.

Table 1 lists the agents (whatever acts on the building or parts of a building) relevant to the performance in use of the structure of a building and its components where fitness for purpose is considered[4]. Agents that apply in any particular situation can be considered separately or in combination with each other.

Structural performance needs to be assessed primarily from three perspectives, namely safety, serviceability and durability.

Generic objectives (level 1) and performance statements (levels 2 and 3) can be derived from parts of ISO 15928 as indicated in table 2.5. The structural performance of the structural system of a building can be fully described should a set of performance parameters be formulated around the principles contained in the last column of Table 2.

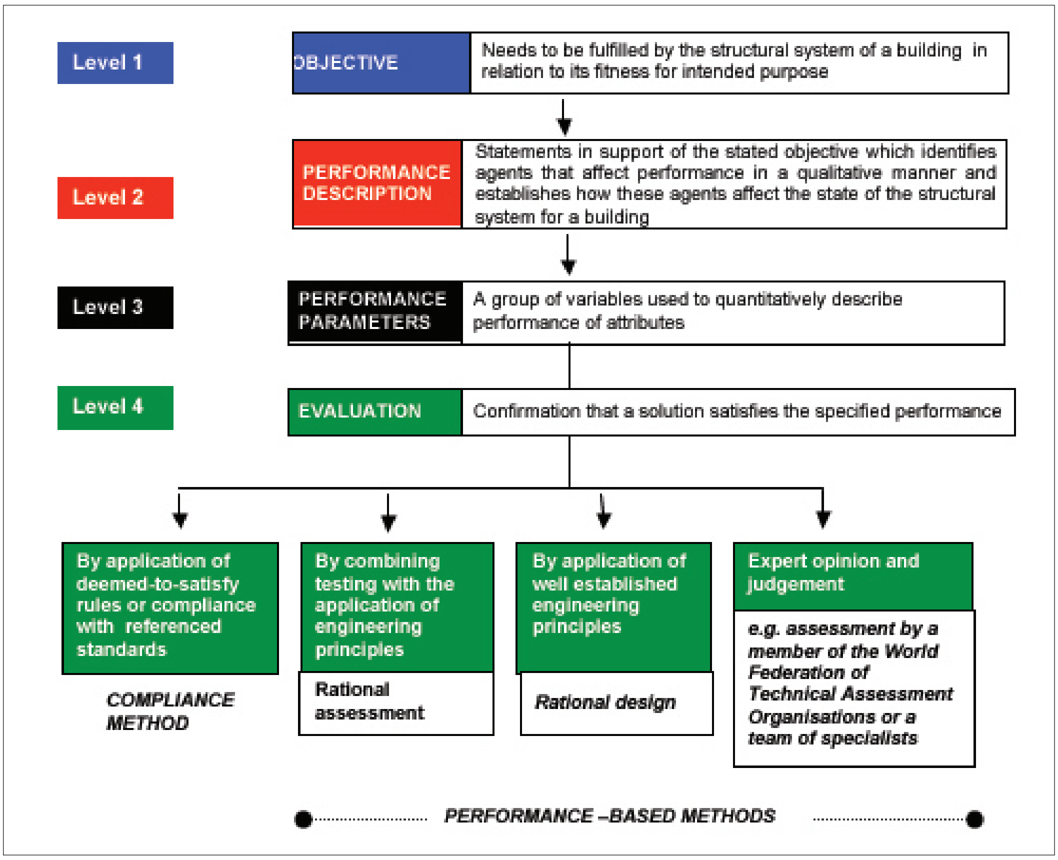
There are also, depending upon the design, nature and usage of buildings, secondary performance requirements to consider in the design of a structural system. Consideration may have to be given to fire safety performance relating to the withstanding of fire and the provision of protection to occupants and adjacent properties when subject to any accidental fire in terms of the probability of ignition occurring, either from internal or external causes. Parameters for describing containment of fire spread can include the resistance to fire spread in terms of the amount of time required for the fire to spread from one storey to another or from one building to another or the combustibility characteristics of the materials. The parameters for the control of structural behaviour under fire conditions can be described by a combination of the control of the collapse mode under fire and fire resistance of load bearing system and components[6].

Consideration may also have to be given to the resistance to

Nature		Origin			
		External to the structure		Internal to the structure	
		Atmosphere	Ground	Occupancy	Design consequences
Mechanical agents	Gravitation	Snow loads, rain-water and hail loads	Ground pressure, water pressure	Live loads, fittings and fixtures	Dead loads
	Forces and imposed or restrained deformations	Ice formation pressure, thermal and moisture expansion	Subsidence, heave, collapse settlement, slip, flood waters, tsunamis	Handling forces, construction loads, indentation (notch)	Shrinkage, creep, forces and imposed deformations
	Kinetic energy	Wind, hail, external impacts, sandstorm,	Seismic (earthquake or mining induced)	Internal impacts, wear	Water hammer
	Vibrations and noises	Wind, wind-borne debris, thunder, aeroplanes, explosions, traffic, machinery noises	Traffic and machinery vibrations	Noise and vibration from music, dancers, domestic appliances	Services noises and vibrations
Electro-magnetic agents	Radiation	Solar radiation, radioactive radiation	Radioactive radiation	Lamps, radioactive radiation	Radiating surface
	Electricity	Lighting	Stray currents	–	Static electricity, electrical supply
	Magnetism	–	–	Magnetic fields	Magnetic fields
Thermal agents		Heat, frost, thermal shock	Ground heat, frost	User emitted heat, cigarette	Heating, fire
Chemical agents	Water and solvents	Air humidity, condensations, precipitations	Surface water, ground water	Water sprays, condensation, detergents, alcohol	Water supply, waste water, seepage
	Oxidizing agents	Oxygen, ozone, oxides of nitrogen	Positive electrochemical potentials	Disinfectant, bleach	Positive electrochemical potentials
	Reducing agents	–	Sulfides	Agents of combustion, ammonia	Agents of combustion, negative electrochemical potentials
	Acid	Carbonic acid, bird droppings, sulphuric acid	Carbonic acid, humic acids	Vinegar, citric acid, carbonic acid	Sulphuric acid, carbonic acid
	Bases	–	Lime	Sodium hydroxide, potassium hydroxide, ammonium hydroxide	Sodium hydroxide, cement
	Salts	Salty fog	Nitrates, phosphates, chlorides, sulfates	Sodium chloride	Calcium chloride, sulfates, plaster
	Chemically neutral	Neutral dust	Limestone, silica	Fat, oil, ink, neutral dust	Fat, oil, neutral dust
Biological agents	Vegetable and microbial	Bacteria, seeds	Bacteria, moulds, fungi, roots	Bacteria, house plants	–
	Animal	Insects, birds	Rodents, termites, worms	Domestic animals	–

NOTE The agents are listed according to their own nature and not according to the nature of their action on the buildings or components; for example, a thermal agent may have a physical action (e.g. heating) or a chemical action (e.g. catalysis); a chemical agent like water also may have a physical action (e.g. dissolution) or a chemical action (e.g. hydration); moreover, the agents combined with each other may have additional physical actions (for example wetting followed by freeze-thaw cycles), chemical actions (e.g. photo-oxidation by atmospheric oxygen and solar radiation) or biological actions (e.g. spread of roots).

Table 1 Agents relevant to the performance of the structural system in relation to fitness for purpose (after ISO 6241)



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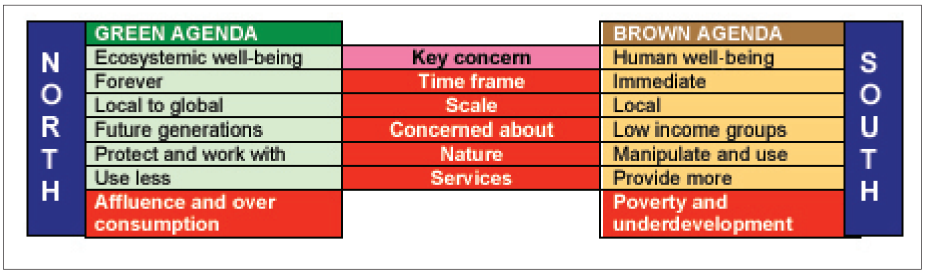
1 The performance framework for the design and appraisal of a structural system for a building to satisfy fitness for purpose requirements (after Watermeyer and Milford, 2003)

Attribute	Objective	Performance statements	
		Performance description	Principles for formulating performance parameters
Structural safety performance (behaviour of buildings under possible actions related to human lives)	The risk of collapse or other kind of severe damage resulting from structural failure, which may affect the life safety of the building occupants, or people in its vicinity, shall not exceed a level acceptable to the user	The whole building and its parts shall, with an appropriate degree of reliability, maintain strength and stability under all actions likely to occur during the building's design working life	Nominate the structural actions on the building (permanent, imposed, wind, seismic, snow and other actions) and the resistance of the structure under the effect of those actions (limit state or allowable stress criteria)
Structural serviceability (structural behaviour of a building for normal use under all expected actions that might affect the occupants and the functioning of the building)	The following characteristics of a building, for normal use and conditions, under all expected actions, shall be kept within levels acceptable to the user: a) functioning and appearance of the building and its components; b) functioning of the occupants and equipment in the building; c) comfort of the occupants; d) asset value of the building	The whole building and its parts shall, with an appropriate degree of reliability, perform within established parameters under all expected actions for normal use in terms of: a) local damage, including cracking b) deformation c) vibration	Nominate the structural actions on the building (permanent, imposed, wind, seismic, snow and other actions, vibratory and impact sources, ground conditions and movements) under normal use and the structural responses relevant to serviceability issues under the effect of those actions (deformations, vibrations, local damages and responses to impacts)
Structural durability (capability of a structure or any component to satisfy, with planned maintenance, the structural design performance requirements over a specified period of time under the influence of the environmental actions, or a result of a self-ageing process)	The structural safety and serviceability performance of the building shall be acceptable to the user over the specified design working life	The whole building and its parts shall, with an appropriate degree of reliability, fulfil its intended safety and serviceability performance in the environment in which it is located over the specified design working life when subject to its intended use taking into account the: a) external and internal environmental agents (including those associated with microclimates that can arise in buildings); b) maintenance schedule and specified component design life; c) changes in form or properties	Specify the component design life, the maintenance schedule, geographical location and influences to be considered i.e. moisture, air and ground constituents and contaminants; biological agents/life, temperature, solar radiation, incompatible chemicals, use or exposure etc.

Table 2 Primary fitness for purpose objectives and performance statements for the structural system of a building (after ISO 15928)



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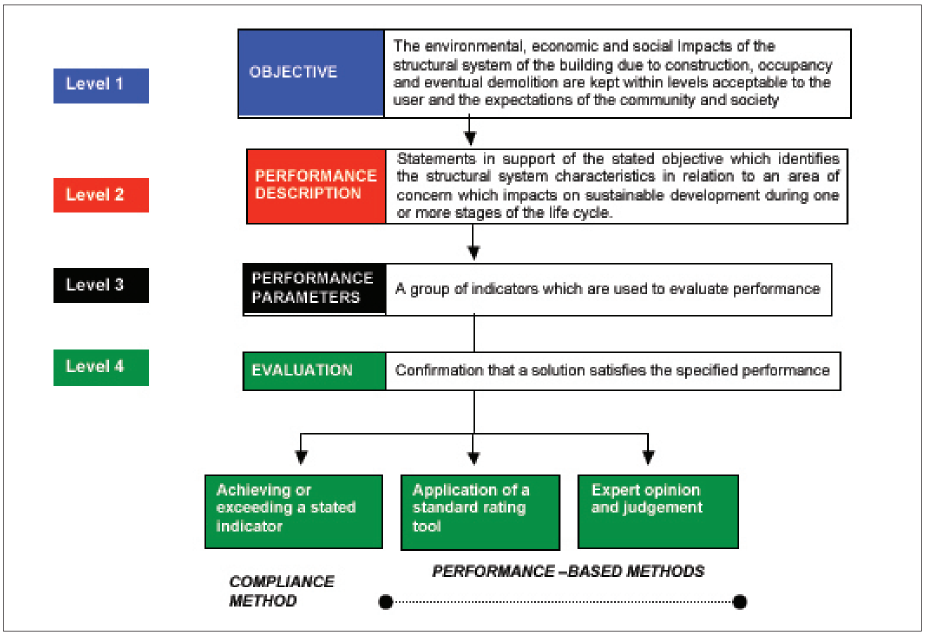

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2 The 'fundamental differences' between the 'green' and 'brown' agendas (Watermeyer 2006)

3 The performance framework for the design of a structural system that contributes to sustainable development

moisture penetration i.e. the ability of the whole building with an appropriate degree of reliability to resist the penetration of rain water and the passage of moisture into its interior[7]. In some instances, performance requirements relating to constructibility might also have to be considered.

Designing for contribution to sustainable development over life cycle

Sustainability and sustainable development within the context of the construction sector

ISO 15392 defines 'sustainability' as the state in which ecosystem components and functions are maintained for the present and future generations whilst meeting current needs and 'sustainable development' as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Sustainability is according to ISO 15392 the goal of sustainable development[8].

Sustainability is a continuous process of maintaining a dynamic balance between the demands of people and what is ecologically possible. Sustainable development, on the other hand, contains two key concepts, namely the concept of the need for sustainable habitats in which present and future generations can live healthy lives and the idea that the state of technology and social organisation, both now and in the future, impose limits on the environment's ability to meet present and future needs. Sustainable development is also very much about eradicating poverty in many parts of the world and social equity in others. Sustainable development is rooted in the simple concept of providing a better quality of life for all, now and for generations to come. It is a way of looking at all resources that will lead to a higher quality of life for the current generation, without compromising that of future generations.

Sustainable development is not just about development that is sustainable i.e. ongoing, viable, feasible or continually growing. Sustainability includes consideration of the three primary aspects of sustainability, namely – economic, environmental, and social aspects. These aspects are inextricably linked to each other and are interdependent. Where structures are owned by public authorities or local government, the capacity and effectiveness of the institutional environment to maintain such structures over their lifetime also needs to be considered.

While the challenge of sustainable development is global, the strategies for addressing sustainability in structures are local and differ in context and content from region to region. Such strategies need to reflect the context not only in the built environment, but also in the social environment which includes social equity, cultural issues, traditions, heritage issues, human health and comfort, social infrastructure and safe and healthy environments. It may in addition, particularly in developing countries, include poverty reduction, job creation, access to safe, affordable and healthy shelter and mitigation of loss of livelihoods.

Given the disparities in standards of living between the developed and developing countries, the general approach to the social component is very different. This results in different development priorities between the 'north' (developed nations) and 'south' (developing nations) as illustrated in Fig 2. In countries with dual economies such as South Africa, the priorities differ regionally and within communities, depending upon where the poor and the affluent live[9].

The so-called 'green' agenda (earth agenda) focuses on the reduction of the environmental impact of urban-based production, consumption and water-generation on natural resources and ecosystems, and ultimately on the world's life support system. As such it addresses the issue of affluence and over-consumption and is generally more pertinent to affluent countries.

On the other hand, the so called 'brown' agenda (people agenda) focuses on poverty and underdevelopment. As such, it addresses the need to reduce the environmental threats to health that arise from the poor sanitary conditions, crowding, inadequate water provision, hazardous air and water pollution, and accumulations of solid waste. It is generally more pertinent in poor, under-serviced cities or regions.

Both 'green' and 'brown' agendas can be brought under the

Attribute	Areas of concern
Usage of resources such as energy and water	Greenhouse gas emissions Use of renewable and non-renewable resources Consumption of fresh water Life cycle costs
Choice of building materials	Use of renewable and non-renewable resources and release of emissions because of materials and energy flows Economics Thermal performance of the building envelope Acoustic performance Potential to generate business and employment opportunities for targeted groups Formation of waste hazards Health and safety
Choice of construction methods and resources	Health and safety Potential to generate business and employment opportunities for targeted groups Economics
Waste disposal	Recycling Hazardous waste
Adaptability for changed usage	Economics Market and rental value Extension of service life Consumption
Accessibility	Ease of use of buildings by all users Equity
Maintainability	Consequences of failure to function Economics Potential to generate business and employment opportunities for targeted groups
Note: An attribute is a characteristic assessed in terms of whether it does or does not meet a given performance	

Table 3 Common attributes of buildings which contribute to sustainable development

performance framework with, of course, different performance descriptions and parameters.

Design considerations

ISO 15392 establishes the general principles for sustainability in buildings. This standard is structured around the notion that addressing sustainability in buildings and other construction works includes the interpretation and consideration of sustainable development in terms of its three primary aspects – economic, environmental, and social – while meeting the requirements for technical and functional performance of the construction works[8].

ISO 15392 defines environmental, economic and social performance in terms of impacts and aspects. 'Impacts' is defined as any change that may be adverse or beneficial while 'aspect' in relation to a building can be considered to be the examination of buildings, part of buildings, processes or services over their life cycle that can cause a change to economic conditions, the environment, society or quality of life.

The description of the performance of the structural system of a building in relation to its contribution to sustainable development can best be described in terms of a hierarchy that starts with an objective followed by a performance description and performance parameters and ends with the means for evaluating solutions for compliance with performance requirements (see Fig 3). The performance descriptions and performance parameters collectively constitute statements of the performance demanded or expected to be fulfilled in response to user requirements and the expectations of the community and society.

Table 3 lists commonly encountered attributes developed in accordance with the performance principles of ISO 15928, which contribute to sustainable development for which objectives and performance statements can be developed in accordance with the principles outlined in Table 4. These may relate to different stages in the life cycle of a building and may be described by a set of indicators, which ISO 15392 defines as a quantitative, qualitative or descriptive measure, that relate to its design, construction, occupation or eventual demolition. Such indicators should be based on the impacts of aspects of the building in relation to the environment, economic value, the well being of users and issues of concern to the community.

The contribution of the structural system to sustainable development can be assessed in terms of the generic objectives (level 1) and performance statements (levels 2 and 3). The sustainability performance of the structural system of a building can similarly be fully described should a set of indicators (performance parameters) be formulated around the principles contained in the last column of Table 4. For example, the indicator relating to the generation of business and employment opportunities for local businesses and local labour may be equated to a contract participation goal i.e. an amount equal to the sum of the wages and allowances for which the contractor contracts to engage targeted labour; and the value of goods, services and works for which the contractor contracts targeted enterprises in the performance of the contract, exclusive of any value added tax or sales tax required by law, expressed as a percentage of the contract amount (see ISO 10845)[10, 11].

The structural system however, forms an integral part of the building's fabric and as such contributes to the operating energy performance of a building (see Table 5) i.e. the calculated or measured amount of energy actually used or estimated to meet the different user needs associated with a standard use of the building which might include energy use for heating, cooling, ventilation, hot water and lighting. Where operational energy performance is considered either in terms of fitness for purpose in use or contribution to sustainable development over life cycle, the thermal resistance characteristics (R-value and Total U-value) and if relevant, thermal mass of the materials (measure of its speed of response to temperature change) comprising the structural system will need to be considered[12].

Dickson *et al* argue that conservation, refurbishment and restoration for extended life are an essential component of sustainable development since rejuvenation of the existing building

Attribute	Objective	Performance statements	
		Performance description	Performance parameters
Sustainability (development that meets the needs of the present without compromising the ability of future generations to meet their own needs)	The sustainability performance of a building should be such that specified environmental, social and economic impacts due to construction, occupancy and eventual demolition can be kept within levels acceptable to the user and the expectations of the community and society	The structural system of the building shall perform during its construction, occupation and eventual demolition within established parameters in terms of the following: a) choice of construction materials; b) choice of construction methods and resources; c) levels of water and energy d) usage; and adaptability for changed usage.	The sustainability performance of the structural system can be described by a set of indicators, based on the impacts in relation to the environment, economic value, the well-being of users and issues of concern to the community Indicators shall be: a) objective, verifiable and reproducible; and b) wherever possible, linked to predetermined benchmarks, reference levels or scales of value which are within levels acceptable to the user and the expectations of the community and society. An indicator should be accompanied by an explanation that describes how to assign the value of the indicator.

Table 4 Principles for developing objectives and performance statements relating to sustainable development attributes

Attribute	Objective	Performance statements	
		Performance description	Principles for formulating performance parameters
Operational energy (energy to meet user needs associated with the use of the building)	The operational energy performance of a building shall be acceptable to the users in terms of comfort, safety and functionality.	The whole building and its parts, with an appropriate degree of reliability, shall fulfil the user needs in an efficient manner in relation to: a) thermal comfort b) lighting c) hot water d) other built-in appliances	The operating energy performance of the building can be described by the energy consumed under normal use in relation to: a) the external climatic environment of the house b) the internal environment to be maintained c) the user functional requirements d) the sources of the energy

Table 5 Objectives and performance statements relating to the operational energy performance of a building (after ISO/DIS 15928-5:2009)

stock brings new, extended use without incurring additional embodied energy[13]. In such buildings, the structural system needs to be appraised rather than designed. Factors such as its current condition, past damage, alterations and service interventions need to be assessed to ensure that the building remains suitable for continued use i.e. fit for purpose. Appraisals of the structural system can be undertaken in accordance with the framework outlined in Fig 1 and Table 2.

Implications of the designing of structural system of a building for traditional and emerging considerations

Paul Jowitt in his 2009 ICE Presidential Address points out that economic and technical progress in an era of technical rationality, which has dominated the past two or three centuries, has generally been embedded in narrow disciplines which did not anticipate wider physical and non-physical consequences at a systems level. It was never anticipated that man's activities would lead to impacts on a global scale that could threaten the environment and humanity's place in it. The emergent properties and behaviour of large and complex systems were neither fully appreciated nor fully understood. It is now becoming clear that the earth is no longer able to withstand and rebound from human activity. It has limits. A more systems orientated view of the world is needed and solutions at a systems level need to be developed[14].

Jowitt argues that a shift needs to take place not just towards whole life costs but towards whole life values and suggests that the following two issues of truly global proportions must be addressed:

1. Engineering the world away from an environmental crisis caused in part by previous generations in terms of greenhouse gas emissions and profligate resource use.
2. Providing the infrastructure platform for an increasingly urbanised world and lifting a large proportion of the world's growing population out of poverty.

The Civil Engineering and Climate Change Protocol signed by the Institution of Civil Engineers, the American Society of Civil Engineers and the Canadian Society for Civil Engineering at St. John's, Newfoundland, Canada, on 2 June 2009, is underpinned by the belief that substantial reductions in greenhouse gas emissions are required to reduce the risk of climate change. This protocol suggests as a mitigation measure, that civil engineering must lead the way in developing new technologies and materials to reduce emissions over the whole life cycle of infrastructure systems[15]. It also commits the three signatories to assist all governments through the development of a low-carbon infrastructure road map setting out key steps up to 2050 to, *inter alia*, increased energy efficiency and low carbon design i.e. lower embedded energy in construction and large reduction in the whole life energy demand and emissions from infrastructure systems.

Structural systems for buildings have evolved during an era of 'technical rationality', with the primary focus being on the identification of the most economical solution that is 'fit for purpose' in use. Reinforced concrete and structural steelwork design standards have become refined and entrenched in structural engineering practice. Masonry and timber design standards are reasonably developed but are generally not as well understood by structural engineers as reinforced concrete and structural steelwork design standards. This is largely due to the incorporation of such materials into the structural system in most low rise buildings in terms of a set of prescriptive rules.

Designing structural systems of new buildings to 'contribute to sustainable development' over life cycle may necessitate the development and introduction of new structural materials or the reintroduction of indigenous materials that have been displaced by 'modern' imported materials and technologies. Appraising the structural system of existing buildings in order to extend their life can require the assessment of materials and construction that are no longer in use. Structural codes of practice, as is the case for the four primary structural materials (concrete, steel, masonry and timber), are not available to establish the fitness for purpose of such materials. Such codes need time to evolve. There is accordingly a need for a rigorous framework within which materials other than the current primary materials may be designed or appraised.

The performance framework for the design and appraisal of structural systems outlined in this paper can provide a means to establish fitness for purpose in use. Performance parameters which are applicable to a particular geographical area can be readily established for different types of buildings. Standard tests can be agreed upon to establish the fitness for purpose of certain materials e.g. hard body and soft body impact tests, tests for fittings, resistance to door slamming, hail resistance etc.

The design of structural systems to contribute to sustainable development over life cycle can be implemented on a routine basis should standard indicators (performance parameters) be developed for a standard set of objectives. Structural engineers, however, require not only the metrics but also credible data to make decisions regarding alternative solutions in the design process. There is accordingly a need for authoritative organisations such as the Institution of Structural Engineers to develop not only standard sets of indicators to enable sustainable development objectives to be prioritised on projects but also to publish data to enable the indicators to be evaluated on a common basis.

Conclusions

Current standards for the design of structural systems for buildings are geared towards the use of concrete, steel, masonry and timber. The design of structural systems for buildings in the 21st century will need to not only satisfy traditional fitness for purpose in use requirements but also contribute to sustainable development over life cycle. New materials and construction technologies may be required in order to achieve this. The life of existing buildings may also have to be extended to satisfy sustainable development objectives. All of this requires a more fundamental approach to the design and appraisal of structural systems.

There is a need for a common performance framework for the design and appraisal of a structural system for a building, and for all existing and new materials to satisfy not only fitness for purpose in use requirements but also contribution to sustainable development over life cycle requirements. The framework, based on the approach adopted in international standards, proposed in this paper can provide such a tool.

The establishment of standard performance parameters by an international organisation such as the Institution of Structural Engineers relating to:

a) fitness for purpose in use of new materials and construction technologies on a regional basis for different building types together with an agreed set of standard test methods to test certain aspects that could be relevant in certain circumstances e.g. impact tests and door slamming tests; and
b) contribution to sustainable development over life cycle for both a 'green' and 'brown' agenda together with credible data, where relevant, which enables the indicators to be measured, will enable structural systems for buildings to be routinely designed and appraised to satisfy 21st century societal imperatives.

References

1 ISO/IEC Guide 2:2004, *Standardization and related activities — General vocabulary*
2 ISO 6707-1: 2004, *Building and civil engineering — Vocabulary — Part 1: General terms*
3 Watermeyer, R. B. and Milford, R. V. (2003): *The Use of Performance Based Building Codes to Attain Sustainable Housing Objectives: The South African Approach,* Global Policy Summit on the Role of Performance-Based Building Regulations in Addressing Societal Expectations, International Policy, and Local Needs, Inter-Jurisdictional Regulatory Collaboration Committee (IRCC) and the United States' National Research Council (NRC), National Academy of Sciences, Washington D.C., USA
4 ISO 6421:1984: *Performance standards in building – Principles for their preparation and factors to be considered*
5 ISO 15928:2003: *Houses — Description of performance*
6 ISO/DIS 15928-4:2009: *Houses — Description of performance — Part 4: Fire safety*
7 ISO/PAS 22539:2007: *User guidance to ISO 15928 – Houses – Descriptions of performance*
8 ISO 15392:2008: *Sustainability in building construction — General principles*
9 Watermeyer, R. B. (2006): 'Poverty reduction responses to the Millennium development goals', *The Structural Engineer*, 84/9, p 27-34
10 ISO 10845-1: 2010: *Construction procurement — Part 1: Processes, methods and procedures*
11 ISO/FDIS 10845-7:2010: *Construction procurement, Part 7: Participation of targeted enterprises and targeted labour (local resources) in contracts*
12 ISO/DIS 15928-5:2009: *Houses — Description of performance — Part 5: Energy usage*
13 Dickson, M., Solomon, J., and Bruyere, D.: 'Let the building speak to you', *The Structural Engineer*, 87/11, 2 June 2009
14 Jowitt, P. (2009): Now is the time. ICE presidential address. November. (http://www.ice.org.uk/downloads//pjaddress.pdf)
15 ICE, ASCE and CSSE. Climate Change Protocol signed by the Institution of Civil Engineers, St. John's, Newfoundland, Canada, 2 June 2009 (http://content.asce.org/files/pdf/CivilEngineeringandClimateChangeProtocol.pdf)