# The impact of structural engineering on the sustainability of human settlements in developing countries

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ABSTRACT: Just under half of the world's population live on less than 2US$ per day. Agenda 21 (1992) recognized that access to safe and healthy shelter should be a fundamental part of national and international action. The Habitat Agenda (1996) linked locally available, appropriate, affordable, safe, efficient and environmentally sound construction methods and technologies that emphasize optimal use of local human resources to the concept of "sustainable construction". The Johannesburg World Summit (2002) includes an action relating to the use of low-cost and sustainable materials and appropriate technologies for the construction of adequate and secure housing for the poor.

Sustainable housing can be considered to be housing that provides adequate shelter whilst satisfying fundamental human needs relating to health, safety and well being of residents; is affordable to access, maintain and live in; minimizes the harmful effects of housing developments on the environment; conserves natural resources in its construction, maintenance and functioning; and provides significant employment opportunities in its construction.

Structural engineering has a major impact on the choices made in the technologies that are employed and the construction materials that are used. These choices impact directly on the nature of the employment generated during construction, the performance of the house in use, the vulnerability of the house to natural disasters, the affordability of a house and the accessibility of housing to the poor.

This case study documents the South African experience including the innovative work done by the Joint Structural Division of IStructE and SAICE in the design of low cost housing in a sustainable manner which has resulted in Standards South Africa reinterpreting national building regulations. It furthermore demonstrates how structural engineers can use performance based standards to promote sustainable housing and how performance standards can be linked to procurement arrangements to realise employment objectives in mass housing schemes.

## 1 INTRODUCTION

Sustainable development has historically been defined "as development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987). The interpretation of this definition has, however, since 1987 broadened and matured is now also very much about eradicating poverty.

A more appropriate definition for sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Government of the United Kingdom 1999). Sustainable development is rooted in the simple concept of providing a better quality of life for all, now and for generations to come.

This paper develops a definition for sustainable housing and identifies the factors which need to be considered in the design and construction of sustainable housing units. It thereafter considers the choices made in the structure of a housing unit (roof assembly, walls and floor) and their impact on sustainability criteria and outlines a means to promote sustainable housing in mass housing projects.

## 2 AN AGENDA FOR SUSTAINABLE HUMAN SETTLEMENTS

20% of the world's population live on less than 1US$ per day while 47% live on less than 2US$ per day (World Bank, 2001); the gap between the rich and poorer nations is widening; and the minority of the global population controls a greater proportion of the world's economic and natural resources. Accordingly, sustainable development for the majority of developing countries becomes meaningful when it is underpinned by objectives which relate to stimulating economic growth including the creation of jobs, achieving social progress and stability, and promoting the sustainable utilisation of natural resources as apposed to a strict protectionist stance.

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One of the targets set at the Johannesburg World Summit for poverty eradication seeks to achieve a significant improvement in the lives of at least 100 million slum dwellers by 2020. The proposed actions associated with this target include:

- improved access to adequate shelter and to basic services for the poor; and
- the use of low-cost and sustainable materials and appropriate technologies for the construction of adequate and secure housing for the poor, taking into account their culture, climate, specific social conditions and vulnerability to natural disasters.

## 3 SUSTAINABLE HOUSING

In line with the aforementioned agenda for human settlements, sustainable housing may be defined as housing that:

1) provides adequate shelter whilst satisfying fundamental human needs relating to health, safety and the well being of residents;
2) is affordable to access, maintain and live in;
3) minimises the harmful effects of housing developments on the local environment;
4) conserves and manages resources including energy and water, in its design, construction, maintenance and functioning; and
5) provides significant employment opportunities in its construction, alteration or refurbishment.

Accordingly, the following must be considered in the design, the construction, alteration and refurbishment of housing units:

- adequacy in terms of accessibility; affordability throughout the life cycle; health and safety; thermal comfort; and vulnerability to national disasters;
- employment potential, including their potential for poverty relief and employment;
- energy efficiency, i.e. cooking, heating, cooling and hot water consumption energy;
- the biodegradability and non-noxiousness of demolition waste, embodied energy, recyclability, and renewability of construction materials;
- sanitation options; and
- water use and savings in terms of appliances and fittings and site and design interventions such as permaculture, rain water harvesting etc.

Choices made in the structure of a housing unit (roof assembly, walls and floor) and the selection of the sanitation arrangements have a significant impact on the degree to which housing units embrace sustainability criteria.

## 4 CHOICES IN TECHNOLOGIES AND CONSTRUCTION MATERIALS

### *4.1 General*

Choices in technologies and construction materials in the envelope of a housing unit, apart from their inherent environmental properties with respect to demolition waste; embodied energy; recyclability; and renewability (IStructE 1999), have a profound impact on the accessibility of housing to the poor, affordability levels, employment opportunities, thermal performance, and energy efficiency.

### *4.2 Impact of choices on employment opportunities*

Choices in technologies and construction materials determine the quantum of employment that is created and where it is generated. This is well illustrated in Tables 1 and 2 which present the outcomes of a case study in South Africa. (Watermeyer & Band 1995; Watermeyer 1999).

Table 1. Comparison of the number of person hours required to construct non-masonry and masonry houses

| Construction type | number of person hours (hours) for non masonry houses | | number of person hours for equivalent masonry houses (hours) | |
|---|---|---|---|---|
| | site labour | total | site labour | total |
| Timber | 1180 | 1480 | 1700 | 1900 |
| Precast concrete panels and posts | 210 | 360 | 1120 | 1240 |
| Steel frame with 110 mm brick infill panels | 880 | 1210 | 1400 | 1560 |

Table 2. Evaluation of non-masonry house types

| Construction type | Non-masonry | | Masonry equivalent | |
|---|---|---|---|---|
| | Cost (1994) (Rand) | Rand / person hour | Cost (1994) (Rand) | Rand / person hour |
| Timber | 47200 | 46100 | 32 | 24 |
| Precast concrete panels and posts | 16000 | 20300 | 44 | 16 |
| Steel frame with 110 mm brick infill panels | 28400 | 30800 | 23 | 20 |

Manufacturing materials on site, e.g. concrete masonry units, can significantly increase the quantum of employment that is created. The use of stabilised forms of earth construction may likewise do so. (Watermeyer & Band 1994)

### 4.2 Thermal comfort and energy efficiency

Choices in technologies can have a significant impact on the thermal performance and heating and cooling energy consumption requirements. Natural thermal comfort, the basis of an energy-efficient house, frees the residents from expensive, unsafe and unhealthy space heating. Very high levels of indoor air pollution due to use of coal and biomass (wood and dung) for heating are frequently encountered in low cost housing in South Africa, resulting in health problems, such as respiratory disease, accidental burns and poisonings and eye and skin irritations. It is estimated that over 60% of South Africa's population is exposed to polluted, unsafe air. The mortality rate of acute respiratory illnesses among children is reported to be 270 times greater than for children in Western Europe (Soderlund & Schutte 2003).

A properly designed, well-insulated home with appropriate thermal mass requires relatively little energy for heating in winter in most South African climatic zones. Indigenous housing technologies (e.g. round huts with thatch roofs and mud walls) have been found to have superior performance to the commonly constructed houses which typically have sold masonry walls and tiles or sheeted roof. Agrément South Africa have recently developed the BESA walling system (soil blocks stabilized with bitumen and polypropylene fibres) which has been found to have an annual energy heating requirement of some 44% less than the 55 m$^2$ solid masonry, reference house in the Johannesburg area and one third of that of a thin walled low cost, concrete hollow block house. (Soderlund & Schutte 2003).

## 5 INDIGENOUS TECHNOLOGIES AND CONSTRUCTION MATERIALS

Materials such as cob, earth-blocks (commonly stabilized with cement or bitumen emulsion), Pisé de terre, straw, stone, wood, wattle and daub are commonly encountered indigenous forms of construction in developing countries. These materials are generally reasonably well understood and, from a sustainability point of view have much to offer developing countries. Several guideline documents are available which explain on a step by step basis how to build houses with these materials. Why then are they frequently overlooked in favour of technologies commonly encountered in developed countries and relegated to rural house construction and "informal" sector housing?

Many of the answers to this question lie in the following:

- houses are regulated in a prescriptive manner, typically to satisfy requirements of financial institutions who require the house to be repaid before significant maintenance is required;
- the regulatory building systems are not geared towards indigenous forms of construction and are modeled along the lines of those in developed countries;
- there is a lack of quantitative technical information with respect to indigenous forms of construction to enable informed design decisions to be made regarding the acceptability of their performance; and
- authorities are reluctant to accept structures whose strength, stability, serviceability and durability cannot be quantified and assessed in terms of national or international codes of practice or building codes.

Developed countries have concentrated on developing codes of practice based on the conventional materials such as concrete, masonry, steel and timber for use in their economies. Even where grant funding is provided to research innovative technologies there is no guarantee, for various reasons, that the research will be used in practice. Frequently, the deliverable in research projects is a set of guidelines which provides valuable insights into the subject matter. These guidelines, however, rarely satisfy building authority requirements, or public body needs and seldom do they enable designers to execute designs with satisfactory levels of confidence. All too often, the research is structured to provide indicative, as opposed to quantitative, results, e.g., engineering properties are established on a non-statistical basis and serviceability aspects such as resistance to rain penetration are ignored. (Watermeyer, 1999)

## 6 THE SOUTH AFRICAN APPROACH TO THE REGULATION OF HOUSING UNITS

### 6.1 The South African Housing stock

South Africa has a very diverse housing stock. According to Census 1996, some 18% of the housing stock comprises traditional dwellings or structures made of traditional materials and 16% informal shacks.

### 6.2 National building regulations

South Africa's National Building Regulations (NBR) are generally functional in nature but contain some prescriptive provisions. Functional regulations are deemed-to-be- satisfied through compliance with the requirements of a national standard, SANS 10400:1990, *the Application of the National Building Regulations*. Provision is made in the regulations for local authorities, who are responsible for the enforcement of the regulations, to require a test report or evaluation certificate issued by the South African Bureau of Standards, the Council for Scientific and Industrial Research or the Agrément Board of South Africa where they are not satisfied as to the adequacy or safety in use of any construction system, method, material, article or product which is proposed to be used in the erection of any building.

SANS 10400:1990 provides a set of deemed-to-satisfy rules in respect of structural design, dimensions, public safety, site operations, excavations, foundations, floors, walls, roofs, stairways, glazing, lighting and ventilation, drainage, non-waterborne means of sanitation, stormwater disposal, facilities for disabled persons, fire protection, space heating and fire installations.

The deemed-to-satisfy rules for structural design are framed around rational designs undertaken by registered engineers in accordance with the provisions of national structural design codes for loadings, concrete, masonry, timber, steel and glazing.

The deemed-to-satisfy rules for foundations, floors, walls and roofs are in effect prescriptive requirements for simple buildings including housing units which have concrete floors, masonry walls and timber roofing structures. There are no deemed-to-satisfy rules for traditional dwellings, the tacit assumption being that they satisfy requirements.

### 6.3 *The Joint Structural Division's approach to housing*

The Joint Structural Division of the SAICE and IStructE) (JSD) recognised that the deemed-to-satisfy provisions as embodied in SANS 10400 were framed around "first" world parameters viz. low maintenance, no penetration of water into interiors, deflections which are not discernible, negligible levels of cracking, etc, i.e. around the parameters embodied in international / national codes of practice found in developed countries. As a result, structures fell into one of two categories viz:

1) formal structures which are constructed in accordance with NBR; and
2) informal structures for which no standards apply.

The JSD found this situation from a health and safety point of view to be unacceptable, but realized that if different user performance levels (i.e. the technical performance criteria applicable for an intended use selected by the user) were defined, it could be possible to regulate the construction of housing units which have comparable safety standards, but have different resistances to rain penetration, behavior in fire, deflections and deviations from the horizontal and vertical, expected damage in walls and floors, maintenance cycles, and resistance to local damage/soft body impact. End users could then choose the housing solution which is within their means without compromising safety and basic health requirements.

The JSD developed a code of practice for the assessment of housing units in South Africa (JSD, 2000) which provided two user performance levels, the basic characteristics of which are as set out in Table 3.

Table 3. User performance levels adopted by the JSD

| User performance level | basic characteristics |
|---|---|
| 1 | Focus is on producing basic shelter at the lowest possible initial cost recognising that shorter maintenance cycles than that contemplated in user performance level 2 may be required. Mortgage lending finance is not involved; short term loan finance may be involved*. Limited rain penetration through walls and roofs permitted in abnormal storms. |
| 2 | Focus is on producing a durable housing unit which requires infrequent maintenance. Mortgage lending finance is usually involved. |

* Housing units may be constructed in terms of self help / sweat equity schemes.

User Performance Level 1 housing units are in terms of this code, restricted to those which have no basements, are of single storey construction, have floor areas of less than 80 m$^2$ and have a maximum length between intersecting walls or members providing lateral support of 6,0 metres.)

The JSD code also established technical requirements for both user performance levels and methods for establishing compliance with requirements.

### 6.4 *Revised interpretation of National Building Regulations*

The revised interpretation of the NBR embodied in SANS 10400:2004 is informed by the JSD's code and work by the ISO TC 59 / SC15 in the development of ISO 15928 (House - Description of performance) and effectively convert the NBR into performance-based regulations. SANS 10400:2004 is now not merely a set of deemed-to-satisfy rules which enable compliance to be established, as it now establishes quantitative technical performance criteria, acceptable solutions and methods by which the performance of solutions can be evaluated.

The revised interpretation of NBRs now makes provision for category A buildings which are used for places of instruction, worship, displaying and selling merchandise to the public, offices, dormitories, domestic residence and dwelling houses, that have no basements, a maximum length between intersecting walls or members providing lateral support of 6,0 metres, and a floor area not exceeding 80 m². Different performance parameters are provided for Category A and non-category A buildings along the lines of that provided for in the JSD code.

SANS 10400:2004 provides a platform for the development of acceptable solutions for indigenous forms of construction alongside those based on the commonly encountered engineering materials, namely concrete, masonry, timber and steel.

## 7 USING STANDARDS TO PROMOTE SUSTAINABLE HOUSING UNITS

Performance based standards which establish requirements for house attributes should be drafted in accordance with the framework provided in Table 4. Typically, the prediction or verification of performance should comprise the application of rules, testing, verification methods, documentary evidence and expert judgment.

Table 4. Content of performance based technical specifications

| Component | Content |
|---|---|
| Design objective / user need | A general statement of requirements for a house that may be regarded as being satisfactory by the user |
| Performance description | A statement which identifies agents that affect performance in a qualitative manner and establishes how these agents affect the state of the house. |
| Performance parameter | User needs, expressed in terms of the quantitative performance of a house attribute. |
| Evaluation | The means by which compliance may be verified |

Performance based technical standards provide tenderers in mass housing projects with the freedom to select the most economical structure (roof assembly, walls and floor) that satisfies performance requirements. The selected structure and its components should either provide work opportunities to vulnerable groups or increase the quantum of employment generated per unit of expenditure. In order to encourage tenderers to respond to this requirement, performance based resource standards need to be developed in accordance with the outline provided in Table 5 to quantify and measure the employment generated or the use of local resources. (Watermeyer, 2003). SANS 1914-4, *Participation of targeted enterprises and targeted labour (local resources)*, and SANS 1914-5, *Participation of targeted labour*, provide such a framework.

A weighted-scorecard approach can be used to rate the characteristics of construction materials with respect to demolition waste; embodied energy; recyclability; and renewability and the evaluation of community preferences.

Value for money in the evaluation of tender offers in mass housing projects can be determined in terms of a weighted summation of the quantum of contract participation goals aimed at providing work opportunities to targeted groups, the scoring of inherent construction material properties and the physical characteristics of the housing units in terms of community preferences and price.

Table 5. Content of a performance based resource specification

| Component | Content |
|---|---|
| Objective | Provide business and employment opportunities to specified target groups (targeted enterprises and / or targeted labour) |
| Performance description | Engage the target groups indirectly or directly in the performance of the contract |
| Performance parameter | Engage target groups to the extent that a contract participation goal ( i.e. a percentage of the value of the contract which represents the inputs of targeted enterprises and/or targeted labour in the performance of the contract) established for the contract is satisfied. |
| Evaluation | The means by which compliance may be verified |

## 8 CONCLUSIONS

Structural engineering can have a profound impact on the sustainability of housing units as it determines the form of construction and materials used in its very fabric. Choices in the fabric of a housing unit determine the degree to which sustainable development values and criteria can be embraced. Performance based standards provide an effective means to promote sustainable housing units.

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