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The response of common building construction technologies to the urban poor and their environment

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A B S T R A C T

There is a need to assist the inhabitants of informal settlements especially in developing countries to improve their living conditions and hence their quality of life. However, it is important to note that the bulk of housing for the urban poor will always be built by the poor themselves. In which case, there is a need for building technologies that are responsive to such communities and their environment in order to empower them to make their own contribution to the process of improving their living conditions.

There exists building technologies considered as such. This paper analyses some of these technologies against a conceptual framework. The framework defines and analyses building technologies in terms of socio-economic, environmental and technical criteria defined in the regional context. It is based on the concept of sustainable development. Building technologies are analysed as an objective function problem using a multi-criteria optimisation technique. The results show that most of the technologies are not responsive in the regional context. That is, the technologies cannot provide a good quality dwelling unit and at the same time address the socio-economic needs of the urban poor while minimising the negative impact on the environment.

1. Introduction

The majority of the urban poor in most developing countries of sub-Saharan Africa find shelter in the informal settlements. According to UN-Habitat [20] and Srinivas [14] the settlements are characterised by mostly self-built dwelling units that, amongst other problems, do not offer adequate protection against the elements. This is because the conventional building technologies are beyond the reach of such communities amongst other causes. This situation is occasioned by poverty which is as a result of market and public policy failure for a significant segment of the urban population in these countries.

This study advocates for building technologies that are responsive to the urban poor and their environment. This is in order that such communities can be empowered to make their own contribution to the process of improving their housing conditions. These are technologies that provide good quality dwellings. At the same time the technologies can be used to address the socio-economic needs of the urban poor while minimising the negative impacts on the environment.

Good quality and durable dwelling units are essential for everyone's excellent quality of life and are a critical component in the social and economic stability of nations. The socio-economic conditions of the urban poor in most of sub-Saharan countries are desparate, for example unemployment is high. The choice of building technologies can be used to address some of these issues, for example, use of labour intensive construction methods in shelter provision can generate employment. There exist a define relationship between, for example, employment creation and the production and selection of building materials and assembly of both the structural and non-structural elements and components that make up the physical fabric and form of a building Watermeyer [21].

The protection of the environment has become a worldwide important criterion in order to sustain the species Homo sapiens Du Plessis [5]. The built environment is considered to have a significant impact on the environment. Some of these according to Kibert [9] include disturbing of eco-balance, land degradation, air pollution, and energy consumption. Energy consumption, in addition, is a major cause of climate change due to the release of carbon dioxide into the atmosphere during the combustion of fossil fuels.

However, literature shows that during the past few decades there has been tremendous development and evolution of alternative building technology options. Some of these are considered

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responsive to the urban poor and their environment. Examples include modified indigenous building technologies, and these include, amongst others, techniques of soil stabilisation, water resistant mud plaster, techniques of preventing contact of earth based construction by rain and stabilised soil-cement blocks, for example see UN-Habitat [16–19], CSIR [4], Mathur [10] and Bolton and Burrough [2]. Other developments include reduction to a minimum the volume of expensive materials needed for components for example, various forms of cavity and perforated masonry use of large, interlocking and self-aligning masonry units Parry [11]. Also included is the use of alternative binding materials such as lime-pozzolana, techniques for production of building materials and equipment close to construction sites, use of plastics and development of advanced composite materials amongst others.

There exists a considerable body of literature describing the production and use of these building technologies in the shelter provision. However, most studies tend to address this theme from a single point of few and independent of other issues. For example, focusing on the technical aspects of technology such as production and manufacturing processes while others deals with social, economic and environmental issues separately. It is, however, necessary to reconsider building technologies that can improve people's life from a holistic point of view. This will enhance understanding the potentials such technologies have and in turn on how to empower the urban poor to make their own contribution to the process of improving their housing conditions.

This paper analyses some of these technologies against a conceptual framework. The framework defines and analyses responsive building technologies in terms of socio-economic, environmental and technical criteria defined in the regional context. It is based on the concept of sustainable development. Building technologies are analysed as an objective function problem using a multi-criteria optimisation technique. The results show that most of the technologies are not responsive in the regional context. That is, the technologies cannot provide a good quality dwelling unit and at the same time address the socio-economic needs of the urban poor while minimising the negative impact on the environment.

2. Methodology

2.1. The conceptual framework

The framework seeks to define and evaluate building technologies from a multidimensional perspective, that is, technical, socio-economic and environmental components. Each of these components has different characteristics and solutions from the others, and more often than not with different units of measurements. Fig. 1 illustrates the three dimensions and their interaction. The optimum technological solution is confined to the area where the three components overlap. It is easy to see that any solution complying simultaneously with the three components has to be contained within this area. However, even if this common area could be known or determined, it is necessary to remember that there can be thousands of different solutions, but only one of them is the optimum. Consider now that there is a set of building technologies that are responsive to the urban poor and their environment. These technologies can be evaluated by comparing the alternatives and a compromise worked out. This allows for the selection of the best combination of technologies.

However, to work out a compromise it is necessary to establish a set of acceptable criteria for the different components of sustainable technology. Consequently, there will be a set of criteria regarding the socio-economic aspect, others for the environmental and technical aspects of the technology alternatives. These criteria can then be used to gauge the contribution of each technology alternatives in attaining the final goal. It is important to note that each criterion can impose a threshold or a pair of them, which must be met by the diverse technology alternatives, but with usually different cardinal values. There exists most likely a common ground for some of the alternatives, considering the interaction of trade-offs, and consequently, the task is to find a method that could identify this common ground for all the technology alternatives.

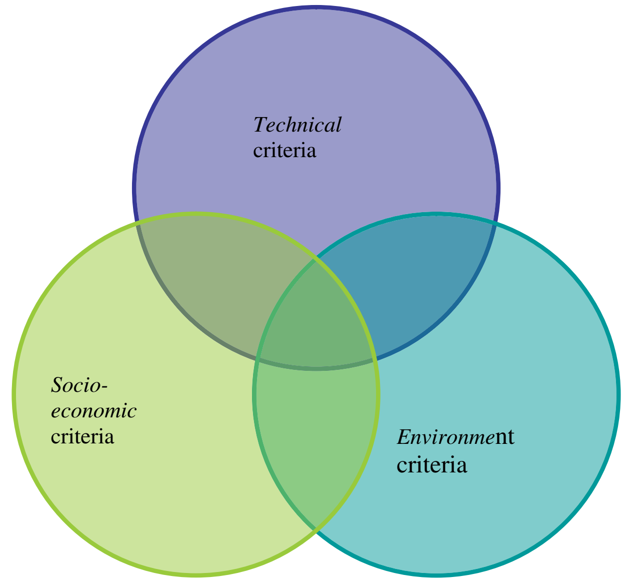

Fig. 1. Superimposing the three components of sustainability.

2.2. The proposed criteria

The proposed criteria was summarised as shown in Fig. 2. It is an objective hierarchy model. Criteria that comprise policy issues were omitted. The goal was a framework that helps to define building technologies that maximise, minimise or maintain a threshold level of the proposed criteria.

The generation of the criteria was based on expert opinion, as reported in the literature. These were grouped in terms of environmental, socio-economic and technical criteria. The environmental criteria are mainly concerned with the minimisation of the negative impacts on the earth's ecosystem and use of non-renewable resources DuBose et al. [6]. In addition, it requires minimisation of harmful emissions and the protection and maintenance of biodiversity Bowen and Hill [3].

Similarly, the socio-economic criteria are related to improving the quality of life for the urban poor. The first step to achieve such aim is poverty alleviation. According to Bowen and Hill [3], Steyn [15], Watermeyer [21] and Gibberd [8] this could be through the use of building construction technologies that: stimulate and support local economy.

Technical objectives aim at achieving good quality and durable dwelling structure while supporting and promoting environmental and socio-economic objectives. The term quality was used to imply the performance of a dwelling unit. This can be described in terms of housing attributes. Becker [1] amongst others provides a list of housing attributes. The national building regulations and design codes, for example, SANS 10400 [13] usually provide for design and construction procedures to meet the performance requirements of these attributes. However, in general it should be substantiated and verified by means of tests, calculations or from first principles that

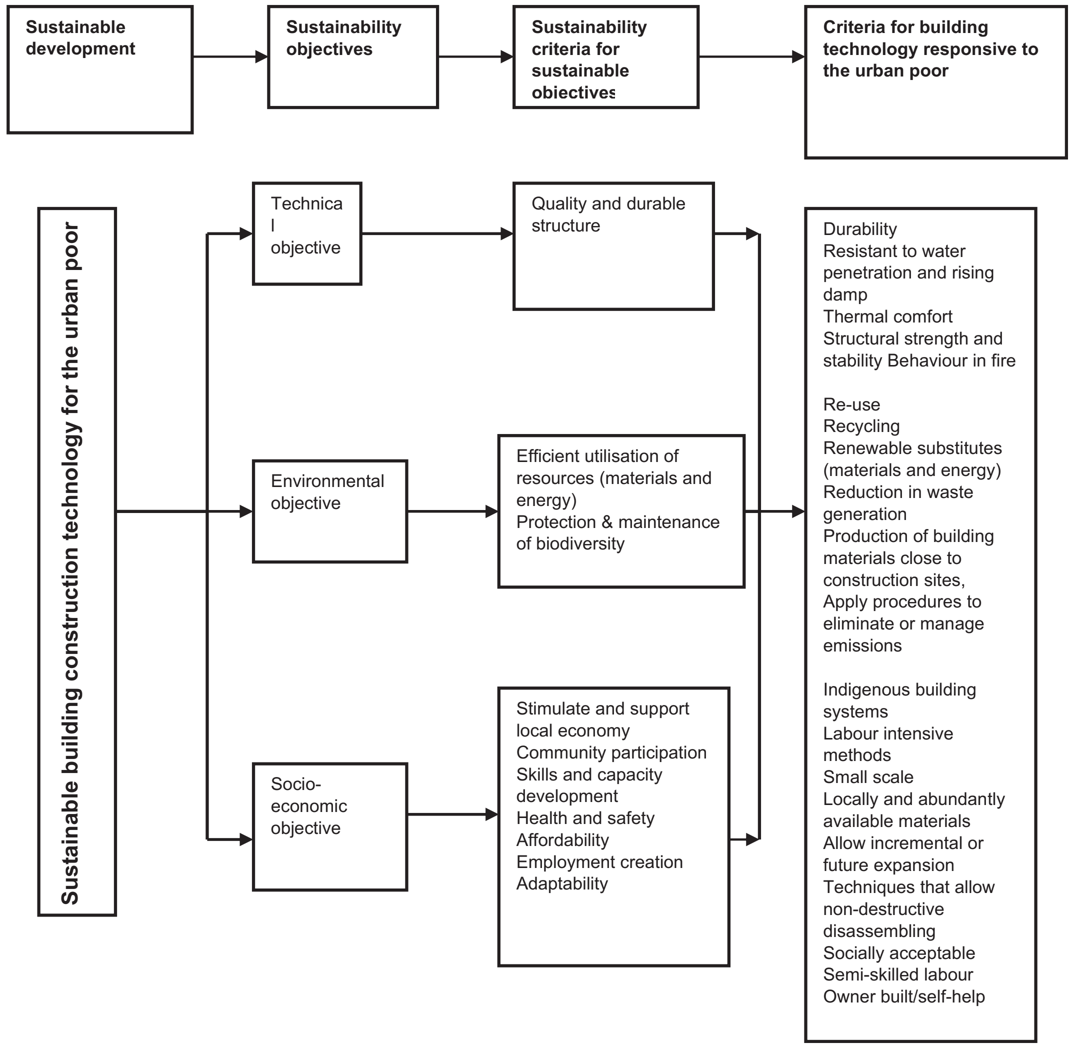

Fig. 2. Objective hierarchy model.

the construction system, materials, element or components satisfy the performance requirements enlisted by the housing attributes SAICE [12].

In this study the housing attributes are taken as the technical criteria. Only the following attributes, Table 1, were considered. This was because these are the most influenced by the type of building technology employed and considered as the minimum requirements (SAICE, 2000: 1-1). A detailed explanation on how these attributes are achieved in building construction can be found in for example, Becker [1].

2.3. Method of assessment

To enable quantitative analysis the criteria needed to be measured and aggregated into one score based on criteria weights. The measurement could be based on existing data or measured in-situ. Where such data do not exist or readily available it was proposed to define these criteria in terms that could be quantified and develop a system for capturing these. However, it was noted that such an exercise constitutes a whole new area of research and could not be pursued in this particular case. Instead, it was proposed to approach several stakeholders including academicians, industry players and the representative of the targeted communities to rate the technology. Table 2 was used for this purpose. Five (5) industry players, five (5) academicians and ten (10) representatives of the urban poor were approached and asked to rate the technologies. The industry players and academicians were identified and selected on the basis of association. The representatives of the urban poor were the residents of Mandela Village, an informal settlement located in Mamelodi Township, east of Pretoria, South Africa. They were identified by the help of students of Tshwane University of Technology (TUT) who had connections in the settlement. The respondents rated the technology on a scale of one (1) to five (5), where one was the lowest score. It is important to note that such score rating is subjective and based on the perception of the respondents. However, statistically the information can be used to draw objective conclusions.

The framework presents a multi-criteria optimisation problem. There are many techniques for multi-criteria optimisation, such as Simple Multi-attribute Rating Techniques, The Analytical Hierarchy Process, Order Preference by Similarity to Ideal Solution see for

Table 1
Housing attributes.

Technical objective	Housing attributes
Good quality and durable dwelling unit	Durability Thermal and condensation Structural strength and stability Behaviour in fire Water penetration and rising damp Structural serviceability

Table 2
Score rating table.

Technology type	Objective of sustainability	Criteria for suitable technology	Sub-criteria for suitable building technology	Score rating on a scale of 1 to 5. Where 1 is the lowest score and 5 the highest. In terms of the production of building materials, selection and assembly of elements/ components				
				1	2	3	4	5
	Technical	Quality and durable structure Health and safe Technical visibility	Durability Water penetration Thermal comfort Structural strength Behaviour in fire Allow incremental expansion Non-destructive disassembling					
	Socio-economic	Poverty alleviation - Generation of employment opportunities - Stimulate and support local economy - Socially acceptable	Indigenous Labour intensive Small scale Local resource materials and labour) Semi-unskilled labour Owner built					
	Environmental	Efficient utilisation of materials Optimisation of energy use Protection and maintenance of biodiversity	Re-use Recycling Renewable resource Min waste generation Site production of materials Minimum emissions (CO_2, of volatile organic comp)					

example Engelbrecht [7]. The Simple Additive Weighting (SAW) which is one of the simplest and probably the best known and widely used techniques was recommended in this study. The model is used to aggregate the scores into one score based on the criteria weights. At first the scores are normalised (converted) by the formulas:

$$x_{ij} = \frac{a_{ij}}{a_j^{\max}} \tag{1}$$

$$x_{ij} = \frac{a_j^{\min}}{a_{ij}} \tag{2}$$

where a_{ij} = the score for the criterion.

When the criteria are maximised, formula (1) has to be used, and formula (2) when the criteria are minimised. The scores are aggregated into one score using the formula:

$$S_{\mathrm{SAW}} = \operatorname*{Max}_j \sum_{i=1}^{m} x_{ij} \times w_j, \quad j = 1, \ldots n \tag{3}$$

where S_{SAW} is the total score, n is the number of criterion, w_i is the weight of each criterion, and x_{ij} is the normalised score of the criterion.

2.4. The selected building technologies

The selected building technologies were analysed against the proposed conceptual framework. The summary of these technologies is given in Table 3. The technologies represent the most common building materials and methods used in low-rise dwelling units in the regional context. The purpose was to demonstrate the use of the proposed framework and determine the extent of responsiveness of these technologies.

3. Results

The scores from the respondents were analysed statistically. These were averaged, normalised and aggregated into one score using the Simple Additive Weighting Method and presented in tabular form see Tables 3–6. It was assumed that the three pillars of responsiveness (technical, social-economic and environmental) had equal importance and were interdependent and hence the weighting of each criterion was assumed to be equal. In reality this is not true because humans have varying needs and such weighting should be determined on the basis of priority of the needs of the target community.

Table 3
Summary of selected building technologies.

Building elements	Conventional technology	Traditional technology	Innovative technology
Foundation	Concrete strip footing Concrete raft	Wood pole	Stone laid in mortar bed
Ground floor	Concrete floor bed Natural stone	Rammed earth	Stabilised rammed earth or blocks
External walls	Burnt clay masonry wall Concrete brick/block masonry wall Natural stone masonry wall Light-weight timber frame wall	Stabilised earth block (adobe) Improved mud wood-pole Cast in-situ rubble stone	Permanent shuttering block masonry Sandwich panel walls Dry-stacked masonry
Roof	Timber or steel roof frame with metal sheeting, clay or concrete tiles	Wood pole roof frame with grass thatch	Timber or steel roof frame with fibre-cement sheeting

4. Analysis and discussion

4.1. Foundation building construction systems

4.1.1. General

Table 3 is the results for the foundation technologies. It shows that, technically, concrete foundation is the best option followed by stone and mortar and lastly the wood pole foundation. This is because wood pole foundation is susceptible to decay requiring seasoning and preservative treatment and therefore not considered durable. It is noted that structural strength and stability criterion is irrelevant in analysing the response of foundation technologies since it is a subject of a rational design. Similarly thermal comfort and fire hazard criteria are of no consequences and therefore irrelevant. Any given foundation can allow incremental expansion especially vertical, if it is designed to do so. Stone in mortar and wood pole foundations allow non-destructive disassembling which is both economical and environmentally advantageous.

Socio-economically, stone laid in mortar foundation was rated as the best option, followed by wood pole and lastly concrete foundation. The use of stone can generated more employment opportunities because the production of the materials and construction methods are largely labour intensive. It requires less amounts of cement and no formwork and hence cheaper. Also, the acquisition costs of materials (sand and stone) are limited to wages for the gatherers and any blasting of rock. Transportation costs are minimised especially if sourced in close proximity to the construction site. Only cement which accounts for approximately 4% of the mass is the only material which is hauled any significant distance. On the other hand, wood is scarce due to over utilisation and has a low social acceptability. However, wood pole is usually obtained without great efforts where available. Concrete foundations are well accepted socially and widely used. However, the production of cement and aggregates are rarely labour intensive and small scale. The costs are usually prohibitive and the manufacturing processes consume a lot of energy which leads to increased costs.

Wood pole foundation was rated the best option from environmental point of view followed by stone and lastly concrete foundation. Round wood does not require sawing and the use of primary energy is minimised. Wood degrades and if not it can then be re-used and recycled. It is a renewable resource if it originates from well managed and sustainable forests. Although stone is not a renewable resource, it can be re-used and recycled. Hardly any energy goes into its production and use. However some minimal energy is used in transporting the material to the construction site, if not locally available. Although concrete can be recycled, the process requires enormous amounts of energy. Also, the manufacturing process especially of cement is energy intensive and in addition adversely affects the ecology of forests and river beds through emissions of particulate matter into the atmosphere and extensive deforestation and loss of top-soil. It appears with some other cheap forms of energy source, concrete foundations will continue to be the best options. However, in this particular case it was established that stone laid in mortar foundation was the most appropriate option. Its durability is comparable to concrete and the energy consumption is greatly reduced in the production and use of the technology. Also its use increases employment opportunities and affords unskilled people access to such opportunities and hence likely to stimulate and support local economy.

4.2. Ground floor slab building systems

Table 5 shows the results for the ground floor slab construction technologies. Concrete floor was rated the best option technically followed by natural stone, soil-cement and lastly rammed earth. Concrete is durable, provides good structural strength, and

Table 4
Results — foundation construction technologies.

Building technologies: foundation								
Criteria for responsive building technologies	Wood pole		Concrete strip		Concrete raft		Stone mortar	
	Aver.	Norm	Aver.	Norm.	Aver	Norm	Aver	Norm.
Technical criteria								
Durability	2.4	0.6	4	1.00	4	1.00	3.4	0.85
Weather penetration	0	0.00	0	0.00	0	0.00	0	0.00
Thermal comfort	0	0.00	0	0.00	0	0.00	0	0.00
Structural strength	3.2	0.80	4	1.00	4	1.00	3.5	0.88
Behaviour in fire	0	0.00	0	0.00	0	0.00	0	0.00
Incremental expansion	3.2	1.00	3.2	1.00	3.2	1.00	3.2	1.00
Non-destructive disassembling	4.2	1.00	1	0.24	1	0.24	2.5	0.60
Aggregated score	1.40		2.00		2.00		1.73	
Socio-economic criteria								
Indigenous system	4.5	1.00	3	0.67	3	0.67	4	0.89
Labour intensive	4	0.89	3.5	0.78	3.5	0.78	4.5	1.00
Small scale	4	0.89	3.5	0.78	3.5	0.78	4.5	1.00
Abundant and locally available	1.5	0.60	2.5	1.00	2.5	1.00	2.5	1.00
Social acceptability	1.2	0.27	4.5	1.00	4.5	1.00	3.5	0.78
Semi-and/or unskilled labour	3	0.94	2.2	0.69	2.2	0.69	3.2	1.00
Owner built	3.5	1.00	2.5	0.71	2.5	0.71	3.2	0.91
Aggregated score	7.58		6.86		6.86		8.18	
Environmental criteria								
Re-use	4	1.0	2.2	0.55	2.2	0.55	3	0.75
Recycling	4	1.0	4	1.00	4	1.00	4	1.00
Energy consumption	2.5	1.0	4.2	0.60	4.2	0.60	3.2	0.78
Waste generation	2.5	1.0	3.5	0.71	3.5	0.71	3	0.83
Site production of materials	3.5	1.0	1.2	0.34	1.2	0.34	2.5	0.71
Particulate and gaseous emissions	1.5	1.0	3.5	0.43	3.5	0.43	3	0.51
Aggregated score	6.00		3.63		3.63		4.58	
Grand aggregated score	14.98		12.49		12.49		14.48	

resistance to water penetration. However, concrete floors with no insulating material do not provide adequate protection against heat loss. There is need to incorporate insulation such as polyurethane forms in concrete floor slab construction to mitigate the problem of heat loss.

Natural stone is similar to concrete floor with regard to all technical aspects except for incremental expansion and non-destructive disassembling. The use of cement improves the durability of soil-cement floor. However, its durability is still low compared to concrete floor. Rammed earth has good thermal properties because soil has high thermal capacity absorbing and releasing heat when required. Traditional construction of rammed earth allows water penetration and rising damp, requiring frequent repair and maintenance. It can be dusty and is likely to habour insects and other parasites that might be harmful to health. However, this need not be the case, soil stabilisers such as starch paste and glues can be added to increase durability and sealing with any oxidising oil such as linseed or hemp oil. Soil-cement floor was rated the best option when compared to rammed earth.

Socio-economically, rammed earth was rated the best option followed by natural stone, soil-cement and lastly concrete floor. Rammed earth use local resources (material and labour), owner built, indigenous system and hence can support the stimulation of the local economy. The construction method is labour intensive and hence can generate employment opportunities. The use of this technology can therefore alleviate poverty. However, the biggest problem is the poor technical performance and hence social unacceptability. On the other hand, concrete is socially acceptable and its technical performance is exemplary, however, cost is the prohibitive factor. Soil-cement floor is an improvement on rammed earth floor however, it is not comparable to concrete floor slab and as a result its social acceptability is low. Natural stone is socially acceptable because of its good technical performance. The production and use of stone in floor construction can also support the local economy especially where stone is available. It allows participation of local contractors and can be owner built. The method is labour intensive which can generate employment opportunities and hence poverty alleviation. In terms of the environmental criteria, rammed earth was rated as the best option. This was followed by natural stone, soil-cement, and lastly concrete floor. Hardly any energy is used in the production and construction of earth floors. The technology allows recycling and re-use of materials. It contributes zero pollution and no waste is generated. Although stone is not considered a renewable resource, it can be re-used and recycled. Although some energy is spent on transportation and particulate matter emitted into the atmosphere in the production and use of stone, overall its environmental impacts are far less when compared to concrete slab. As mentioned earlier concrete is the worst performing materials environmentally because of its high-energy consumption in the production and use.

Overall, concrete is the most universally applicable form of ground floor construction. However, it is not responsive to the urban poor and their environment. This is mainly due to the high amount of energy consumed in the production and use. Natural stone laid in mortar floor slab was the overall best option. It is technically comparable to concrete floor, and socio-economically and environmentally to rammed earth. It was noted that rammed earth was the lowest rated technically but the highest socio-economically and environmentally. On the other hand concrete floor was rated the highest technically but the lowest socio-economically and environmentally.

4.3. Wall building systems

The results for wall construction technologies are shown in Table 6. Technically, all the selected wall building systems were

Table 5
Results — ground floor construction technologies.

Building technologies: ground floor								
Criteria for responsive building technologies	Concrete floor		Rammed earth		Soil-cement		Natural stone floor	
	Aver.	Norm	Aver.	Norm.	Aver	Norm	Aver	Norm.
Technical criteria								
Durability	4.2	1.00	1	0.24	2.4	0.57	3.5	0.83
Weather penetration	2.5	1.00	3.5	0.71	3	0.83	3	0.83
Thermal comfort	2.5	0.71	3.5	1.00	2.5	0.71	3	0.86
Structural strength	4.5	1.00	1.5	0.33	2.5	0.56	4.5	1.00
Behaviour in fire	4	1.00	4	1.00	4	1.00	4	1.00
Incremental expansion	1	1.00	1	1.00	1	1.00	1	1.00
Non-destructive disassembling	1	1.00	1	1.00	1	1.00	1	1.00
Aggregated score	4.71		3.29		3.67		4.52	
Socio-economic criteria								
Indigenous system	1	0.2	5	1.00	3.5	0.70	4	0.80
Labour intensive	3.5	0.78	4.5	1.00	4.5	1.0	4.5	1.00
Small scale	3.5	0.78	4	0.89	4	0.89	4.5	1.00
Abundant and locally available	1	0.20	5	1.00	3.5	0.70	2.5	0.50
Social acceptability	4	1.00	2	0.50	2.5	0.63	3	0.75
Semi-and/or unskilled labour	2.5	0.60	4.2	1.00	3	0.71	3.2	0.76
Owner built	2.5	0.71	3.5	1.00	3.5	1.00	3.2	0.91
Aggregated score	6.27		8.39		7.63		7.73	
Environmental criteria								
Re-use	1	0.22	4.5	1.00	2.2	0.49	4.5	1.00
Recycling	4	0.89	4.5	1.00	3.5	0.78	4.8	1.07
Energy consumption	4	0.25	1	1.00	2.5	0.40	2.5	0.40
Waste generation	3.5	0.29	1	1.00	2.5	0.40	1.5	0.67
Site production of materials	2.4	0.48	5	1.00	2.5	0.50	3.5	0.70
Particulate and gaseous emissions	4.5	0.22	1	1.00	2.5	0.40	2	0.50
Aggregated score	2.35		6.00		2.97		4.33	
Grand aggregated score	13.33		17.67		14.27		16.58	

Table 6
Results – wall building construction technologies.

Building technologies: walls																				
Criteria for responsive building technologies	Burnt clay masonry		Concrete masonry		Natural stone		Stabilised earth blocks		Dry-stack masonry		Improved mud & wood pole		Cast in-situ rubble		Sandwich panels		Shuttering blocks		Timber frame	
	Aver.	Norm	Aver.	Norm.	Aver	Norm	Aver	Norm.	Aver.	Norm	Aver.	Norm.	Aver	Norm	Aver	Norm.	Aver.	Norm	Aver.	Norm.
Technical																				
Durability	4.5	1.00	4	0.89	4.5	1.00	3	0.67	2.8	0.62	3	0.67	3	0.67	2.5	0.56	3	0.67	3	0.67
Weather penetration	2.5	0.80	2.5	0.80	2	1.00	3	0.67	3	0.67	3	0.67	3	0.67	3	0.67	3	0.67	3	0.67
Thermal comfort	3.5	0.88	3.5	0.88	3.5	0.88	3	0.75	3	0.75	3	0.75	3	0.75	4	1.00	4	1.00	3.5	0.88
Structural strength	4.5	1.00	4	0.89	4	0.89	3	0.67	2.5	0.56	3	0.67	3	0.67	2.5	0.56	3	0.67	3	0.67
Behaviour in fire	2	1.00	2	1.00	2	1.00	2	1.00	2	1.00	3.5	0.57	2	1.00	4	0.50	3	0.67	4	0.50
Incremental expansion	3	1.00	3	1.00	3	1.00	3	1.00	3	1.00	3	1.00	3	1.00	3	1.00	3	1.00	3	1.00
Non-destructive Disassembling	2.5	0.60	2	0.48	3	0.71	2.5	0.60	4	0.95	2	0.48	2.2	0.52	4	0.95	3	0.71	4.2	1.00
Aggregated score	4.68		4.45		4.76		3.75		3.59		3.32		3.75		3.28		3.67		3.38	
Socio-economic																				
Indigenous system	3	0.75	3	0.75	4	1.00	3.5	0.88	3	0.75	3.5	0.88	3.5	0.88	1	0.25	1.5	0.39	2	0.50
Labour intensive	3.5	0.78	3	0.67	4.5	1.00	4.5	1.00	3.5	0.78	4.5	1.00	4.5	1.00	2.5	0.56	3.2	0.71	3.5	.78
Small scale	3.5	0.78	4	0.89	4	0.89	4.5	1.00	4	0.89	4	0.89	4	0.89	2	0.44	2.5	0.56	3	0.67
Abundant and locally Available	2.5	0.60	2.5	0.60	2.5	0.60	3.5	0.83	3.5	0.83	4	0.95	4.2	1.00	2	0.48	2.5	0.60	2	0.48
Social acceptability	4	1.00	4	1.00	4	1.00	2	0.50	2.5	0.63	2.5	0.63	2.5	0.63	2.5	0.63	3.5	0.88	2	0.50
Semi-and/or unskilled labour	3	0.75	3	0.75	3	0.75	3.2	0.80	4	1.00	3	0.75	3.2	0.80	3.2	0.80	3	0.75	2.5	0.63
Owner built	2.5	0.71	2.5	0.71	2.5	0.71	3.5	1.00	3.5	1.00	3.5	1.00	3.5	1.00	3	0.86	3.5	1.00	3	0.86
Aggregated score	6.96		6.84		7.66		7.60		7.83		7.57		7.71		5.96		6.58		6.40	
Environmental																				
Re-use	2.5	0.60	2	0.48	4.2	1.00	4	0.95	4.2	1.00	3.2	0.76	2.5	0.60	4	0.95	2.5	0.60	4.2	1.00
Recycling	3.5	0.88	2.5	0.63	4	1.00	3	0.75	3	0.75	3	0.75	2.5	0.63	3.5	0.88	2.5	0.63	3.5	0.88
Energy consumption	4.2	0.52	4	0.55	2.5	0.88	3	0.73	2.5	0.88	2.2	1.00	2.5	0.88	4.5	0.49	3.5	0.63	2.5	0.88
Waste generation	3.5	0.57	4	0.50	2.5	0.80	3	0.67	3	0.67	2	1.00	2	1.00	4	0.50	2.8	0.71	3	0.67
Site production of materials	2.5	0.71	2	0.57	2.5	0.71	2	0.57	2.5	0.71	3	0.86	3.5	1.00	1	0.29	1	0.29	3	0.86
Particulate and gaseous emissions	3	0.67	4.2	0.48	2.5	0.80	2.5	0.80	2.8	0.71	2	1.00	2	1.00	3.5	0.57	3.8	0.53	2	1.00
Aggregated score	3.95		3.20		5.19		4.47		4.73		5.37		5.10		3.67		3.38		5.28	
Grand aggregated score	15.58		14.49		17.62		15.83		16.15		16.26		16.56		12.91		13.62		15.06	

rated as having similar performance. However, these have varying degree of incremental expansion and non-destructive disassembling. Generally masonry wall construction (stone, brick and concrete) have better resistance to water penetration. However, concrete masonry may require plastering or rendering to be water resistant. Also they have the advantage of a single system fulfilling several functions (structural strength, fire protection, thermal and sound insulation, etc.) and are durable. They have negligible or manageable dimensional change with changes in moisture content. Thus, there is no risk of shrinkage cracking. Earth wall building system, on the other hand, have better thermal properties when compared to burnt clay brick, concrete brick/block and stone masonry. However, this advantage might be less when compared to sandwich wall panels or walls with insulation such as permanent shuttering block masonry. Although sandwich wall panels have the advantage of better thermal characteristics, if there is a temperature difference between the inner and outer skins, this may cause the panels to warp or dish markedly.

Socio-economically, the selected wall building systems had similar performance, apart from the sandwich wall panels. The main differentiating factors were costs and social acceptability. Sandwich wall panels are factory made, with the advantages of standardised and mass production. This is advantageous to masonry construction that takes too long, and the productivity is low. However, this delineates the urban poor because in most cases acquiring a plant for production of such wall building system requires massive initial investment cost. This requires technologies that can be implemented in light and cottage industries.

Environmentally, improved mud and wood pole walling system was rated the best option. This was because the construction method and materials rely on low use of energy and the system is degradable. Similarly, timber frame wall building system was considered environmentally friendly because timber is a renewable resource when it originates from sustainable forests, uses low energy in production, has the potential of re-use, recycling, energy production, produces minimum waste and it is easily degradable in nature. On the other hand, permanent shuttering block masonry wall building system, especially those made from plastics such as polystyrene, have extremely high-embodied energy (117.0 MJ/kg). This makes such building systems extremely environmentally unsuitable. All the other wall construction technologies that rely heavily on cement (burnt clay, or concrete brick/block, natural stone, cast in-situ rabble, and stabilised earth blocks) are also environmentally unsuitable due to the reasons associated with the production of cement as mentioned previously. However, it should be noted that the degree of environmental impact will vary depending on the amount of cement used.

These findings suggest walling systems that utilises less energy in production and construction as the best option besides meeting the technical requirements. Also, there is the need to educate the urban poor on the available wall building technology options that perform equal well when compared to the conventional brick and mortar. In addition, there is need to decentralise the production of building materials and enable more people to participate in production, for example, by public funding of small scale enterprises such as cottage industries with the view to reduce costs.

4.4. Roof building construction systems

Table 7 shows the results of roof construction technologies. Technically, concrete and clay tiles were rated the best option, followed by fibre-cement sheets, metal sheets and lastly grass thatch. Concrete and clay tile are durable, provide adequate strength and stability and prevent penetration of inclement weather. On the other hand, grass thatch lacks durability. It is prone to biological attack and it is susceptible to fire. The commonly

Table 7
Results – roofing construction materials and technologies.

Sub-criteria for responsive building technologies	Grass thatch		Metal sheets		Fibre-cement sheets		Concrete tiles		Clay tiles	
	Aver.	Norm	Aver.	Norm	Aver.	Norm	Aver.	Norm	Aver.	Norm
Technical criteria										
Durability	2	0.50	2.8	0.70	3	0.75	3	0.75	2.5	0.63
Weather penetration	4	0.50	2.5	0.80	2.5	0.80	2.5	0.80	2.5	0.83
Thermal comfort	4	1.00	2	0.50	3	0.75	3	0.75	4	1.00
Structural strength	4	1.00	4	1.00	3	0.75	3	0.75	2.5	0.63
Behaviour in fire	4	0.50	3	0.67	3	0.67	2	1.00	2	1.00
Incremental expansion	3	1.00	3	1.00	3	1.00	3	1.00	3	1.00
Non-destructive disassembling	4	0.95	3.8	0.90	4	0.95	4.2	1.00	4.2	1.00
Aggregated score	3.50		3.67		3.72		4.05		4.05	
Socio-economic criteria										
Indigenous system	5	1.00	2.5	0.50	3	0.60	2.5	0.5	3.5	0.70
Labour intensive	4.5	1.00	2.5	0.56	4.5	1.00	2.5	0.56	3	0.67
Small scale	4.5	1.00	2	0.44	4	0.89	2.5	0.56	3	0.67
Abundant and locally available	2.5	0.71	3.5	1.00	3	0.86	2.5	0.71	2.5	0.71
Social acceptability	2	0.40	3.5	0.70	4.2	0.84	5	1.00	5	1.00
Semi-and/or unskilled labour	3.5	1.00	3.5	1.00	3	0.86	3.2	0.91	3.2	0.91
Owner built	4.5	1.00	2.5	0.56	4.2	0.93	2.5	0.56	3	0.67
Aggregated score	8.07		6.66		7.93		6.80		7.33	
Environmental criteria										
Re-use	4	0.95	3.8	0.90	3.2	0.76	4.2	1.00	4.2	1.00
Recycling	4	1.00	2.5	0.63	2.5	0.63	2.5	0.63	2.5	0.63
Energy consumption	1.2	1.00	4.2	0.29	3.5	0.34	4	0.30	4.2	0.29
Waste generation	1.2	1.00	4	0.30	3.5	0.34	3.5	0.34	3	0.40
Site production of materials	4	1.00	2.5	0.63	3	0.75	2.5	0.63	4	1.00
Particulate and gaseous emissions	1	1.00	4.2	0.24	3	0.33	3.5	0.29	2.5	0.40
Aggregated score	5.95		2.98		3.16		3.18		3.71	
Grand aggregated score	17.52		13.31		14.80		14.02		15.09	

available fibre-cement roofing sheets are not durable. Metal roofing sheets, comparatively, also lack durability due to corrosion.

Socio-economically grass thatch was rated the best option, followed by fibre-cement, clay tiles concrete tiles and metal sheets. Grass is an indigenous material and the construction method is labour intensive. It is also suitable to small-scale local constructors. However, good grass for thatching is not abundantly, available resulting in high cost. The use of burnt clay and concrete tiles are seldom considered cheap enough for low-income households.

However, the construction methods and materials are largely labour intensive and small scale. Also, the use of fibre-reinforced roofing sheets is rarely considered. This is because most of the available good fibres such as carbon are very expensive and thus beyond the reach of the urban poor. There is need for fibres that can result in the required properties and are available in large quantities.

Grass thatch was rated environmentally superior to other materials. Grass thatch is well adapted to the natural environment and decays. It does not require a lot of energy in its use. Metal sheets, on the other hand, have a high-embodied energy. The manufacturing process is extremely energy intensive. However, metal sheets can be re-used and recycled. In addition, some of the bi-products of metal sheets manufacturing, such as slag, are used in cement production. Similarly, the production of clay and concrete tiles requires an enormous amount of energy which increases costs.

Overall, grass thatch was rated the best roofing option. However, the use of grass thatch in the urban setting on a large scale has adverse socio-economic implications and it is not recommended. In the first instance, there is scarcity of good grass as a result of a breakdown in sustainable practices. In terms of safety, the requirements are more stringent when compared to other roofing materials. More land is required due to large spacing which puts more pressure on the already scarce good building sites. There is need to adopt other roofing materials such as fibre-cement roofing sheets which are durable and can be manufactured on demand. However, such fibres are hard to come by.

5. Conclusions and recommendations

The idea of analysing building technologies in terms of technical, socio-economic and environmental aspects simultaneously is a noble one. It enables building technologies to be viewed from a holistic manner which in turn can enable solutions that are suitable to the target community to be proposed. For example, this analysis as shown that most of the available building technologies are not responsive to the poor and heir environment in the regional context. This perhaps explains why, in addition to other causes, the urban poor live in precarious environments. In fact, none of the selected building technologies scores consistently high in all the three categories of responsiveness. The technologies that are technically suitable in most cases are not economically and environmentally responsive. For example, when technical suitability increases, so does un-affordability. When the environmental suitability increases the technologies have poor technical performance and suffer from social acceptability. This confirms the fact that the development paradigm has been at the expense of the environment and exclusion.

The analysis also shows that energy consumption, durability and employment generation are the best criteria for evaluating foundation technologies. During design, besides the technical requirements, it will be appropriate to propose durable foundation solutions that take these issues into account. The findings suggest technology solutions that allow in-situ upgrading without the need to demolish the existing system, for example, upgrading of rammed earth floor slab to the level of concrete slabs. Such solutions should but emphasis on durability, heat loss and employment generation. In addition, the findings suggest walling systems that utilises less energy in production and construction as the best option besides meeting the technical requirements.

These findings suggest that the best options are technologies that are both socio-economically and environmentally responsive. However, such technologies, for example, informal building technologies, in most cases, have poor technical performance. This, therefore, calls for research work to focus on improving the technical performance and maintaining or enhancing the socio-economic and environmental benefits of building technologies currently accessed by the urban poor. Further, it is recommended that some specific case studies should be carried out in order to understand and intensify the effectiveness of the proposed methodologies, for example, savings in terms of energy and labour involved in a specific technology. Also it is recommended to develop some correlation between technical, economical and environmental responses. Any future research of this kind should strive to arrive at optimal technologies which fulfil all the above mentioned responses. This will enhance understanding the potentials such technologies have and in turn on how to empower the urban poor to make their own contribution to the process of improving their housing conditions.

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