The efficacy of innovative technologies in subsidised housing in South Africa: A case study

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Abstract

The Millennium Development Goals are the world's targets for addressing extreme poverty in its many dimensions – income poverty, hunger, disease, lack of adequate shelter, and exclusion – while promoting gender equality, education and environmental sustainability. Regrettably the number of people living in slums and slum-like conditions in the world's cities is growing, and in many instances, the quality of existing shelters is "deteriorating" (UNDP 2005:2). Progress toward achieving the Millennium Development Goals has been slow in sub-Saharan Africa: one of the reasons for this is the "very slow diffusion of technology from abroad" (UNDP 2005:148). An essential priority for African economic development therefore is to mobilise science and technology targeted at Africa's specific ecological challenges, i.e., food, disease, nutrition, construction, and energy (UNDP 2005:156).

The South African Government's aim is to deliver 220,000 subsidised houses per annum between 2010 and 2014: the current backlog for state-subsidised housing as of 2010 was reported as approximately 2.1 million, which translates to about 12 million South Africans still in need of a better shelter (Sexwale 2010). Of those households occupying RDP or state-subsidised housing, 16,1 per cent stated that the walls were weak or very weak and 14,9 per cent regarded their roofs as weak or very weak. More than 30 per cent of households in the Western and Eastern Cape reported problems with the quality of the roofs and walls (StatsSA 2009:5).

This case study arises out of CSIR appointment by the Department of Science and Technology in January 2008 to "develop, test and implement innovative technologies aimed at improving the performance of the houses and contributing toward sustainable human settlements." The objective of the research is to achieve comfortable subsidised housing that performs as well as or equal to conventional suburban housing, is durable and quick to build, readily alterable, easily extendable, less dependent on municipal services, and able to facilitate sustainable human settlements. Accordingly the CSIR developed and tested an alternative house design using innovative technologies to improve the performance of the house. The innovative technology process was aligned with the typical construction processes for easy reference, i.e., sub-structure, super-structure, roof, finishes, and services (Llewellyn-Davies & Petty: 1960; Barry: 1974; and Emmitt & Gorse, 2005).

With regard to the *sub-structure*, as the CSIR has successfully developed, tested and implemented a thin concrete technology for roads, this technology was adapted for use on House 3 (the CSIR experimental design). The technology for continuously reinforced concrete pavement (CRCP) comprises the use of a compacted base course treated with a diluted bitumen emulsion topped with a 193 steel mesh reinforced 50 mm concrete layer.

With regard to the *super-structure*, House 3 was redesigned along modular lines, where the dimensions of the house are determined by the module of the hollow concrete block. Strict joint control and careful planning of the room dimensions resulted in a zero-waste circumstance requiring no cutting of blocks.

With regard to the *roof assembly*, two courses of U-shaped hollow concrete blocks are used below wall plate level: these are reinforced with a steel reinforcing bar and filled with concrete resulting in a continuously reinforced ring beam around the full perimeter of the house. The wall plates are laid on a screed laid to fall from front to back and secured to this reinforced beam by hoop iron fixed to the reinforcing bar and cast in. The fall enhances the discharge of rain water to water harvesting points at the corners of the building. The roof beams are orientated in a manner that results in the roof sheets running longitudinally rather than vertically: this enables the roof overhang to be structurally supported while making the whole roof act as a gutter.

Very little scope exists for improving or enhancing the *finishes*: given the financial constraints placed on low-cost houses, the decision was taken to focus on improving the performance of the structure rather than on the cosmetic appearance of the house. However, as the housing location qualifies for the 'coastal allowance', an external plaster coat of 'Perlite' is applied which promises improved thermal and water resistance.

With regard to *services*, significant attention was paid to prefabricating the plumbing installation: to this end, a plumbing 'manifold' was developed that picks up the plumbing fittings and could be inserted into prepared penetrations through the block. The result is a significantly shortened plumbing installation, and critically, since most of the installation is fixed internally, the potential for damage or vandalism is reduced.

Two modeling studies were undertaken post-construction of the test houses to determine whether the application of science, engineering and technology (SET) did result in measurable performance improvements.

With regard to the first, the study found that House 3 (the CSIR experimental design) required 56,2% less energy than House 1 (the default subsidy house) to maintain a comfortable indoor temperature.

With regard to the second, the study found that the CSIR house requires about 35% less material resource input by weight compared to the default subsidy house, largely due to the replacement of conventional foundations with the thin concrete floor, the replacement of solid concrete blocks with hollow concrete block, and the elimination of floor screed. The study found that the CSIR house contributes less to climate change than House 1, the potential difference between the two designs being 685 kg CO_2 equivalents excluding operational reductions due to lower heating loads. The study further found that House 3 contributes less to water depletion than House 1.

The study finds that innovative technologies developed through SET can deliver measurable performance improvements across a range of metrics that would substantially improve the quality of life of the inhabitants as well as contribute to national goals.

1. General introduction

The Millennium Development Goals are the world's time-bound and quantified targets for addressing extreme poverty in its many dimensions – income poverty, hunger, disease, lack of adequate shelter, and exclusion – while promoting gender equality, education, and environmental sustainability. They are also basic human rights – the rights of each human being to health, education, shelter, and security as pledged in the Universal Declaration of Human Rights and the UN Millennium Declaration (UNDP 2005:1). The UN Millennium Goals are interpreted as country goals: that is to say they must be made operational by the individual sovereign state, and the state must be held accountable as a co-signatory.

Regrettably the number of people living in slums and slum-like conditions in the world's cities is growing: between 1990 and 2001 the slum population grew in every region except North Africa (UNDP 2005:19),

and in many instances, the quality of existing shelters are "deteriorating" (UNDP 2005:2). For all developing countries the UN recommends that the MDG-based frameworks to meet the 2015 targets be designed around seven "clusters", one of which is "Promoting vibrant urban areas, by encouraging job creation in internationally competitive manufactures and services, upgrading slums, and providing alternatives to slum formation" (UNDP 2005:64). The UN Millennium Project recommends that known interventions reach the scale of investment needed to achieve the goals. The need to scale up arises from the limited impact of pilot projects implemented at local or district levels without a measurable impact on national indicators. National scale-up however remains a major institutional challenge requiring an intersectoral approach and a carefully designed multiyear planning framework.

Progress toward achieving the Millennium Development Goals has been slow in sub-Saharan Africa: one of the reasons for this is the "very slow diffusion of technology from abroad" (UNDP 2005:148). An essential priority for African economic development therefore is to mobilise science and technology targeted at Africa's specific ecological challenges, i.e., food, disease, nutrition, construction and energy (UNDP 2005:156).

Within the South African context, the South African population was recorded in the 2009 Community Survey as 49 383 000 with the total number of households recorded as 13 812 000. The net population growth was recorded as 430,000 per annum.

Government's aim is to deliver 220,000 subsidised houses per annum between 2010 and 2014: the current backlog for state-subsidised housing as of 2010 was reported as approximately 2.1 million which translates to about 12 million South Africans who are still in need of a better shelter (Sexwale 2010). Government has budgeted R16-billion on subsidised housing for the 2010/2011 financial year. Fifty six per cent of households lived in formal dwellings in 2009 (StatsSA 2009:5) with 13,4 per cent of households living in informal dwellings. The number of households living in 'RDP' or state-subsidised dwellings was recorded as 12,8 per cent with an almost equal percentage of households having at least one member of the household on a demand database/waiting list for state-subsidised housing.

Of those occupying RDP or state-subsidised housing, 16,1 per cent stated that the walls were weak or very weak and 14,9 per cent regarded their roofs as weak or very weak. More than 30 per cent of households in the Western and Eastern Cape reported problems with the quality of the roofs and walls (StatsSA 2009:5).

With regard to other infrastructures services, 82,6 per cent of households are connected to the mains electricity supply; however, 24,8 per cent (or one-in-four) of households still use wood or paraffin for cooking. While 89,3 per cent of all households had on- or off-site access to piped or tap water, only 42,1 per cent accessed their main source of drinking water from inside their dwelling. With regard to sanitation and waste removal, 6,6 per cent of households had no access to a toilet facility or were using a bucket toilet and 46,9 per cent of households do not have their refuse collected by the municipality.

2. Project Background and Context

This case study arises out of a request made by the Department of Science and Technology (DST) to CSIR in 2007 to evaluate two applications for funding made to DST with regard to subsidised housing projects. The applications were submitted by Overstrand Municipality and Buffalo City Municipality for additional funding for 711 and 500 houses respectively. The CSIR in its evaluation reports of September 2007 noted that both applications offered unique opportunities to develop, test and implement innovative technologies aimed at delivering sustainable human settlements and improving the performance of the house. Arising out of the evaluation reports, the CSIR was contracted by DST in January 2008 to "develop, test and implement innovative technologies aimed at improving the performance of the houses and contributing toward sustainable human settlements."

The houses were intended to be built in accordance with a low-income house plan as approved by the National Home Builders Registration Council (NHBRC). This is a 40 square meter housing unit comprising two bedrooms, a living area including a kitchenette, and a bathroom having a shower, a basin and a water closet (wc). The house is to be constructed of 140 mm-wide hollow concrete blocks on conventional concrete foundations, a conventional 75 mm concrete floor slab on a damp proof course on compacted fill, steel window frames, steel door frames with timber doors internally and externally, and a roof assembly consisting of timber beams with a cranked steel roof sheet. Provision was to be made for cold water supply only, and for a single electrical board comprising a light and two plug points. No ceilings, roof or wall insulation, plaster, or rain water goods were provided. Both projects are located on hilly terrain, with slopes ranging from gentle to steep. Both projects were to be provided with roads (unpaved in the case of Mdantsane), and bulk water, storm water and sewerage reticulation. The Kleinmond project was to include street lighting and tarred roads (chip and spray). Due to the findings of the environmental impact assessment, the number of houses in the Kleinmond project was reduced to 411 units.

3. Research Question

The overarching question that guided the research programme was developed from the contextual motivation described in Section 1 and 2; learning derived from at least a decade of internal and external research projects on the issue of sustainable building and construction activities; and participation by the team members in international activities and discussions on the topic of human settlement.

> **Guiding research question:**
> *How, and in what way, can innovative material, production and assembly technologies in science, engineering and technology (SET) be applied to construction manufacturing to improve building performance, and construction processes, and facilitate sustainable human settlements?*

The emphasis of the study is on the technological system that constitutes the physical built environment and how this system interacts with the natural system. However, the solutions developed would be guided by an overarching set of principles:
- Would the technologies developed improve the quality of life for the communities in which they are implemented through the following:
    - Providing a healthy living and working environment; and
    - Providing opportunities for economic development and sustainable livelihoods?

Objective
The objective of the research is to achieve comfortable subsidised housing that performs as good as or equal to conventional suburban housing, is durable and quick to build, readily alterable, easily extendable, less dependent on municipal services, and able to facilitate sustainable human settlements.

3.1 Development framework

The research framework was predicated on supporting certain key national objectives:
i) **Treat Development Holistically** – any technology proposals recommended for the housing project should be treated holistically, that is to say, that all proposals support a common set of national goals and objectives. Certain technologies are known to offer other benefits, such as job creation. Similarly, potentials to be found in the specific geographic conditions of the site and its surrounding areas, for example local soils, may well add value to the development if properly exploited. In addition, the location of the site and its connections to existing and adjoining sites, such as public open space systems, must also be explored to ensure that these connections are maximised. Local authorities are increasingly unable to sustain the expansion of urban areas within their jurisdiction: thus, if any development proposal is to serve as a model development, it must demonstrate an ability to operate in a manner that will not further undermine the financial sustainability of local authorities. One of the ways that it can do this is to reduce the dependence of the development on municipal services. This approach should be explored at the level of the entire development, and not only at the level of individual housing units.

ii) **Scaled-up technology** – technologies employed should be capable of being scaled-up across similar subsidised housing projects in South Africa. The development of innovative technologies should therefore have in mind the skills levels within the construction industry, the beneficiaries, and the ability of the local authority and the community to service and maintain those technologies over time. The use of innovative products should similarly ensure that the technology solution be available to the beneficiaries over the life cycle of the dwelling.

iii) **Assess the impacts** – one of the objectives of DST is to improve the quality and depth of SET statistical information to support development and investment decision-making as well as to drive improvements in the quality of SET activities against the backdrop of internationally recognised benchmarks. To accurately assess the impacts of the proposed technologies requires that a base technology level be determined in conjunction with alternative technologies, and that the technology be applied in the same manner. In other words, occupancy rates and occupancy usage should, as far as possible, be comparable. As stated above, certain technologies are more effective at certain scales than others: thus, the overall development must be assessed for scale opportunities and all technologies assessed against the range of scales offered within the development.

iv) **Reduce extreme poverty** – virtually all countries face critical decisions about the best strategies for managing the massive transition of rural populations out of agriculture anticipated in the coming decades. Challenges that this presents are related to determining how urban growth can be made more effective for poverty reduction and how new forms of urban growth can be captured cost effectively. Development technologies that support job creation, are labour intensive, and create opportunities for skills development and training are among the strategies that can support economic growth opportunities for urban communities.

v) **Explore global incentives** – climate change and global warming have stimulated new opportunities in the field of alternative energy technologies, especially those that reduce carbon emissions. The scale of this development may well meet the requirements for carbon trading with a developed country.

3.2 Research methodology

The research methodology was based on two limitations, namely that all technologies would need to comply with the requirements of the National Building Regulations and Standards Act (Act 103 of 1977), and that the CSIR would test any innovative technologies prior to recommending such technologies for implementation. This was done for two reasons:

● To ensure that the liability held by the NHBRC for low-income housing would not be invalidated; and
● To ensure that technologies with a high risk of failure would not be implemented.

Having regard for the above, the CSIR proposed to:
1) Investigate the identified technology requirements for each technology and best practice within the context of the projects including the applicable statutory and policy confines.
2) Determine the availability and suitability of each identified technology and best practice requirement having regard for the potential impact of each technology.
3) Perform a financial evaluation of each identified technology and best practice requirement.
4) Prepare and submit to DST a list of recommended technologies and best practices.
5) Upon instruction from DST, prepare technical specifications for each approved technology and best practice requirement for inclusion into the Contract of Works to be entered into by the relevant municipality.
6) Monitor the implementation of the approved technologies and best practices for compliance with the technical specifications.
7) Monitor the performance of the approved technologies and best practices for a minimum period of 12 months.
8) Evaluate the performance of the approved technologies and best practices at the completion of the monitoring period and compile an evaluation report for submission to DST.

In addition, two modeling studies of the test houses were undertaken post-construction to determine whether the application of SET did result in measurable performance improvements.

4. Development of Innovative Building Technologies

The building technologies and materials described in section 2 offer minimum performance standards with regard to the ingress and egress of heat and cold and moisture. The delivery of 2500 units however created sufficient critical mass to warrant the investigation of the mass production of housing components in a manner that also creates job and skill obtaining opportunities for the local community. Since most of the units conform to one house plan, it is possible to prefabricate whole components, such as the roof, the plumbing installation, the wiring installation, and the bathrooms.

Accordingly the CSIR developed and tested an alternative house design using innovative technologies to improve the performance of the house. The CSIR undertook a technology scan to determine and evaluate how, and in what way, innovative technologies could be used to improve the performance of the dwelling unit and contribute towards sustainable human settlements.
Thereafter the CSIR constructed three houses on its test site on the Pretoria Campus:
- House One was constructed according to the typical low-income house building plans as approved by the NHBRC;
- House Two was built according to the same layout but with building technologies typically used in suburban housing; and
- House Three was built based on the findings of the technology scan, the outcomes of the analysis derived from the construction of the first two houses; the examination and determination of construction best practice; and design proposals aimed at improving the performance of the house (van Wyk, de Villiers, and Kolev 2009).

The innovative technology process was aligned with the construction processes for easy reference, i.e., *sub-structure*, *super-structure*, *roof*, *finishes*, and *services* (Llewellyn-Davies & Petty: 1960; Barry: 1974; and Emmitt & Gorse, 2005).

Observations carried out on the construction of House One and House Two revealed a number of areas where improvements were either required or desirable. The plan layout of the NHBRC house is such that any extension of the unit requires substantial demolition of the existing structure. There are two causes of this: the first is that the roof sheets slope down toward the area of the site typically available for extension, limiting the vertical height of the extension and thus its horizontal dimension. To overcome this requires the removal of the entire roof sheet as the roof consists of one sheet cranked over the entire floor plan. The second cause has to do with the location of the services (bathroom and kitchen) as well as the window of bedroom three on the back wall of the house, requiring either the loss of a bedroom or the demolition of the kitchen and/or the bathroom – the most expensive components of the house – if horizontal expansion is to occur. Given that the subsidised house is meant to be a starter house, the inability to expand the house economically is a serious deficiency and is highly detrimental to the beneficiary.

House Three is thus designed so that no services are located on that part of the house to be extended, that no windows are placed in that part, and the roof slope is orientated in a manner that enables the ridge to be extended without the removal of any roof sheets. In addition, the rear door of the house is placed in the wall to be extended so that the beneficiaries can construct the addition and simply open up the door to access the extended house.

Problems typically arising out of the *sub-structure* construction relate to inadequate depth of excavations, inadequate backfilling, using inappropriately sized rubble for the backfilling, and inadequate structural strength of the foundation wall. As the CSIR has successfully developed, tested and implemented a thin concrete technology for roads, this technology was adapted for use on House 3. The technology for continuously reinforced concrete pavement (CRCP) comprises the use of a compacted base course treated with a diluted bitumen emulsion topped with a 193 steel mesh reinforced 50 mm concrete layer. The advantage of this technology is that it removes the need for excavations, concrete footings, foundation walls, backfilling, compacted sand layer and dpc and construction can be done using local

labour and materials. For mass housing contracts it has the added advantage of facilitating the creation of a continuous platform, similar to road construction, requiring only the individual slabs of the houses to be excavated and cast. The platform is prepared 1 m wider on each side, resulting in a hard, stable external surface that also reduces mud splashing onto the lower courses when it rains.

Construction of the *super-structure* reveals typical severe shortcomings with regard to the control of the thickness of the mortar joints, and the cutting and wastage of a large number of blocks. This wastage was a result of a lack of co-ordination between the dimensions of the structure and the dimensions of the block, and the lack of joint thickness control during construction. With this in mind, House 3 was redesigned along modular lines, where the dimensions of the house are determined by the module of the hollow concrete block. Strict joint control and careful planning of the room dimensions resulted in a zero-waste circumstance requiring no cutting of blocks.

Construction of the *roof assembly* typically results in severe vibration at the junction between the wall and the roof sheet causing a horizontal crack in the top masonry course; and the thermal performance of the roof is extremely poor as a result of a lack of roof insulation. For House 3 two courses of U-shaped hollow concrete blocks are used below wall plate level: these are reinforced with a steel reinforcing bar and filled with concrete resulting in a continuously reinforced ring beam around the full perimeter of the house. The wall plates are laid on a screed laid to fall from front to back and secured to this reinforced beam by hoop iron fixed to the reinforcing bar and cast in. The fall enhances the discharge of rain water to water-harvesting points at the corners of the building. The roof beams are orientated in a manner that results in the roof sheets running longitudinally rather than vertically: this enables the roof overhang to be structurally supported while making the whole roof act as a gutter. Tests on the site have confirmed that the overhangs protect the wall surface from rain, thereby minimising moisture penetration, and the rain water discharges at the corners.

Very little scope exists for improving or enhancing the *finishes*: given the financial constraints placed on low-cost houses, the decision was taken to focus on improving the performance of the structure rather than on the cosmetic appearance of the house. However, as the housing location qualifies for the 'coastal allowance', an external plaster coat of 'Perlite' is applied which promises improved thermal and water resistance.

With regard to *services* significant attention was paid to prefabricating the plumbing installation: to this end, a plumbing 'manifold' was developed that picks up the plumbing fittings and could be inserted into prepared penetrations through the block. The result is a significantly shortened plumbing installation, and critically, since most of the installation is fixed internally, the potential for damage or vandalism is reduced.

With regard to environmental efficiency, the measures implemented in House One and House Two to improve the water and thermal efficiency were also applied. Specific NBR requirements for lighting and ventilation to the rooms, being 5% of the room area for ventilation, and 10% of the room area for light, are exceeded by the provision of an additional window in bedroom one and two additional windows to the kitchen area. With regard to water, the requirements for water-efficient taps, shower-heads, and dual-flush cisterns apply. With regard to thermal efficiency, an insulated ceiling board is installed. To minimise thermal bridging at the windows, precast concrete window frames were used for four of the seven windows. Provision was made for the installation of two rain-water tanks at the rear of the building, and the roof was sloped from front to rear so that the entire roof acts as a gutter. Evaluation done in rainy conditions demonstrated that the rain water was indeed flowing to the rear corners as predicted.

5. Performance modeling

Two modeling studies were undertaken post-construction of the test houses to determine whether the application of SET did result in measurable performance improvements.

The first study used computational modeling of each of the houses described in Section 4 and ran analyses to determine their thermal properties and to assess how they behaved in respect to daily and seasonal changes (Osburn 2010). The houses were constructed computationally using Energy Plus in

accordance with the technical specifications of each house. A purchased air analysis was used to calculate the energy required to maintain a comfortable indoor environment. In addition, simulations were run without a purchased air analysis for the hottest and coldest day for House 1 and the daily internal temperature of House 1 and House 3 were compared.

The second study undertook a life cycle analysis (LCA) to assess the environmental performance of the default subsidy house (House 1) and the CSIR experimental house (House 3) to determine whether the application of SET delivered any measurable environmental performance improvements (Naalamkai Ampofo-Anti 2010). The LCA software tool, SimaPro 7.1, served as the main source of the life cycle inventory (LCI) data used in the study. The datasets applied in the study included transport services, energy services and building materials with a view to assessing climate change impacts, energy consumption, material depletion, and water consumption.

With regard to the first, the study found that House 3 (the CSIR experimental design) required 56,2% less energy than House 1 (the default subsidy house) to maintain a comfortable indoor temperature.

Table 1: Comparison of Total Load between House 1 and House 3

House	Heating Load (GJ)	Cooling Load (GJ)	Total Load (GJ)
House 1	12.29	7.50	19.78
House 2	8.66	0.00	8.66

In order to assess other interventions that could be made to improve thermal performance it was modeled with carpeting, additional roof insulation, and wall insulation. The study found that the addition of a carpet further reduced the energy required by 73,0%; the addition of carpeting and 150 mm thick polystyrene roof insulation provided a reduction of 76,0%; while the addition of carpeting, 150 mm thick polystyrene roof insulation and 50 mm thick polystyrene wall insulation provided a reduction of 85,4%.

Table 2: Impact of Additional Insulative Materials on House 1

House	Heating Load (GJ)	Cooling Load (GJ)	Total Load (GJ)
Carpet	4.77	0.55	5.33
Plus roof insulation	4.54	0.20	4.74
Plus wall insulation	2.85	0.02	2.87

With regard to the second, the study found that House 3 requires about 35% less material resource input by weight compared to House 1, largely due to the replacement of conventional foundations with the thin concrete floor, the replacement of solid concrete blocks with hollow concrete blocks, and the elimination of floor screed. The study found that House 3 contributes less to climate change than House 1, the potential difference between the two designs being 685 kg CO_2 equivalents excluding operational reductions due to lower heating loads. The study further found that House 3 contributes less to water depletion than House 1. In addition to the two studies, simple calculations were done to determine the net energy and water savings that would accrue at a national scale if the technology was scaled-up. Assuming that the current backlog of 2.1 million units were constructed using this technology, the following reductions would accrue.

Table 3: National Resource Reductions

Innovative technology	Per House	National
Energy reduction heating/cooling	11,12 GJ	23 352 000 GJ
CO_2 reduction from materials	0,685 ton	1 438 500 ton
Material mass reduction	18,8 ton	39 480 000 ton
Water from materials	19,73 m^3	41 433 000m^3
Water, through rain-water harvesting	22m^3	46 200 000m^3
Electricity savings SWH	1762.95kWh/annum	3.7 billion kWh/annum
Electricity saved PVP	36kWh/annum	75.6 million kWh/annum
CO_2 reduction SWH	2.11 ton/kWh/annum	4.4 million ton/annum

| CO2 reduction PVP | 0.04 ton/kWh/annum | 90 300 ton/annum |

6. Conclusions

The study finds that innovative technologies developed through SET can deliver measurable performance improvements across a range of metrics that would substantially improve the quality of life of the inhabitants as well as contribute to national goals. Due to the extent of the housing backlog, individual savings per housing unit can be translated into significant national savings. However, for these to be realised will require an inter-governmental approach aimed at coordinating the necessary institutional arrangements.

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