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The efficacy of innovative technology in improving the performance of low cost housing in South Africa: A case study

ABSTRACT AND KEYWORDS

Purpose of this paper
The purpose of this paper is to evaluate the efficacy of Science, Technology and Innovation (ST&I) interventions piloted on the Kleinmond Sustainable Human Settlement Project.

Design/methodology/approach
Two surveys were undertaken: the first was a condition assessment of the ST&I interventions applied (quantative analysis) and the second to obtain the views of the beneficiaries of the ST&I interventions through structured interviews (qualitative analysis).

Findings
The condition assessment found that the anticipated performance enhancements were achieved. The interviews found the services interventions were perceived as beneficial but that better communication and training on their purpose, performance and use was required.

Research limitations/implications (if applicable)
As there were 411 housing units a representative sample was used for inspection and interview purposes. The condition assessment only considered the outcomes from those ST&I interventions applied and not the development as a whole.

Practical implications (if applicable)
The research has resulted in the development of a viable and sustainable innovative low cost house type. The research also highlighted challenges on how beneficiaries interact with ST&I interventions.

What is original/value of paper.
The paper will be of value to all stakeholders involved in the planning and design of human settlements.

Keywords.
Science, technology, innovation, post-occupancy evaluation, sustainability.

1. BACKGROUND AND CONTEXT

The Council for Scientific and Industrial Research (CSIR) was appointed by the Department of Science and Technology (DST) in 2006 to apply, examine, test, and evaluate STI interventions aimed at delivering more cost effective houses of improved quality and providing a more sustainable lifestyle with regard to the development of 411 subsidy-houses in Kleinmond in the Western Cape. The project was formally completed in December 2011.

Anecdotal evidence collected during the construction process indicated that the outcomes of the application of the ST&I interventions held substantial promise in terms of improving quality of life for the poor and meeting sustainability imperatives. In 2015 the CSIR was contracted to undertake a Post-Occupancy Evaluation (POE) to determine the efficacy of the ST&I interventions on improving quality of life.

1.1 Post-Occupancy Evaluation (POE)

Preiser, Rabinowitz and White (1988) define POE as "the process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time". POE forms part of evidence-based design, where the objectives of design decisions can be validated for future use. Proponents of POE note that POE usually involves feedback from the building occupants, through questionnaires, interviews and workshops, but may also involve more objective measures such as environmental monitoring, space measurement and cost analysis (Preiser et al 1988: Aitken 1998). POE proponents note that a POE usually includes a mix of quantitative and qualitative techniques. More recently, PoEs tend to include sustainable measures such as energy consumption, waste levels, and water usage.

1.2 The Kleinmond Sustainable Human Settlement Project

Low cost subsidy housing in South Africa is generally the delivery of basic building with minimal services to reduce costs and to maximise the quantity delivered. Subsidised housing is generally of a poor construction quality (cidb 2011:4). In addition, the design of the house typically limits the extension and alteration of the house with regard to future expansion by virtue of the location of services (kitchen and bathroom) and the direction of the fall of the roof.

The focus on this project was to apply ST&I to subsidised housing to improve its performance with little or no increase in cost. The project is located on steeply falling land adjoining the nature conservation area.

2. REVIEW OF INNOVATIVE TECHNOLOGIES APPLIED

The following section provides an overview of the applied ST&I interventions relevant to this paper. The interventions were aimed at overcoming the structural shortcomings and installing rainwater tanks, solar water heating, and photovoltaic panels.

2.1 Description of the house layout

The house layout is based on a prototype developed by the CSIR (Figure 2.1). The prototype is designed to be expanded without having to remove any component. The house is also capable of entry from either end.

In Kleinmond this flexibility facilitated the orientation of the unit towards the street without compromising the sea views. The roof layout was also modified to facilitate the building of semi-detached units.

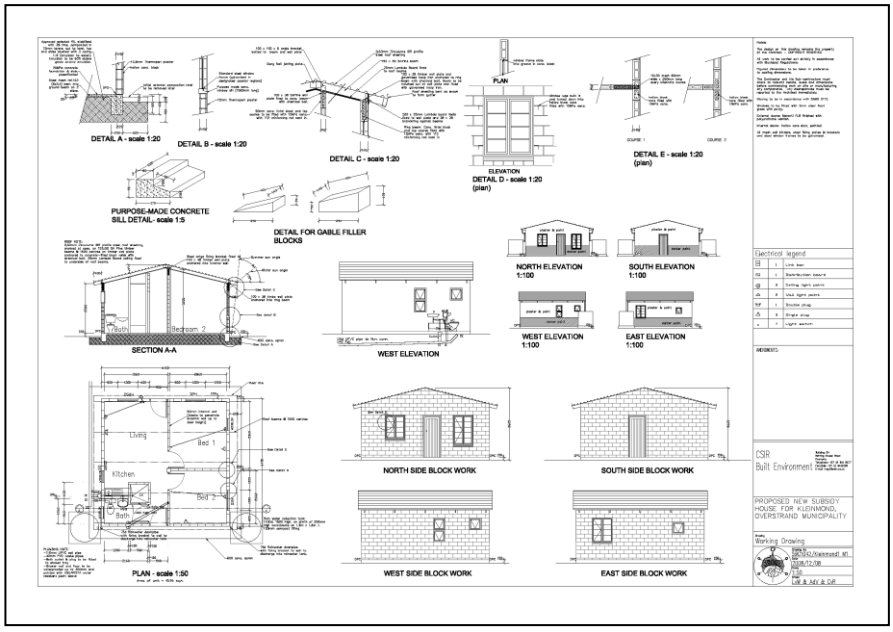

Figure 2.1 Layout of CSIR prototype subsidised house.

2.2 Description of the house construction

As stated above improving the structural integrity of the unit through ST&I interventions was one of the objectives. To this end an ultra-thin continuously reinforce concrete pavement (UTCRCP) technology was used

to form a raft slab. The UTCRCP consists of an ultra-thin (50 mm), continuously reinforced concrete slab with a 400mm deep and 350mm wide concrete foundation downturn ring beam. This is a new innovation in subsidised housing. Unfortunately, due to concern raised by the local building inspector in Kleinmond, the thickness of the slab was increased to 100mm which reduced the cost benefit from the UTCRCP significantly.

The application of the conventional hollow concrete masonry blocks was done in strict accordance with Concrete Manufacturers Association guidelines (CMA undated). However, to improve structural integrity a 390 mm deep reinforced concrete ring beam is formed at wall plate level. A conventional U-shaped lintel block row is built in at door and window head height and is filled with 15 Mpa concrete and reinforced with a single Y12 steel reinforcing bar. With an open hollow block above it, filled with concrete, the effective depth of the beam is 390mm. At the corners of the house, the lintel blocks are 45° mitred for continuity of reinforcing and concrete filling.
This forms a full perimeter beam that binds the entire structure together.

To further improve the structural integrity the house dimensions are all based on modules of 400 mm. This not only avoids unnecessary cutting or breaking of blocks thereby minimising wastage, but also retains the structural integrity of the masonry block. Further to the use of modular dimensions, precast concrete window sub-frames were installed into which were fixed aluminium-framed windows. This aided in improving the joint between the window and the window reveal thereby improving the airtightness of the house.

2.3 Description of the additional services installed

A low-pressure, gravity-fed Solar Water Heater (SWH) of 100 litre capacity was installed at each house. Optimum orientation could be achieved by fitting an adjustable bracket to the ridge of the roof. The heated water is piped to the kitchen sink and the shower. The hand wash basin was not provided with hot water since the intermittent use of small quantities of water, as is normal for hand basins, wastes water while waiting for the water to run warm.

An 80 Watt Photovoltaic Panel (PVP) was provided to each house. This was coupled to a ‘deep-cycle’ battery located in an insulated container in the ceiling. The PVP was wired to supply electricity to 5 Compact Fluorescent Lights (CFL) fittings and a cellphone charger. CFL fittings were installed in lieu of incandescent light fittings as they are more energy efficient. Light-emitting Diode (LED) fittings were investigated but the replacement cost was beyond the financial means of the beneficiaries at the time.

Each unit was provided with a 2500 litre rainwater tank. No first-flush interceptor was installed, and no provision was made for filtering or treating the water. It was intended that the rainwater be used for gardening

purposes or for car washing where it would represent a resource and financial saving to the occupant and to the municipality

3. RESEARCH METHODOLOGY

In order to evaluate the efficacy of the proposed interventions, a quantitative and qualitative approach was used.

The quantitative study involved the physical inspection of a sample of the 411 houses using a pre-prepared and piloted survey sheet. The areas of assessment involved the structural integrity of the foundation slab, the walls, and the roof. The functioning of the rainwater tank, the PVP, and the solar water geyser was also assessed. In addition, improvements made to the unit were recorded and a general overall condition rating giving to the unit.

The qualitative study involved interviews with a sample of occupants from the project, municipal officials involved with the project, a local estate agent, the chairperson of the ratepayer's association, and members from the ward committee. The group interview followed a list of structured questions that served to guide the discussions.

4. QUANTITATIVE ANALYSIS

4.1 Sample selection

To expedite the physical inspection a representative sample of houses was selected. The selected houses were chosen at random from an aerial photograph of the development. The selection was done before the physical inspections were done to ensure that no bias was included in the selection process, i.e. selecting only the "best" or "worst". Although the intention was that at least 50 houses would be assessed, a total sample of 65 houses was identified to allow for the possibility that some houses may not be available for inspection due to unexpected logistical problems.

Officials from the Overstrand municipality visited the selected houses to inform the households that they would be visited during the physical inspection and to obtain the written consent of the household, where possible.

4.2 Data collection and capture

The survey team, consisting of four technical staff members from the CSIR, visited the project on Wednesday 28 October 2015 and managed to inspect 56 of the selected houses. Where the households had not given their

consent forms to the municipal officials, consent was obtained from the households prior to inspection.

The team used a check-list which had been developed and piloted on houses on the CSIR Innovation Site. After the pilot test, the team discussed aspects of the assessments where team members had differed. Small adjustments were made and definitions clarified. The team then physically inspected each identified unit and took supporting photographs of some of the physical features and the appearance of the unit (permission for this was included in the formal consent form).

The completed checklists were captured into separate Microsoft Word documents by each member of the inspection team, and the associated photographs were added at the bottom of the completed checklist. The data from the checklists was separately captured into a Microsoft Excel spreadsheet and analysed using Statistical Analysis Software Version 9.4 (SAS).

4.3 Data analysis methodology

Since the objectives of the condition assessment were to establish the structural soundness of the building units five years after construction with particular reference to the specific structural aspects addressed by the CSIR in the design of the building, as well as to establish whether the technology additions were still in place and working, the data analysis focussed on summarising these portions of the survey. Data analysis consisted mostly of combining the assessment of various features into a combined overall assessment.

4.4 Results obtained

4.4.1 Condition assessment of cracks in the houses

The findings presented in Table 1 to Table 8 show an encouraging picture regarding the overall structural condition of the housing units. In order to read the tables, note that the descriptions are ordered from the biggest to the smallest number found in the sample. In each table the percentage that the count represents out of the total sample is also provided. It should be clear that in each of the tables the categories related to small or no structural problems was by far the biggest category. The survey team were able to assess all the aspects on the survey list.

The results indicate that 89.29 percent of the houses in the sample either showed no damage or showed only minor damage (such as hairline cracking) on each of the various structural aspects listed.

Table 1 Summary of foundation slab condition.

Raft Slab Status	Count	Percentage of Sample
No cracks	52	92.86
Hairline cracks only	4	7.14
TOTAL	56	100.00

Table 2 Summary of external wall condition.

External Wall Status	Count	Percentage of Sample
No cracks	33	58.93
Hairline cracks only	17	30.36
2 to 5 Substantial Cracks	4	7.14
1 Substantial Crack	1	1.79
More than 5 Hairline and Substantial Cracks	1	1.79
TOTAL	56	100.00

Table 3 Summary of walls around the doors and windows

Cracks around doors and windows	Count	Percentage of Sample
No cracks	26	46.43
Hairline cracks only	21	37.50
2 to 5 substantial cracks	7	12.50
1 substantial crack	2	3.57
TOTAL	56	100.00

Table 4 Summary of condition of wall at wall plate level

Wall plate level cracks	Count	Percentage of Sample
No cracks	40	71.43
Hairline cracks only	8	14.29
2 to 5 substantial cracks	4	7.14
1 substantial crack	1	1.79
2 to 5 cracks	1	1.79
TOTAL	54	96.44

4.4.2 Condition assessment of the additional technologies provided

As stated above each of the housing units was supplied with a rain water tank (RWT), a solar photovoltaic panel (PVP) and a solar water heater (SWH). A condition assessment was performed for these fittings as well.

Table 5 Summary of observed condition of rain water tanks

Rainwater Tank Status	Count	Percentage of Sample
Present and in good condition	49	87.50
Not used/present	5	8.93
Present but damaged	2	3.57
TOTAL	56	100.00

Table 6 summary of observed condition of solar water heaters

SWH Status	Count	Percentage of Sample
Present and undamaged	39	69.64
Tubes damaged or missing	14	25.00
Present but not working	2	3.57
Missing	1	1.79
TOTAL	56	100

Table 7 Summary of condition of photovoltaic panels

PVP status	Count	Percentage of Sample
Present and working	28	50.00
Missing	11	19.64
Present, not sure it's working	8	14.29
Not present, not working	3	5.36
Present, but damaged	3	5.36
Present not working	3	5.36
TOTAL	56	100.00

4.5 Condition assessment summary

The findings indicate that the slabs and the walls surveyed are structurally sound. The innovative interventions introduced into the structure of the house appear to be successful. The technology additions were mostly still in place, although some damage had occurred, and are mostly still working.

Since there does not seem to be any reason to suspect that the sample was not representative, the findings from the survey can safely be assumed to represent the entire development. As such, the survey findings are very encouraging, since it seems that most of the design features have "worked" in the intended way.

Table 8 Summary of overall condition assessment score by team

Overall score of house by team	Count	Percentage of Sample
Similar to handover with normal wear and tear	22	40.00
Better than handover condition	19	34.55
Worse than handover condition	9	16.36
Significantly better than handover	5	9.09
Not recorded = 1	1	0.00
TOTAL	56	100.00

5. QUALITATIVE ANALYSIS

As stated earlier, the qualitative analysis involved interviews with identified stakeholders involved in the project. The aim of the focus group interview was to determine how individuals responded to the additional technologies provided. Invitations were sent to the occupants who had granted consent to the physical inspection of their homes. Of the invitees, 17 attended the discussion session held in the local community hall. While this number may seem low, we were satisfied, in the light of the consensus among participants to the issues raised, that the responses were typical of what might be found in the broader community.

5.1 Focus group response to rainwater harvesting

There was overwhelming endorsement of the rainwater tanks among the focus group members. The group was aware that the water quality prohibits human consumption although they described the water as looking 'clean'. The group indicated that they use the waster 'as is' from the tank, predominantly for laundry, gardening, and car washing respectively. They

indicated that they do not treat the water before use and were not aware of any treatment methods. The group indicated that in their experience the tanks do not run empty during the dry, summer months, nor do they overflow during the wet, winter months. The group acknowledged that the tanks save them money and that they would have had less water available without the tank. The group did indicate that they would have liked a bigger tank as this would enable them to wash large items such as blankets.

It is the view of the interviewers that the appreciation of the water is a consequence of the members' background. Many came from the squatter camp where running water is not provided to each shack: occupiers had to collect water from a separate water point some distance away. It is thought that the continual presence of water in the tank is due to their careful management of this resource.

5.2 Focus group response to solar water heaters

There was overwhelming support for the solar water heater among the focus group members. Respondents indicated that they preferred solar water heaters to conventional geysers from an operating cost perspective anyway but not from a usage perspective. The water is used predominantly for dishwashing, personal bathing, and cleaning the floors of the house.

Differing views were expressed regarding the availability of hot water with one member of the group indicating that hot water is only available for 2 hours while another indicated availability for 24 hours. On further enquiry it became apparent that the availability was connected to the number of people in the house. In addition, the overcast conditions found in the area impacts negatively on the performance of the SWH. Respondents noted that when there was hot water it was very hot, which is typical of evacuated tubes. Respondents noted that the evacuated tubes are susceptible to damage especially as the children throw stones onto them.

5.3 Focus group response to photovoltaic panels

The focus group agreed that the PVP was beneficial and that "the panel saves electricity when it works." The focus group noted that replacing the CFLs were more expensive than conventional lights.

The comment relating to "when it works" is probably a result of the overcast conditions predominant in the area and a rapid draining of the battery. It was noted that there were many hours in the day when it is overcast thus impeding the performance of the PVP. It is also likely that under these conditions the battery is unable to recharge sufficiently and this is likely to have a negative impact on the battery life over time.

6. DISCUSSION OF FINDINGS

6.1 Improved building quality

The visual assessment indicates that the buildings have stood up well over the past five years. The building failures typically associated with low income housing appear to be absent in this project. Where cracks have appeared they are generally consistent with typical settlement cracks.

It is estimated that the UTCRCP reduced the concrete material mass by 1 123 tons (CSIR 2011). Using a weighted average of 0.83 t CO_2/t this equates to a carbon emission saving of 932 t CO_2 equivalent (CSIR 2011).

6.2 Rainwater harvesting

The provision of rainwater tanks is probably the most successful intervention from the beneficiary perspective: this is most likely due to rainwater harvesting being a familiar concept for the respondents. Assuming the tank is filled only once a year about 1 027.5Kl of water may be harvested annually (CSIR 2011). Given the water challenges facing South Africa, enforcing the installation of rainwater tanks should be considered. Greater use of the water could be achieved if a sand filter was attached to the system to improve water quality.

6.3 Solar water heating

The reaction to the installation of solar water heaters was generally favourable. Given that it was a modest installation (only 90 litres) and the greater than usual number of occupants, providing the entire family with sufficient hot water for the duration of the day is not possible. However, a larger installation, obviously at greater cost, would better meet the needs of the occupants. In addition, this installation made use of evacuated tube units, which comes with the risk of tube damage. Although the unit continues to function, its efficiency is diminished. Future installations should make use of flat plate units which are more robust.

It is estimated that the energy savings associated with SWH amounts to 724 572,45 kWh/annum for the project (CSIR 2011). Together with the PVP electricity generated, it is estimated that the beneficiaries enjoy an overall saving of R2 266.67/annum (CSIR 2011).

6.4 Photovoltaic panels

The PVPs produced the most reaction. The PVPs were tampered with and were not immediately accepted, in part because of the restricted solar exposure and in part because of improper use (not allowing the battery to recharge). Proper training in the use and maintenance of ‘new’ technologies is crucial for them to be used correctly and last the lifetime they were intended to.

It is estimated that on a sunny day the project is collectively generating about 32,88 kW at any point in time from a modest installation (CSIR 2011). The design and installation of a solar farm would have increased the number of panels (from the saving from omitting the cost of the batteries) and allowed the installation of more powerful panels (200 W in lieu of 80 W). This would have undoubtedly increased the electricity generated.

7. CONCLUSION

The stated intention of the intervention was to improve quality of construction and enhance sustainability through the application of ST&I. The POE indicates that these objectives have been met. The study finds that the community has benefitted from the additional investment and that they understand and acknowledge the benefits accruing to them as a result of this investment.

The study has however identified a number of areas where greater performance could have been achieved. It is therefore important that future interventions of this kind take note of the recommendations made in the POE.

8. REFERENCES

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