Conceptual Design

"Humans have always been emotional and have always reacted to the artefacts in their world emotionally." —Alan Cooper.[1] Take the example of the Apple iPod, launched in the 4th quarter of 2001, it took the market by storm and literally turned Apple Inc.'s fortunes around. From selling 125,000 units in its first year, it became one of the bestselling products of all time. When it was discontinued in 2014, it had sold in excess of 400 million units.[2] It was not the first MP3 player—that honour belongs to the MPMAN-F10 launched 1998.[3] It was also not the cheapest; on the contrary it was criticised for being too expensive and it was also locked in the Apple ecosystem. So, why was it so successful? There certainly were many factors, but two things stood out, namely a truly intuitive design and seamless integration with the iTunes platform, taking the complication out of music management—in other words, a pleasant user experience packaged as a quality product.[4] The creation of a pleasant UX (user experience) therefore is key to create a product that is:

- Desirable—Product creates attraction and provides satisfaction on use;
- Usable—Product is easy to use; and
- Useful—Product performs the tasks required of it.

[1] Weprin, M. 2017. UX Design Managers: The Good, The Bad, and The Ugly—Revisited. <https://uxdict.io/ux-design-managers-the-good-the-bad-and-the-ugly-revisited-760c738a66ea> accessed 31 March 2018.
[2] Costello, S. 2018. This is the Number of iPods Sold All-Time. <https://www.lifewire.com/number-of-ipods-sold-all-time-1999515> accessed 17 January 2019.
[3] Ionescu, D. 2009. Evolution of the MP3 Player. <https://www.pcworld.com/article/174725/evolution_of_the_mp3_player.html#slide1> accessed 31 March 2018.
[4] Adner, R. 2012. Innovation Success: How the Apple iPod Broke all Sony's Walkman Rules. <https://knowledge.insead.edu/blog/insead-blog/innovation-success-how-the-apple-ipod-broke-all-sonys-walkman-rules-2791> accessed 30 March 2018.

C. Kotze, *A Broadband Apparatus for Underserviced Remote Communities*, Southern Space Studies, https://doi.org/10.1007/978-3-030-15766-1_3

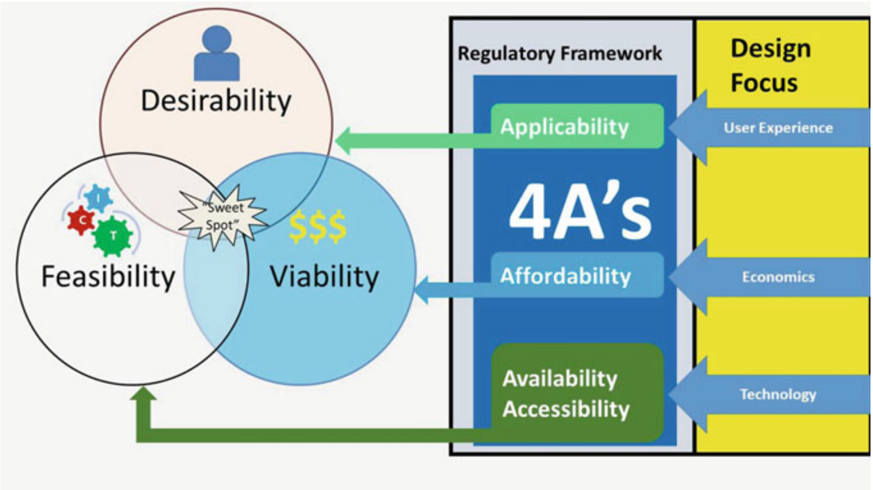

Fig. 1 Conceptual design framework showing the linkage between acceptance criteria and design focus areas

The “design thinking” philosophy with its human-centric “empathic” approach was chosen as primary design guide for the iPod. Tim Brown, the CEO of IDEO (who designed Apple’s first mouse) summed up “design thinking” as a methodology to meet the “needs and desires” of people in such ways that it is technologically possible and creates both customer value and market opportunity (Brown 2008). In addition to UX the design also needs to take into account the economics of the design and available technology in terms of the key user requirements and any regulatory requirements. The ideal design will be the optimal intersection of desirability, feasibility and viability within the identified framework of opportunities and constraints. Figure 1 illustrates these required design focus areas and their relation to the four identified acceptance criteria. The same will apply for the requirements identified by the FURPS model Fig. 1.

1 Design Philosophy

The generic design philosophy was to create a design to satisfy not only the technical requirements but to do it in such a way that will invite the user to explore the use of the product. This can be translated into the following practical design statement.

> Create a familiar form that can blend into any rural environment, adding additional function over and above the intended technical performance to serve the community in a larger way through form.

In this context the words "larger way" mean that the community derives utility from the product in ways that significantly exceeds the original goal.

One can think of the example of the product providing shelter during the day from sun and rain, which is purely a function of the form, but then at night it adds illumination to the area which is a technical performance feature. Another example could be to be associated with storage of collected water, which could be particularly relevant in Sub-Saharan Africa where, in addition to the lack of reliable electricity; ready access to water remains a problem in many rural areas. Providing these associated functions to the community could enhance community acceptance of the product and willingness to use the full bouquet of services.

This suggests that technologies that can support designs featuring smooth, flat surfaces will be designs of particular interest. Such "flat" technologies include satellite broadband antenna systems, integrated thin-film PV technology and ultrathin LEDs. In addition to satisfying the identified requirements and constraints as referred to in the above section, the use-case scenario analysis also indicates that a modular design might be more appropriate to aid installation and maintenance. Design concepts will be modular from component level to functional level, making it possible to add additional functions when it becomes available.

The proposed BARC design will support the ability to easily integrate with other BARC systems should additional capacity be required to create a local network following a P2P (Peer to Peer) model.

2 Design Concepts

The philosophy behind the design was to create an "apparatus" with a basic recognizable form that can blend into any rural environment. Form can add additional functionality over and above the intended technical functionality by providing very basic services as well. A design that can, for example, provide shade during the day and an illuminated area at night could be put to regular use by the community and visiting support services (e.g. health services) alike. Another example could be storage of collected water, which could be particularly relevant in Sub-Saharan Africa where in addition to the lack of reliable electricity, ready access to water remains a problem in many rural areas. Providing these associated functions to the community could enhance community acceptance of the product and willingness to use the full bouquet of services provided these services are packaged in a relevant UX.

Process

This concept product development process followed the "top-down" variant of the "Innovation Funnel" approach using a single screening process[5] (IfM 2018)—an appropriate option for the scale of the intended development. The basic design concept was broadly defined as a rough sketch to identify the key components and

[5]IfM. 2018. Innovation Funnel. <https://www.ifm.eng.cam.ac.uk/research/dstools/innovation-funnel/> accessed 12 May 2018.

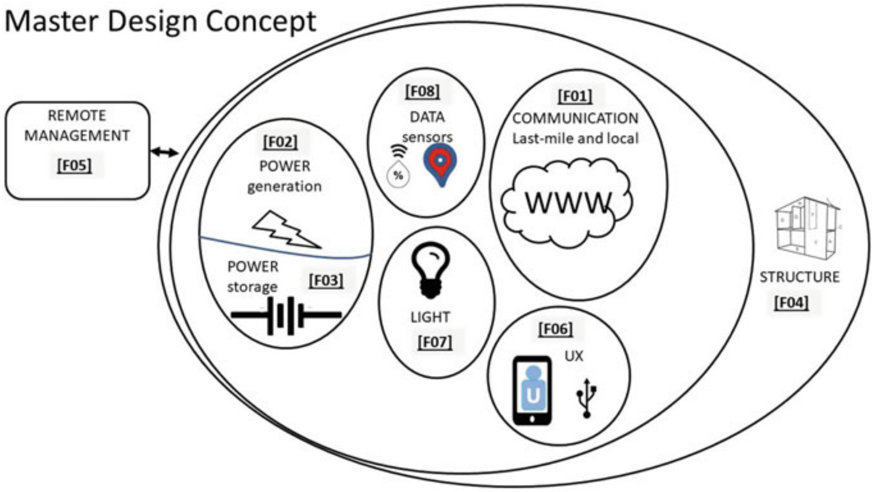

Fig. 2 Master Design Concept

refined as a diagram to indicate the different components in relation to each other as represented by Fig. 2. The master design concept identifies the main functional "modules"—power, data, communications and light, which are integrated into the structure. The initial eight functional requirements as identified (refer Sect. 2.2), were mapped as indicated by F01 to F08. The user interface (UX) is positioned "away" from the structure, as it will only "exist" when used. This master concept was applied to a number of ideas that were inspired by common forms and/or objects normally associated with a convergence of people. From the initial idea shortlist, five ideas were selected to generate design concepts. The following sections describe each of these five design concepts.

2.1 C1—"Rondavel" Concept

The first design option drew inspiration from African architecture. The "Rondavel" is a traditional type of housing comprising a cylindrical structure with a distinct conical shaped thatched roof that is prevalent in Southern Africa (Steyn 2006) (Fig. 3).

This design concept features a conical-hexagonal roof which is supported by a central pillar and a number of smaller peripheral support pillars which are interlinked horizontally at roof level. It consists of a round roof support section clad in canvas with integrated PV collectors. The underside of the "roof" sections will feature integrated ultrathin LED's on the ground-facing side to provide an even distributed light at night. LED strips are also integrated in the outside facing support pillars for visibility at night. The small hexagonal panel at the top of the roof contains the communication and data collection systems. The central support pillar

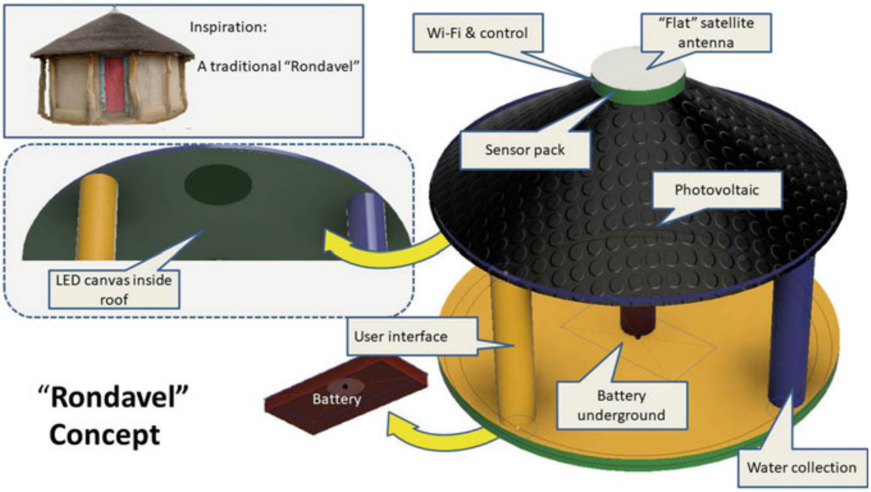

Fig. 3 "Rondavel" Concept

links the communications systems and the power storage unit, which is housed underground for safety, security and structural reasons. The central support pillar also contains all the user charge points, additional sensors and all other electronics not housed in the top or bottom sections. The roof section contains micro-channels to divert rainwater to a collector, installed around the base of the roof, where it is diverted via one of the support pillars for harvesting.

The "Rondavel" is a familiar shape in Southern Africa which is relatively easy to construct and adaptable to many surface conditions. The design caters for all of the functional requirements as defined in initially.

2.2 C2—"Cantilever Umbrella" Concept

This concept features a collapsible "roof" centrally suspended from a cantilever frame. The frame is anchored to a flat base at ground level where the battery packs are held. The roof cladding is made of canvas with integrated PV collectors; with the ground-facing underside of the roof featuring integrated ultrathin LED's similar to the previous design concept (Fig. 4).

An umbrella construction typically features a canopy supported on a collapsible frame normally mounted on a central pole with the purpose of providing the user protection against the sun. The cantilever umbrella design—a departure from the traditional central pillar umbrella—optimises the functional area underneath the umbrella whilst allowing access the frame for functional use.The roof section contains channels to divert rainwater to a central collection point for rainwater harvesting. The data collection module is located on the top of the vertical section of the frame which also houses an enclosure containing all the control and local

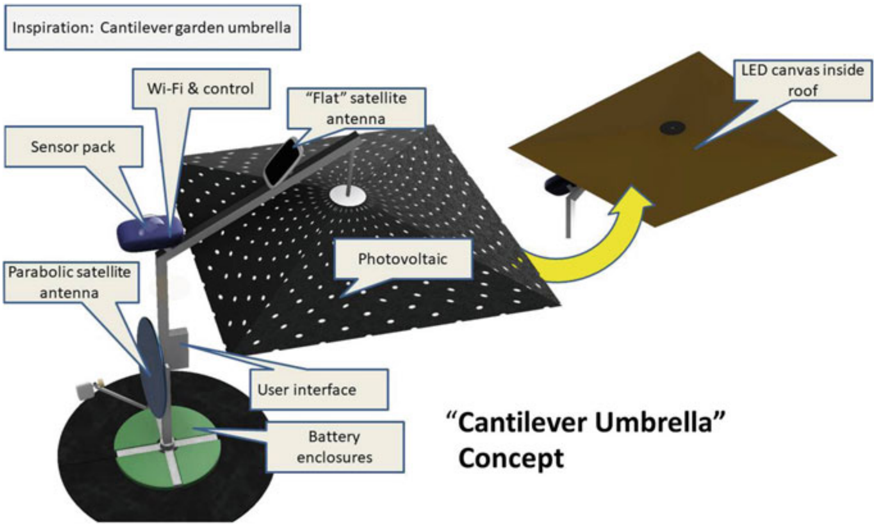

Fig. 4 "Cantilever Umbrella" Concept

Wi-Fi communication. The design caters for the use of both a "flat" and parabolic satellite antennae; The flat panel is mounted on top of the cantilever section of the frame, whilst the parabolic is mounted on the vertical section of the frame. A round utility area on top of the base contains the batteries and other functional modules and charge points for users. This design is relatively easy to construct and can be collapsed under special circumstances and satisfies all of the functional requirements as initially defined.

2.3 C3—"Back2Back Bus Stop" Concept

This design took inspiration from the common bus stop shelter. Almost all public transport systems feature some form of shelter where passengers board or leave the transport—a bus stop. Most of these shelters share at least two common design features—an enclosure providing shelter and a place for the waiting passengers to sit. This design features a "V-shape" roof section housed in a frame connected to a seat section.

The bench used to seat users also functions as a storage area for the batteries of the local power module. The flat sections flanking the "back support" section (coloured red in Fig. 5) contain the user-interface, featuring charge points for utilisation by users. The roof frame sections are covered with canvas with integrated PV collectors, with the ground-facing flipside of the roof featuring integrated ultrathin LED's similar to the other design concepts. A tubular frame section connects two supporting pillars of the roof located at the bottom of the "valley" formed where the two roof sections meet. All control modules and Wi-Fi access

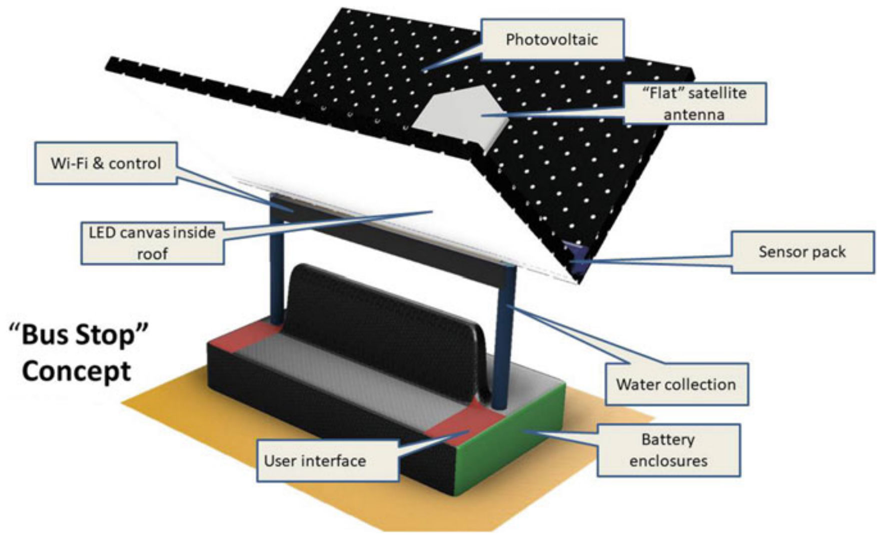

Fig. 5 "Back-to-back Bus Stop" Concept

points, used for local communication, are also housed within this frame section. The "Last-Mile" communication module is contained in an enclosure featuring a flat panel satellite antenna, mounted on one of the PV roof sections. A tubular section running end-to-end at the base of the roof serves as part of the support structure securing the roof, but also contains the sensor module for data collection. The "V-shape" of the roof creates a natural opportunity for water harvesting and the roof itself contains canals to aid this process by diverting rainwater to a central collection point. This unique design shape offers an additional degree of user functionality in that it offers integrated seating for users in addition to supplying shelter from the sun. The design meets all the functional requirements as defined.

2.4 C4—"Smart Tank" Concept

This design option takes its functional inspiration from the central role water plays in any community. In the developing world, access to safe potable water is limited and most water needs to be carted daily from source to usage point, usually by women and children. According to UNICEF, globally women and girls daily spend 200 million hours per day in the process of collecting water, time that could have been used for productive work and education.[6] Localised rainwater harvesting can

[6]UNICEF. 2016. UNICEF: Collecting water is often a colossal waste of time for women and girls. <https://www.unicef.org/media/media_92690.html> accessed 12 May 2018.

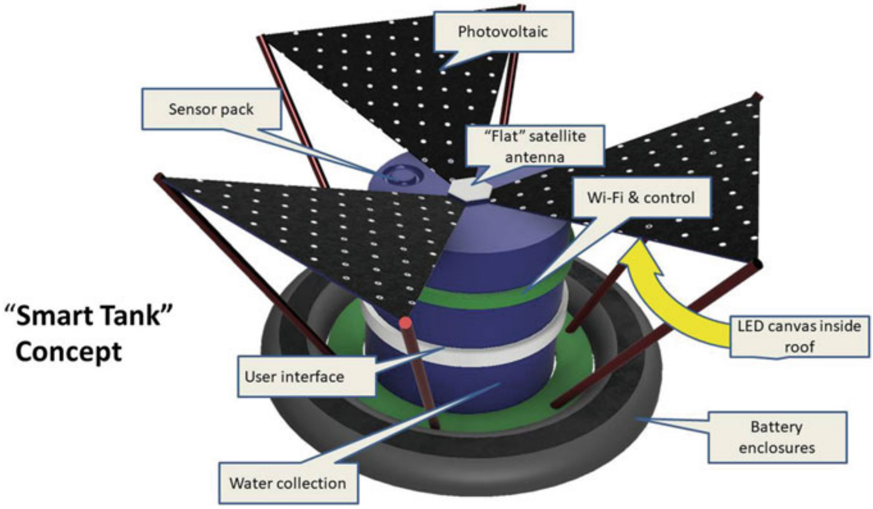

Fig. 6 Rainwater harvesting "Smart Tank" Concept

help to alleviate this problem through capture and storage of rainwater to ensure amore continuous access to water (Wisser 2009). Demand for water storage tanks has grown significantly in recent years (Fig. 6).

The concept revolves around the integration of the BARC into a rain water harvesting system. A rain water harvesting tank (5,000 to 10,000 litres) is used as the central support structure. The design shape was inspired by the "nuclear warning" symbol featuring three flat trapezoidal roof frame sections. These roof sections are each supported by two adjustable primary support pillars connected at the corners of the "wide side" of the trapezoid, terminating at an angle into a support structure located around the base of the tank. The batteries and control systems for the power module are housed in a torus shape surrounding the structural base where the support pillars of the roof sections terminate. This structure can also be used to provide seating for users. The other end, the "narrow" side of the trapezoid, is attached to a mounting module situated on top of the tank at a tilted angle. The roof sections feature the same arrangement of canvas with integrated PV collectors and ground-facing ultrathin LED's as seen in the previous designs concepts. The data collection module is contained in an enclosure mounted on top of the tank. The local Wi-Fi communication module and other control systems are housed in a circular structure installed towards the top of the water tank. A similar structure is located towards the base of the tank, which houses the user interface i.e. charge points. The slight angle of the roof section and water guiding micro-channels divert rainwater to a circular structure used to mechanism guide harvested water into to the rainwater tank. A flat panel satellite antenna is mounted on top of the aforementioned water collection point.

The design needs a certain degree of preparation at the intended deployment site before it can be deployed in the form of a level plinth on which to rest the tank. In addition to shade, this design provides a much-needed function for many communities of rainwater collection and storage in the developing world. The design caters for all of the functional requirements as set initially defined.

2.5 C5 “Car-Port” Concept

Canvas-covered car-ports are a common sight at public areas around the world, normally featuring a very basic construction consisting of a frame covered by a sun-blocking fabric. The reference design option took inspiration from a very basic carport with a flat roof. The concept features two rectangular planar frames (bottom and top) linked together by four support pillars to form a three dimensional “box”. Beams connected to the “top” planar frame form the roof. The bottom planar frame features adjustable “feet” to accommodate uneven terrain. The support pillars are made from hollow square tubes. Storage batteries are housed in the four corner structure tubes which also contain charge points. A square section containing the communication and data collection system featuring a “flat” satellite antenna is integrated on the roof surface. The roof cladding is made of canvas with integrated PV collectors, with the ground-facing underside of the roof featuring integrated ultrathin LED’s similar to the first design concept (Fig. 7).

The roof section contains channels to divert rainwater to a central collection point where it could be used for rainwater harvesting. This familiar shape is

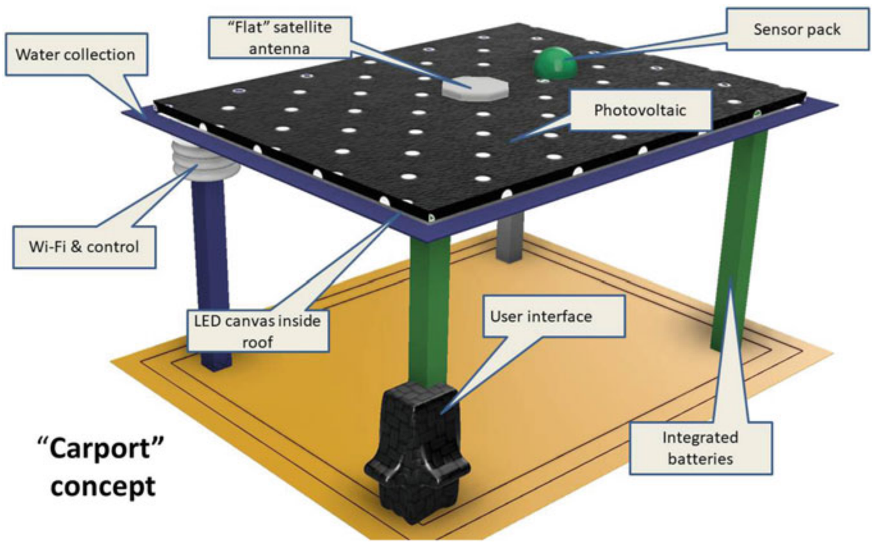

Fig. 7 Reference “Car Port” Concept

relatively easy to construct and adaptable to many surface conditions, because of its adaptability this design concept can be deployed virtually anywhere. The design caters for all of the functional requirements as initially defined.

3 Concept Selection

To evaluate the five designs—all having unique features which can benefit the community—a variant of a Pugh Matrix was used. This decision support technique was developed by Stuart Pugh (Pugh 1991) and is widely applied for concept section from a list of alternatives. The process involves laying down a list of selection criteria against which concepts are evaluated. Selection is aided by comparing the products in the selection pool against a reference product. The reference product is allocated a neutral score against each of the selection criteria. That is, if an evaluation scale of 1 to 5 is used, the reference product will be allocated a "3" against all criteria. Each of the other alternative choices will subsequently be rated and allocated a score reflecting its performance relative to the reference design or product in terms of the evaluation criteria, i.e. either better, worse or equivalent to the reference. Selecting the reference design involved an internet search of the available "Commercial Off-The-Shelf" systems with the ability to create a wireless access at remote locations lacking infrastructure using solar power generation, storage batteries, Wi-Fi access point and a satellite links.

Systems such as the Renewable Energy Satellite Internet Skid[7] and the container-based "CONTAINER DD v.5" from the Digital Doorway[8] project in South Africa (DigitalDoorway 2018) were investigated. The Digital Doorway product was found to be more comparable to the design concepts than the Renewable Energy Satellite Internet Skid.

3.1 Reference Concept

The "CONTAINER DD v.5" is the marketing name for the product produced by the "Digital Doorway project.[9] It is essentially a closed container housing three user terminals accessible inside via a door. On the roof of the structure a number of photovoltaic panels are mounted to generate electricity. Batteries housed in the container are used to store the generated power. It features a parabolic satellite

[7]BlueTide. 2015. BlueTide Communications premieres skid for remote and emergency communications needs. <https://www.bluetidecomm.com/index.php?option=com_content&view=article&id=55:bluetide-communications-premieres-skid-for-remote-and-emergency-communications-needs&catid=9&Itemid=275> accessed 24 November 2017.

[8]DigitalDoorway. 2018. Hardware. <http://www.digitaldoorway.org.za/index_main.php?do=hardware> accessed 12 May 2018.

[9]The "CONTAINER DD v.5" is an existing design that is available and was used as a reference concept for the evealuation using a Pugh matrix.

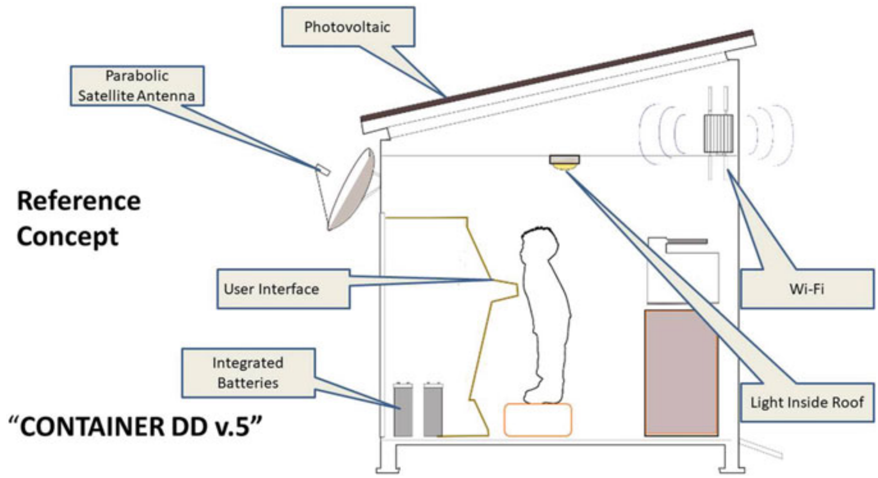

Fig. 8 Reference Concept "Container DD v.5" (see footnote 9)

antenna to receive a broadband internet signal anywhere and the signal is distributed locally using Wi-Fi. The design caters for all of the functional requirements as set out initially, with the exception of the full sensor module. For the purpose of a reference design the assumption was made that such a module could be integrated in the design with relative ease, as all the communication and power structures to support it already exist (Fig. 8).

3.2 Selection Process

A basic Pugh Matrix (Table 1) was constructed as a decision support tool to evaluate the five concepts against a reference to propose a final selection. This process involved creating a list of eleven selection criteria, with each criterion allocated a weighting (W) from 1 to 3 according to the perceived importance.

The selection criteria attempt to provide a lens to view the product from additional perspectives of form, function and practicality. As all the designs need to conform to the functional requirements, it is included for completeness as the very first selection criterion. The other nine criteria evaluate the concepts from different angles related to form, function and installation. Each design concept was scored individually against the selected criteria using a scale of 1 to 5 where: [1 = Worst], [2 = Bad], [3 = Neutral], [4 = Good] and [5 = Best]. Where C1 to C5 (C1 = "Rondavel", C2 = "Umbrella", C3 = "Bus Stop", C4 = "Smart tank", C5="Car-Port"). The last column named "RC" is used for the reference concept.

Table 1 Pugh Matrix Concept selection matrix

#	Criteria	W	Concept Score*					
			C1	C2	C3	C4	C5	RC
1	Meets all the functional requirements	3	3	3	3	3	3	3
2	Form provides additional function—high score represents a high degree	3	3	3	4	5	3	3
3	Provides shade—low score represents low degree	3	5	1	3	3	5	3
4	Site topography dependence—low score indicates a high degree of reliance	3	2	3	2	1	4	3
5	Complexity of form—low score indicates more complicated	2	3	2	1	1	4	3
6	Required degree of site preparation—Low score indicates a high degree of reliance	2	2	3	2	1	4	3
7	Water required for construction—low score represents low degree	2	3	3	3	1	3	3
8	Ability to endure windy conditions	2	3	1	2	3	3	3
9	Ease of delivery of materials—low score represents les ease	1	3	3	2	1	3	3
10	Effectively aids rainwater harvesting—high score indicates high degree of effectiveness	1	2	1	4	5	2	3
11	Visibility—high score clearly visible day and night	1	3	1	3	5	2	3
Un-weighted score			32	24	29	29	36	33
Weighted score			0	−16	−8	−10	11	0
Score* refer Sect. 3.3								

3.3 Scoring

Each selection criterion was allocated a weighting from 1 to 3. Each concept was scored against the criteria using a scale of 1 to 5 where:

$$[1 - \text{The Worst}][2 - \text{Worse}][3 - \text{Neutral}][4 - \text{Better}][5 - \text{The Best}]$$

The median score, namely 3, was subtracted from the allocated score and multiplied with the allocated weight, to reflect the relative importance which was applied to each score to create a weighted total that was used for the final selection.

$$C_x = \sum_{i=1}^{n} W(S_i - 3)$$

where

- C_x = Design Concept C1 to C5.
- W = Criterion weight

- S_i = Criterion score
- n = 11

3.4 Final Concept Selection

The “Car-Port” concept (C5) scored the highest overall score against the reference relative to the other designs, both in the weighted and the un-weighted category. The “Rondavel” (C1) design came second and scored the same as the reference in the weighted category. The lowest score was allocated to the “Umbrella” (C2) concept due to the form providing significantly less functionality than the other conceptual designs.