An Approach Towards Developing Technical Sanitation Solutions for Informal Settlements

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by

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Executive Summary

Introduction

The world is characterised by increasing population growth and rapid urbanisation, which has seen the burgeoning of informal settlements. These unplanned settlements around major cities are often located in low lying areas, floodplain or hilly zones and wetlands (Wegelin-Schuringa and Kodo, 1997), which presents particular challenges for service provision to urban centres in developing countries including South Africa (Lagardien and Cousins, 2005).

Many urban centres are experiencing a substantial increase in the number of people living below the poverty line in informal settlements, many of which are illegal. These settlements are often dense, disorganised, lacking access road, urban structure and adequate and affordable basic services such as water supply and sanitation (Mitlin and Mogaladi, 2013; Smit, 2006; DWAF, 2002); thus limiting the implementation of proper sanitation. This challenging situation puts pressure on the delivery of basic water and sanitation services.

Access to either water or sanitation has always been a prerequisite for establishing human settlements (Mjoli, 2009; WSP, 2007). To achieve the goals of access to sanitation set for 2015, increased focus will especially have to be given to the urban and peri-urban areas where millions of people lack access to improved water and sanitation facilities (Tipping, 2006). Given a total of 2.6 billion people without improved sanitation, only 58% of the world's population and less than half of all people living in developing countries have access to improved sanitation facilities (Unicef and WHO, 2012). The lowest coverage rates are in sub-Saharan Africa (36%) and South Asia (37%). In some countries, such as Afghanistan and Ethiopia, less than ten per cent of the population has access to adequate sanitation facilities. In South Africa, 12 million people still do not have access to improved sanitation (Ministry in the Presidency, 2012) despite efforts and funds allocated to eradicate sanitation backlogs.

Conventional approaches to environmental sanitation are unable to make a dent in existing service backlog. Conventional sanitation concepts and solutions are not able to cope with the new challenges arising from these issues (Luthi, 2012). Several sanitation technologies are being developed using available guidelines and compendiums that are often too general and not specific to informal areas. A number of emerging sanitation technologies provided to informal areas are not often documented or adequately established to ascertain their feasibility. In addition, the developed sanitation technologies are being provided without understanding the main sanitation issues in the context of particular informal areas.

Bearing this in mind, it was hypothesised that developing sanitation concepts and solutions is subject to the knowledge and understanding of innovations being developed and related drivers. Therefore new sanitation concept and solutions for informal areas can be developed only if the sanitation issues are understood in each particular context. For the purposes of this research, technical sanitation solution was defined as the approaches or processes applied to adequately ensure the safe collection, containment, disposal or reuse of human excreta without adversely

impacting the general environment and human health. These approaches and processes should inform the development of sanitation concepts and technical sanitation solutions.

The words informal settlement and informal area are used interchangeably to refer to unplanned and illegal settlements situated on privately or government owned land, characterised by the poor, inadequate or lack of basic infrastructure including water and sanitation. Innovation refers to a new idea or proposal intended to respond to sanitation challenge; and driver refers to underlying factors for innovation.

This study has shown that there is mismatch between the sanitation solutions and concepts. Sanitation solutions investigated were found to be developed without an established concept. This mismatch can be seen as core to the failure of sanitation solutions.

Key questions addressed by the research included:

- What technologies are currently used to respond to the sanitation challenges in informal areas?
- How different sanitation solutions are being developed?
- What technical sanitation solution can adequately respond to different informal areas conditions?

Given the unique context of informal areas and the lack of a specific approach for developing sanitation solutions, the main aim of this study was to investigate the current technologies used to deal with sanitation in informal areas with the view to develop an approach for developing sanitation concepts and solutions.

Research aims and methodology

The research aimed at investigating technical sanitation solutions for informal settlements in response to numerous sanitation challenges faced by dwellers. The intention of the research is mainly to develop an approach for developing sanitation concepts and solutions that respond to particular conditions of informal settlements.

These aims were achieved through the following means:

- *Literature review*

A review of local and international literature on the development of appropriate sanitation and innovations targeting informal areas was undertaken. The review covered the sanitation problems and responses (in terms of technologies) in general and broader context, success and failures. Further the review focused in finding innovation solutions and proposal, drivers and concepts used for their development as well as the extent of the application (where applicable).

- *Interviews*

Structured, unstructured and semi-structured questionnaires were developed and administered to stakeholders in the Western Cape, KwaZulu-Natal and Gauteng provinces to collect information. The structured interview was used for engineers and manufacturers; the semi-structured interview

was used for municipal official, organisations (CSO, NGO, scientist, etc.) to facilitate capturing opinion, beliefs and behaviours of interviewees. The open-ended interview was used for the user group and community leaders.

The focus of the interview was mainly to collect additional information regarding specific sanitation challenges, extent of sanitation responses, factors underlying success and failures, understanding emerging innovation for informal settlement and drivers or factors underlying these innovations. Three informal areas namely Masiphumelele 1, Enkanini and Pook se Bos in Western Cape were selected to test the developed sanitation solutions models in order to understand users and municipal officials' views and perceptions of different sanitation solutions.

- *Observation*

Following the interviews, visual observation was carried out through transect walk to ascertain the views expressed by user groups, NGO, community leaders and municipal officials. A physical view of the sanitation solutions and practices verified the conditions and ascertained their technical feasibility within the case study site. Information collected through visual observation was documented and recorded using a checklist and camera.

- *Focus group discussion*

Findings from the literature and information collected from interviews and observation were collated into a discussion document (appendix B) and presented to the sanitation stakeholders for validation. The focus was to:

- validate information collected through literature review, interviews and observation,
- confirm sanitation innovation solutions that were identified and discuss their relevance to informal areas and technical feasibility,
- present and discuss drivers for each sanitation innovation in terms of their relevance to informal areas,
- culminate a discussion to develop the sanitation concepts and solutions.

It should be noted that both English and local languages were used, where applicable, during the data collection process for quality control purposes.

Key findings from the research

Solving the sanitation problems in informal areas requires a holistic approach that considers social, economic, institutional and technical perspectives. Considering one of these perspectives in isolation may not provide long term solution to the problems; therefore each of these perspectives should be carefully studied and considered when developing sanitation technologies.

Key findings emerging from this study relate to the following:

- Appropriate sanitation technologies and innovations for informal areas
- Further research agenda.

a) Appropriate sanitation technologies and innovations for informal areas

- *Sanitation challenges in informal areas*

The variable nature of sanitation challenges faced by informal settlements residents are interlinked across social, institutional, economic, and technical perspectives, because:

- Socially, sanitation problems are related to poverty, high levels of unemployment, disorganised social landscape, lack of leadership and accountability. Direct impacts of vandalism, negligence, theft and lack of ownership can be used as criterion to assess the adequacy of a sanitation solution.
- Institutionally, sanitation problems are related to the lack of or poor governance, poor planning and lack of relationship service providers and users, and most importantly, fragmentation of responsibilities, complicated institutional arrangements, and lack of adequate and dedicated operation and maintenance budgets.
- Economically, cost is a key determinant factor in selecting sanitation technologies for informal areas. Other incurred costs such as operation and maintenance, replacement and suitability to the physical settlement conditions are intentionally ignored, thus making the provided sanitation solutions unsustainable.
- From a technical perspective, sanitation problems can be attributed to the lack of alternative options, poor or inadequate design, low level or lack of O&M, high O&M costs, difficult or inadequate operational requirements, and irrelevance of the sanitation solution to the local context.

These findings suggest that the interlinked nature of challenges encountered in informal areas can impact severely on sanitation infrastructure. The extent of impacts varies according to the nature of the challenges. For example, social challenges such as poverty and unemployment are reflected by vandalism, theft, negligence and lack of ownership which have several impacts on various components of the sanitation technology. Economic and institutional challenges are considered as operational issues that should be addressed in terms of specific impacts on functioning of the technology. Technical sanitation challenges are mainly related to the design, operational requirements, operation and maintenance. Social, economic and institutional sanitation challenges can constitute the technology assessment framework that can be used to assess the adequacy of a sanitation technology in a particular context and develop alternative solutions.

- *Sanitation technologies provided to informal areas*

In view of the current sanitation backlog and the increasing number of people living without access to adequate or any form of sanitation, municipalities have selected and provided number of sanitation technologies (water and non-waterborne, communal and individual). Communal sanitation technologies provided to informal areas include ablution facilities, communal ablution block, shared facilities (such as containers and chemical toilet), full flush communal toilet (Kayaloo for example), pour flush toilet, etc. Individual sanitation technologies include urine diversion toilet, VIP toilet, Enviroloo, etc. Communal sanitation technologies are being provided in dense informal areas where spaces are lacking while individual sanitation technologies are provided in low and medium dense informal areas. It emerged from this research that users prefer waterborne sanitation technologies to dry systems citing comfort and equity (meaning that sanitation technology should be same for formal and informal settlements) as mean reasons.

- *Factors underlying success and failure of sanitation in informal areas*

Success and failure of sanitation technologies provided to informal areas were identified and documented with the view to find innovation and drivers that can inform further development of sanitation solutions. Findings emerging from this review suggest that success of sanitation systems is registered where the interaction between service providers and users are evident. Appropriate design, adequate and planned O&M, consideration of local conditions, technology choice and compliance with the operational requirements were identified as key to the success of the sanitation technologies in general. Failure of sanitation technologies is attributed to the lack of long term vision, poor design and inadequacy of the sanitation solutions, lack of operational planning and poor management. A sanitation technology may be successful in one area and fail in another.

It is therefore suggested that failure is considered as a motivation for further improvement rather than an opportunity to criticise the service providers or designers. Success should be used as well for further improvement and uptake; however, it should be noted that success may not be replicable in a general manner – but should be based on similarities or contextualised where applicable. Factors underlying success and failure of sanitation technologies are context based and should not be generalised to all informal areas.

- *Innovative sanitation solutions and drivers*

Innovative sanitation solutions and related drivers were reviewed intentionally to identify emerging trends and develop the sanitation concept(s) that can inform the development of the sanitation solution(s) and further research agenda.

  - *Innovative sanitation solutions*

Sanitation role-players have and are still developing sanitation technologies that can respond to sanitation related challenges facing informal areas. These include individual sanitation (such as urine diversion toilet, pour flush toilet, chemical or container toilets) and communal sanitation (such as MobiSan, communal ablution block, etc.). These technologies can be water or non-waterborne with on or off-site treatment.

This research established that drivers for sanitation concepts and solutions for informal settlements are related to functioning of the facility and components innovation. For functioning of the facility drivers such as acceptable location, user access and safety; nightsoil and greywater disposal and decentralised facility and user management were identified. Drivers for components innovation include water conservation, beneficiation and low O&M costs.

Emerging sanitation technology alternatives identified were found to be related to one or more components of the sanitation technology and include for example:

- Facility: micro-flushing sanitation system – intended to reduce water consumption
- Treatment: sanitation system that produces energy and fertilisers – beneficial use, waste reduction
- All components: decentralised community managed sanitation system – user responsibility
- Facility, containment and treatment: low cost O&M sanitation system, etc. – locally operated and maintained and job opportunity.

These alternatives are developed around concepts including beneficiation, community management, low water use, self-cleaning and energy generation. The current trend emerging from these alternatives points out beneficiation, O&M and water conservation as a new approach towards achieving sustainable sanitation. However, the relevance of particular approaches should not be generalised to all informal settlements as "typical", given their changing nature and dynamics, as they are context specific. These alternatives should be carefully studied when envisaging piloting or implanting in informal areas as they may not have the same characteristics.

Using the approach for developing sanitation concepts and solutions (presented in this report), thirteen concepts emerged and most of these where either alternative to conventional or ecological sanitation. Three of these were selected based on their relevance to sanitation problems and were further explored. The selection was based on their technical appropriateness and potential in addressing sanitation problems in informal areas. The concepts developed emerged from the innovative sanitation solutions and related drivers and were used to inform the sanitation solution.

The most important concepts of relevance to informal settlements were found to be those focusing on resource recovery and reuse, low O&M, zero waste generation and economic incentive for both users and service providers.

- *Sanitation solutions*

Having identified the sanitation concepts relevant to the informal areas conditions, this study established that communal sanitation systems are the most suitable option within the context of informal settlements. This choice is mainly driven by many factors including lack of sense of ownership, the settlement density and physical site characteristics that are not permitting the provision of individual facilities. Communal and shared (rows of units) in "dry" or "wet" systems are common, depending on space, settlement (soil) conditions, availability of water, sewer collection and treatment system. Two options suggested in this report address issues related to the location of the facility, nightsoil and greywater disposal, and decentralised community management. In addition, issues related to water conservation, low O&M and beneficiation are also included. The characteristics of the suggestions sanitation options include:

- Option 1: Dry communal sanitation: Sanitation solution treating human excreta for beneficial use
  - Location: The facility should be located far from flood prone, no water table or ingress of storm or ground water, optimal location, safety of user and able to accommodate number of user during peak hours;
  - Nightsoil and greywater disposal: separate dedicated nightsoil and greywater disposal to be provided
  - Decentralised systems: handling, transport, (on or off-site) treatment of faecal sludge and disposal should be a localised function of users (job or business opportunities)
  - Water conservation: provision for rainwater harvesting system for cleaning the facility and handwash – potential greywater reuse;
  - Beneficiation: treatment of faecal sludge for easy handling, transport, disposal or reuse

- Low O&M cost: use of locally available materials and labour to operate and maintain the facility

- Option 2: Wet sanitation system: Sanitation solution treating human excreta to recover nutrient and generate energy
  - Location: facility to be located close to a sewer line or septic tank system as to reduce the cost of sewer and frequent maintenance work in case of blockages or leaks;
  - Nightsoil and greywater disposal: separate nightsoil disposal equipped with inlet funnel (to prevent spilling); provision to be made for collecting greywater into a tank, and preliminary treatment using oil and grease and sand traps;
  - Decentralised system: the O&M and maintenance, security and management of the facility should be a localised function of the users (caretaker for example);
  - Water conservation: provision of rainwater harvesting and pre-treatment system (at the facility), use of water saving devices (micro-flushing for example) and provision of grey and blackwater treatment on or off-site
  - Beneficiation: provision of treatment (aerobic and anaerobic treatment where applicable) to generate energy and recover nutrients available;
  - Low O&M: use of locally available materials and local community for O&M; monitoring of the facility to reduce the frequency of breakdowns and repairs.

Key functional elements of each option suggested above include toilet, containment or collection and conveyance (depending on the technology), treatment (on or off-site), reuse (energy and nutrients recovery) or disposal. Findings suggest that each of the components of the sanitation solution should be carefully studied and designed according to specific local conditions while considering social aspects. In the context of informal areas, the following issues related to the sanitation solutions were identified:

- Toilet:
  - Water repellent or self-cleansing pedestal (self-cleaning pedestal)
  - Low or no water use (micro-flush or pressurised flushing)
  - Robust structure (shipping container)
- Conveyance should be made of solid pipes laid at shallow depth, with inspection chambers at each and every 50 m (in case of waterborne sewerage treated off-site because misuse and vandalism)
- Containment to be designed according to the number of user and provision to be made for a standby containment tank.
- Treatment to be considered on site preferably and rapid dehydration and further treatment leading to safe reuse to be envisaged.
- Features such as rainwater harvesting tank, laundry point and urinals were accepted;
- Separation of users (according to gender) and the inclusion of security were acknowledged by users.

b) Further research agenda

Having identified these two options above, it is believed that lot still needs to be done to ensure that sanitation solutions meet the users' needs and desires and respond to the local context. Further research should address the following issues related to:

a) Functional facility

- Location – access to sanitation is often subject to adequate location of the facility within the settlement. It is suggested to investigate criteria for determining optimum sanitation location with a settlement and the extent to which location impact on the use of a facility and impart change on sanitation practices.

- Nightsoil disposal – many sanitation solutions do not make provision for nightsoil disposal. Therefore, this study suggests to investigate the design of nightsoil disposal facility based on conditions pertaining to informal settlements (referring to density, distance) while considering operation and maintenance aspects.

- Greywater disposal – one of the biggest sanitation challenges in the disposal of greywater in informal settlements. The development of localised community-based greywater treatment solutions using locally available materials and investigation of potential reuse of locally in-situ treated greywater for irrigation or toilet flushing are suggested.

- Decentralised system – Lagardien et al. (2009) guidelines suggested that to ensure adequate functioning of sanitation facility certain tasks should be performed by the local community living in the settlements. In this line, this study suggests piloting of the guidelines in informal settlement context in order to determine the context of application and identify gaps.

b) Components innovation

- **Water conservation**
  - Toilet – conserving water is one of biggest challenges hindering wet sanitation systems in informal settlements. This research suggests investigating water conservation devices/systems for sanitation facilities in informal settlements.

- **Beneficiation**
  - Greywater disposal or reuse (when dry sanitation system is provided) – treated greywater may be used for many purposes including dust suppression or cleaning of toilet facility (sweeping floor for example). Further investigation should address the development of localised greywater treatment system to meet non-potable reuse standards.

  - Rapid dehydration of human faeces using natural bulking agent – faecal sludge is another challenge faced by informal settlement. In this line, further research should address the following:

- Investigation into faecal sludge dehydration process – efficiency of aeration in stabilising faecal sludge;
- Extraction and handling of faecal sludge from communal mobile sanitation facilities in informal settlements;
- Management of faecal sludge from mobile or permanent structure sanitation in densely populated informal settlement;
- Development of an environmentally friendly transport mechanisms for faecal sludge from dry sanitation system in densely populated informal settlements;
- Development of sustainable business model for managing faecal sludge from dry sanitation systems in the context of urban informal settlements

- **Low O&M costs**
  - Operation and maintenance of sanitation facilities in informal settlements – assessing viable options from community perspectives

Conclusions

This study has provided an overview of the development of sanitation concepts and solutions for informal areas. It is understood that sanitation technologies are developed to respond to particular sanitation challenges that can be viewed from social, institutional, economic or technical perspectives. From social and technical perspectives, sanitation challenges are related to the profile of the served community and the components of sanitation solutions respectively. These challenges include non-compliance with operational requirements, poverty, density, inadequate design, operation and maintenance.

Several sanitation technologies including individual and communal are being developed in responses to these issues. These include individual and communal designs which are different in terms of components, operational requirements and level of management, and are designed for specific conditions and contexts. Some have been successful while others have totally failed. Success is attributed to many factors including a sense of ownership amongst users, level of management and planning, etc. Failure is attributed to poor design, lack of collaboration amongst sanitation stakeholders, poor operation and maintenance, etc. This research established that both success and failure should be considered as an opportunity to understand and analyse, with a view to identifying gaps and drawing lessons for further uptake.

Further, the research established that innovative sanitation solutions are mainly related to the components of sanitation and cover containment, conveyance, treatment and reuse or storage. The key trend emerging from these innovations is the beneficial use of human excreta for various purposes, the need to generate zero waste, use less or no water and generate energy from waste. These innovations are driven mainly by the need for functional facility and appropriate components that respond to a particular situation.

Each of these emerging innovative sanitation solutions should be considered in the context of informal settlement based on their relevance to address particular sanitation challenges. It is important to note that sanitation innovation solutions may not provide the expected outcomes to

the sanitation challenges as such; each proposed solution should be carefully explored and the context of its application established prior to selection.

The sanitation concept should be developed by assigning prioritised drivers to a particular or group of innovative sanitation solutions. This will allow further understanding of the meaning and manner by which the developed concept will address the sanitation problems. Knowledge of the sanitation concept and its intention can assist in assigning functional elements to the concept and develop sanitation solutions that can be later translated into models.

From the information captured in this report, it is evident that sanitation solutions should be developed using concepts that are appropriate to specific contexts; as it will assist in developing solutions that respond to users' needs while addressing number of challenges. Consequently, sanitation solutions cannot be developed without a relevant and documented sanitation concept. The concept cannot be developed without understanding of the innovation solutions, emerging trends as well as associated drivers.

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List of Acronyms, terms and concepts

AB	Ablution Block
BMGF	Bill and Melinda Gates Foundation
CLTS	Community Led Total Sanitation
DMT	Dignified Mobile Toilet
DWAF (DWA)	Department of Water Affairs and Forestry (now Department of Water Affairs)
EcoSan	Ecological Sanitation
IDP	Integrated Development Planning
IRC	International Water and Sanitation Centre
IS	Informal Settlement
MCSF	Mobile Communal Sanitation Facilities
MDG	Millennium Development Goal
M&E	Monitoring and Evaluation
NGO	Non-Governmental Organisation
NMT	Nepal Mobile Toilet
O&M	Operation and Maintenance
PRA	Participatory Rural Appraisal
SFWS	Strategic Framework for Water Services
SusanA	Sustainable Sanitation Alliance
UDS	Urine Diversion System
UN	United Nations
UN-HABITAT	United Nations Human Settlements Programme
VIP	Ventilated Improved Pit
WRC	Water Research Commission
WSP	Water and Sanitation Programme

Concept	Theoretical idea that has been used as basis for developing sanitation solution
Driver	Factor conducive to the development of sanitation solution or innovations
Innovation	An idea, a product, or a process that is perceived as new. In each case, innovation is an innovation because it is perceived as new and different from existing idea, product or process. It is a value added not a replication of existing one.

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1. Introduction

The world population is characterised by an increasing population growth and rapid urbanisation which has seen the bourgeoning of informal settlements (around major cities). These settlements are located in low lying areas, floodplain or hilly zones and wetlands and have been cited as a critical challenge for those in charge for providing services to urban centres in developing countries (Lagardien and Cousins, 2005).

Many urban centres are experiencing a substantial increase in the number of people living below the poverty line in informal or unplanned settlements, many of which are illegal. These settlements are often dense, disorganised, lacking access road, urban structure and adequate and affordable basic services such as water supply and sanitation (DWAF, 2005). This challenging situation poses major pressure on the delivery of basic services such as water and sanitation. According to UN-Habitat almost one billion people or one in six people live in informal settlements. This number is expected to increase to 1.4 billion by 2020, with the biggest growth taking place in Africa and South Asia (UN-Habitat, 2006). In South Africa, 58% of the population lives in urban centre (UNDESA, 2010) and about 2 million household living in informal areas. Many governments are reluctant to accept the extent of urbanisation and fail to acknowledge how many of their citizens lack access to water, sanitation, and habitable dwellings and secure land tenure. This situation is

1.1 Background

The development of South Africa has been characterised by rapid urbanisation that is associated with rapid rise in the establishment of informal settlements (IS). Most people in informal settlements are categorised as poor poverty, without many of basic necessities for healthy life, including water and sanitation (Great Britain Treasury, 2004). The draft strategy of sanitation services in informal settlements estimates that about 11 million people in the urban and peri-urban areas of South Africa have no access to adequate sanitation.

The number of people in need of adequate sanitation still in the rise and to date, 12 million people have no access to adequate sanitation despite efforts by the Government to provide universal sanitation access and meet the Millennium Development Goals (MDG), (Ministry in the Presidency, 2012). Several reasons have been given to justify this slow pace in the sanitation delivery, including economic, financial, societal constraints; backlog of inadequate provision of sanitation; growing/bourgeoning of informal settlements; costs of conventional sewage systems; huge consumption of water; status of the lands; density of the settlement; etc.

1.1.1 Sanitation issues in informal settlements

Despite severe constraints, local governments are mandated to provide basic services in all settlements within their area of jurisdiction in accordance with the rights described in the constitution. However, providing service in informal settlements is one of the most complex issues on the municipal agenda, and must be viewed in the context of broader spatial development and housing delivery objectives. The approach adopted by local government will therefore require an

integrated approach to service delivery including water and sanitation among many other needs taking into account the institutional and social framework of the settlements (DWAF, undated).

Besides these issues, the sanitation technology remains the focus and its choice requires a number of considerations. The choice of the most appropriate sanitation technology for an informal settlement will depend on a range of factors including (but not limited to) financial, land use and permanency, accessibility, environmental and social issues.

1.1.2 Sanitation practices in informal settlements

Access to water and sanitation has always been a prerequisite for establishment of a human settlement (Mjoli, 2009; IRC, 2007). A total of 2.6 billion people live without improved sanitation – less than half of all people living in developing countries (Unicef and WHO, 2012). Worldwide, the proportion of the population deemed to have access to adequate sanitation had risen from 49% in 1990 (the baseline for the MDG targets) to 58% in 2002, (IRC, 2007) and to 63% in 2010 (Unicef and WHO, 2012). Globally, 63% of the population use improved sanitation facilities, an increase of almost 1.8 billion people since 1990. This means that we are within 10% of being 'on track'. At current rates of progress, 67% coverage can be attained in 2015, better than previous projections but still far from the 75% needed to reach the target (Ibid).

The lowest coverage rates are in sub-Saharan Africa (36%) and South Asia (37%). In some countries, such as Afghanistan and Ethiopia, less than ten per cent of the population has access to adequate sanitation facilities. In South Africa, 12 million people still not have access to improved sanitation (Ministry in the Presidency, 2012) despite efforts and funds allocated to eradicate the sanitation backlogs. Behind the statistics is a further dilemma: what kind of sanitation solution is appropriate in the widely varying dynamic informal settlement? Inevitably, a wide range of options is needed, with the prime criterion being appropriateness and acceptability for a specific user group.

IRC (2007) suggested that the main reasons people give for wanting some sort of sanitation are mainly driven by:

- Convenience – women in particular dislike having to walk long distances to relieve themselves;
- Comfort – people dislike the smell of excreta and public toilets in densely populated communities are generally appalling;
- Safety – defecation sites are dangerous places for women and children; and
- Status – families are ashamed when they cannot offer guests proper toilet facilities.

Meeting these desires can be a challenging exercise that may require looking at alternative sanitation solutions. Sanitation solutions should therefore be developed by taking into account number of these issues. Despite the available wealth of knowledge available with regard to the sanitation issues, little has been done to provide adequate sanitation solutions that meet the desire and needs of user.

In informal areas, sanitation practices adopted by users include:

- No sanitation – especially when the settlement is new; the common practice here is the Open Defecation (OD). This occurs in the open spaces, field, ravines, trenches, nearby bush, etc. Men can urinate wherever they can while females can cover themselves behind a tree and a bush.
- Bucket: people use bucket or plastic to defecate during day or night. Collected excreta are discarded into open field, trenches or nearby watercourses or wetland.
- Traditional toilet: where space is available and the soil conditions permitting, dweller can dig a hole ranging from 0.5 to 1.5 m deeper and cover with wood or scrap metal positioned as a squatting pedestal while the top structure is covered by old shade clothes or iron sheet.
- Open ditches for disposal of greywater are commonly practiced; when full, greywater overflows throughout the settlement to reach the low laying areas.

It should be noted that all these practices are not adequate and increase the occurrence of sanitation related diseases while impacting on the human health and the environment. The adverse impacts of poor sanitation can extend well beyond the direct impacts on health. Health risks and epidemics from waterborne diseases can greatly reduce tourism and agricultural exports, with economic costs much greater than the cost of investments in water supply and sanitation to address the problems. Hence the need for adequate and appropriate sanitation solutions becomes a necessity.

1.1.3 The provision of sanitation services to informal areas

The main purpose of sanitation is to collect and dispose human excreta in an environmentally sound manner that is not harmful to both human and the environment. With this view in mind, we can assume that the practice of safely collect and dispose human excreta is applicable by all in urban, peri-urban or rural areas regardless of their conditions. This assumption may not be true when it becomes to informal settlements considering their nature and the manner by which it develops. It is widely documented that these settlements are developing in the boundaries of town and in most of cases located in areas unsuitable for housing. In these new illegal settlements, basic services (including water and sanitation) are lacking, thus opening the way to dwellers to adopt certain behaviour that are not aligned with the good practices pointed in the definition of sanitation (referring to purpose of sanitation).

In South Africa, access to adequate sanitation is a human right; and providing this service is one of the government responsibilities. However, the government's intention to extend access to sanitation services has provided several challenges, one these being the technology. Numerous sanitation technologies are provided to informal areas without considering local conditions or users' needs. The choice of technologies is based mainly on cost and other criteria are being neglected. As consequence, several sanitation technologies have failed, leaving thousands of users without choice than reverting to unhygienic sanitation practices similar to those outlined above.

1.1.4 Need for alternative sanitation concept and solution for informal areas

The impacts of inadequate sanitation in terms of human suffering and financial loss are enormous. The current lack of adequate sanitation systems also impacts the future of millions of people. It is a fact that in many cities centralised infrastructure networks cannot be constructed quickly enough

to keep up with the growing urban populations. It is also a fact that present urban solutions are usually disposal oriented and completely neglect to consider the reuse potential of different waste streams.

According to Tilley et al. (2009) sanitation is a multi-step process in which waste (human excreta) is managed from the point of generation to the point of use or ultimate disposal. A sanitation system comprises functional groups (referring to toilet, containment, treatment, reuse or disposal) which may differ depending on technology and the context of use. A sanitation system also includes the management, operation and maintenance (O&M) required for ensuring safe and sustainable functioning of the system. Given the unique nature of informal areas and number of sanitation related challenges occurring, conventional sanitation approach may not be adequate to address these challenges despite being the most preferred options by informal settlement dwellers. Therefore, sanitation role-players should think beyond the conventional sanitation approach and develop alternatives that can respond better to these challenges while considering the social aspects as one of the key elements of successful sanitation solutions. In this context, it has been found that alternative sanitation concepts and solutions are being developed using existing guidelines and compendiums that are often not specific to informal areas. The emerging sanitation solutions are often being developed without adequate knowledge of specific sanitation issues in the context informal areas; which in this research are labelled as office based design. These so called innovative solutions are developed without adequate or no established concept; and related drivers are generally not addressing the sanitation challenges faced by informal settlement dwellers.

The review of available literature shows that the development and provision of technical sanitation solutions to informal settlements should follow a given approach in order to ensure the reliability and sustainability of the technology provided. To date various approaches such as supply driven, demand driven, target driven, etc. have shown their limitation in informal settlement. The limitations observed are mainly attributed to many factors one of these being the lack of alternative sanitation solutions. Conventional sanitation concepts and solutions are not able to cope with the new challenges arising from these issues (Tilley and Zurbruegg; 2007). Therefore new sanitation concept and solutions are required to respond adequately to the growing sanitation challenges in informal areas.

For the purposes of this study, technical sanitation solution refers to a range of technological approaches and processes that can be used to ensure adequate and appropriate collection, containment, conveyance, treatment, disposal or safe reuse of human excreta and related waste without harming both human and the general environment. The words informal settlements and informal areas (are used interchangeably to) refer to unplanned and illegal settlements situated on privately or government owned land, characterised by the poor, inadequate or lack of basic infrastructure including water and sanitation.

1.2 Aims of the study

The overall aim of this study was to investigate current technologies used to service informal settlements with respect to innovation trends with the view to developing a sanitation concept for

technical sanitation solutions for informal settlements. This concept will inform the further research agenda.

Additional aims are to:

- Consolidate international knowledge on new and on-going development of appropriate sanitation technologies and innovations targeting informal or undeveloped settlements
- Investigate both communal and individual technologies provided to urban informal settlement residents
- Document successes and failures of implemented technologies
- Develop and conceptualise new appropriate sanitation technology concepts and solutions
- Develop a research agenda to further develop, test and pilot these new technologies

1.3 Development of the report and structure

1.3.1 Development of the report

This document is a final consolidated report that emerged from various reports developed during the course of the research. The report was developed in five different phases. In the first phase, researchers reviewed current literature on sanitation, covering mainly the sanitation problems and issues in general, responses to these problems, innovations and trends in the sanitation sectors and drivers for these innovations. This phase was concluded by interviews with various sanitation role-players (from various sectors) in order to obtain additional information.

The second phase comprised a discussion and analysis of findings from the literature and interviews. Develop the approach for developing sanitation solutions. Findings of this phase of the research were presented to the sanitation role-players during the workshops. The intention was to validate information, understand the views of the sanitation role-players (with regard to the developed approach and its application), apply the approach to develop sanitation concept and create a common understanding of the element of a sanitation concept and further develop the sanitation illustrative sanitation concepts for further discussion.

The third phase comprised a discussion during which the developed concepts were presented and discussed. The intention was to stimulate the debate with the view to refine or improve concepts and identify the key components of the proposed concepts. In addition, it was expected from the discussion to identify emerging sanitation solutions from each concept and its relevance to informal settlements.

The fourth phase comprised a presentation and discussion of the solution developed during the previous workshop, by identifying the key and additional features relevant to each solution and develops models. The developed models were presented to the sanitation role-players with the view to discussion their relevance, values and identify gaps for further discussion.

The fifth phase of the report consisted of writing and review of the progress reports that emerged from the four phases outlined above. The final draft was reviewed during the Reference Group meeting in order to consolidate and validate findings.

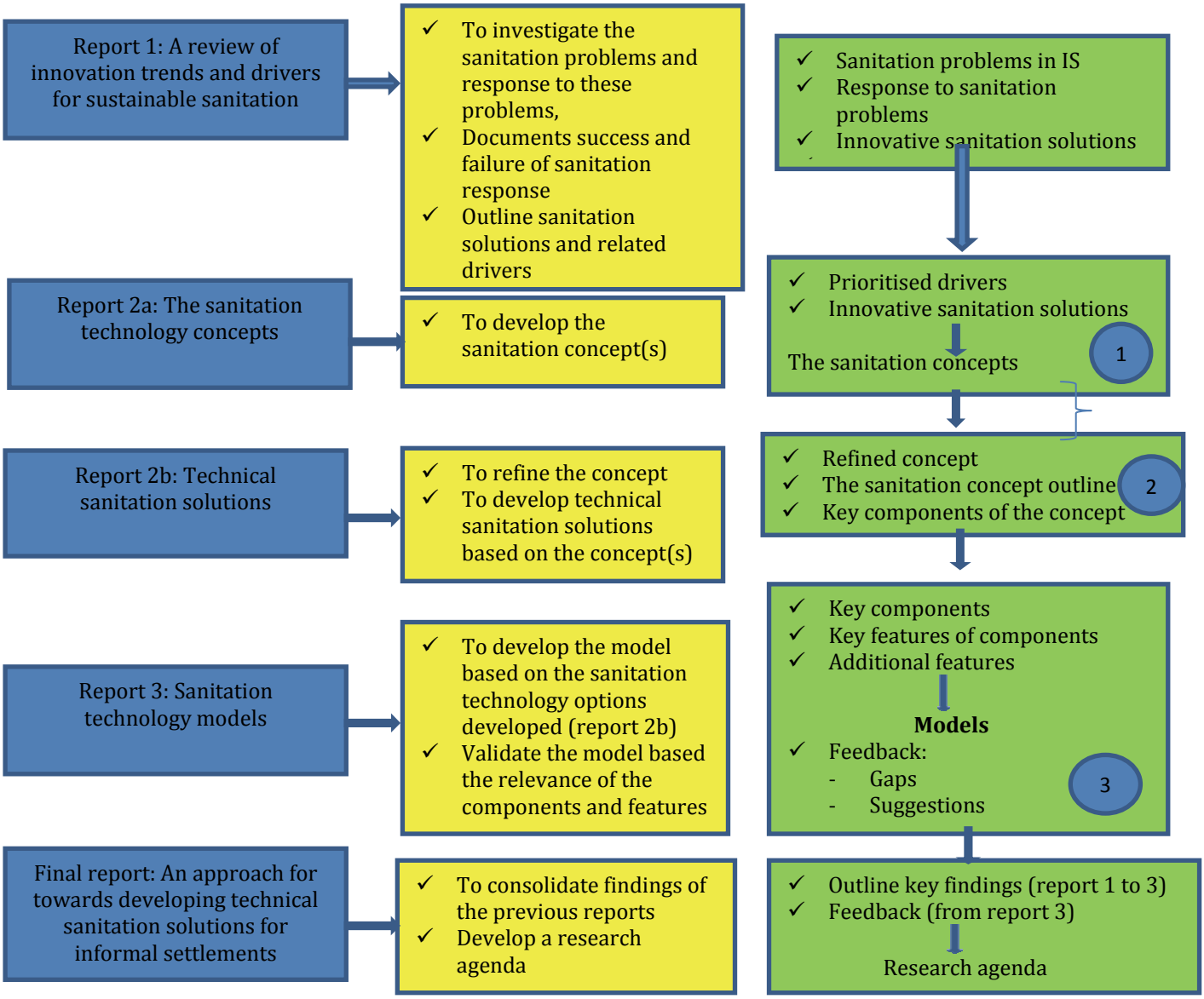


Figure 1: The research flow chart

1.3.2 Structure of the report

The research report is structured as follows:
Section 1 presents the background and the rationale for the study and the section 2 presents the study's methodology and conceptual framework.

Section 3 presents the review of the sanitation approaches in the context of informal settlements. An outline of the sanitation problems and responses in provided as well as a documentation of success and failures of the sanitation responses. In addition, the innovations in the sanitation fields and their trends as well as their related drivers are documented.

Section 4 outlines the approach for developing the sanitation concepts and solutions for informal settlements. Section 5 provides an example to illustrate the application of the approach to develop sanitation concepts and solutions for informal settlements.

Section 6 outlines the consolidated findings and gaps and further research agenda. The last section is a conclusion summarising key findings emerging from this research. Appendices provide a detailed overview of the evidence gathered during the research and other supporting details.

1.4 Intended users

The lack of adequate and available guide for developing sanitation solutions was found to be one of the multiple factors affecting the sustainability of sanitation especially for informal settlements. This document, in addition to suggesting the technical sanitation solutions for informal settlements should be considered also an informational tool that can help project designers better understand and confront the problems in improving sanitation in peri-urban areas. It is not a technical design manual, but a simple informational guide for developing sanitation concept and solutions. The document is believed to be useful for those involved in developing sanitation solutions and sanitation-players of various backgrounds.

2. Research methodology and framework

The nature of the study required an adequate understanding of various issues related to the sanitation in informal settlements. To achieve this, a comprehensive literature review was conducted in order to gather relevant information. In addition, interviews with various sanitation role-players were conducted to collect additional information and validate those collected in the literature. The literature review and the interviews were based on the key questions outlined below.

2.1 Key questions

The key questions addressed by this research include:

- ***What is the current approach to the sanitation problems in informal settlements?***
  - What sanitation problems are dwellers are facing?
  - How these problems are dealt with by the service providers?
  - Are these responses adequate to the sanitation problems?

- ***What is motivating certain role-players to develop sanitation solutions for IS?***
  - What drives the development of innovative sanitation solutions?
  - Are these drivers relevant to the sanitation problems?
  - How significant these drivers address the sanitation problems?

- ***What are the key innovative solutions emerge from sanitation development?***
  - What are the innovative solutions or trends?
  - How these innovative solutions differ from the existing solutions?
  - To what extent do these innovative solutions respond to the sanitation problems? (Gaps?)
  - How these innovative solutions are prioritised?

- ***How sanitation solutions are being developed?***
  - What process is being used to develop sanitation solutions?
  - Is this process considering the sanitation problems?
  - If this process is considering the sanitation problems, why failure is observed?
  - What characterises a technical sanitation solution in the context of informal settlement?
  - What are the components of sanitation solutions?

- ***What sanitation model can be applicable to informal settlement?***
  - What are the features of a sanitation model?
  - What are the attributes of a typical sanitation model?
  - How the model responds to the sanitation problems identified in informal settlement?
  - What gaps should be addressed?

2.2 Role-players and case study selection

2.2.1 Role-players

Sanitation remains one of the biggest issues that affect the life of every individual; today it has become a political tool and accessing to sanitation considered as human right. Given the sensitive nature of the research, it was decided to involve large number of role-players in order to get a broader understanding of their thinking and the way the approach the sanitation matters.

An extensive literature review was undertaken to identify the key role-players. The literature suggests that key role-players in the sanitation matters are broadly categorised as:

- Users
- Service providers (local government, municipalities, contractors)
- Business (Vendors, Manufacturers, Designers)
- Advocacy and implementing groups (CSO, NGO, CBO)
- Interested parties (researchers)

From this review, it was therefore agreed that we should incorporate at least 2 to 3 role-players under each of these categories of role-players with the view to get a broader sense of their understanding of the technical sanitation solution for informal settlement.

2.2.2 Case study selection

The study (as indicated by its title) is limited to informal settlements (of South Africa). Within this scope, it was decided to select only case study within the Western Cape Province due to budget constraint. In this regard, 3 study sites, namely Pook se Bos, Masiphumelele 1 and Enkanini, were selected.

The selection of these case study sites was motivated mainly by the willingness of community and their leaders to participate in the research, the availability of municipal officials, and the availability of two or more sanitation solutions (provided by selected manufacturers or contractors). In addition, these case studies were selected based on the differences in terms of location, culture (of dwellers), accessibility, unavailability/availability of sanitation solutions, etc.

Other case studies (outside the boundary of the Western Cape Province) were used only to test the findings of the study by comparing the views of role-players from other parts of the country. These include Claremont (in eThekwini) and Alexandra (in Gauteng).

2.3 Research methods, analytical tool and process

2.3.1 Research methods

a) Literature review

The nature of this research required adequate understanding of the sanitation problems at global and local contexts. In this regard, in depth literature review covering local and global experience in sanitation was undertaken. The review covered mainly the following issues:

- The sanitation problems in informal settlements (IS)
- The responses to the sanitation problems (from users and service providers)
- Innovations and emerging trends in the sanitation sectors
- Drivers for the development of sanitation innovations
- Sanitation concepts
- Sanitation solutions for informal settlements

The intention was to understand the sanitation problems and responses in order to document success and failures. The understanding of success and failures was deemed important as it informs the development of innovations while pointing to drivers. Knowing drivers and innovation, the next phase was intended to understand the way sanitation solutions are developed.

b) Interviews

Semi structured interviews were conducted with key informants drawn from role-player groups that included users, municipal officials, non-government organisations (NGO), Civil Society Organisation (CSO), engineers (consultant and municipal), researchers and manufacturer/designers and sanitation vendors.

The interviews were tailored according to the level and role of each role-player in the sanitation field. In general, the interviews covered number of questions related to:

- The sanitation problems in informal settlements
- The way these problems are attended (referring to the solution)
- The success and failure of the solutions provided
- Innovation trends and drivers
- The sanitation solution development mechanism and process

c) Focus group workshop

The main purpose of the focus group workshop was to present, discuss and validate findings collected from the literature and during interviews with various role-players. The focus group discussions were conducted with a number of role-players in four phases:

- Phase 1: Presentation of the interviews findings: a datasheet with information related to the sanitation problems, response, innovation and drivers was developed and presented to the sanitation role-players.
- Phase 2: Validation of findings: the sanitation role-players were requested to provide additional information and validate those provided
- Phase 3: Development of the sanitation concept and solution – role-players were given the pack comprising the developed framework and taken through the process and then asked to develop the concept
- Phase 4: Selection of the sanitation solutions and models – role-players were asked to use their developed concepts to come-up with sanitation solution(s) and model(s)

Each of the workshops has been used as a step for developing the technical sanitation solutions. Findings from each workshop were used as information for the following one – and the final

discussion was used to develop concepts and related sanitation solutions and models. Gaps that were identified were used later to develop the research agenda.

2.3.2 Analytical tool

The nature of this research required adequate methodology. To collect required information, standard questionnaires were developed from the key questions (outlined in section 2.1) and administered to different role-players. In addition, a workshop pack comprising of a guide for the facilitator and handouts with relevant information were developed for role-players during the work. A matrix was developed to analyse information collected, identifying trends and gaps.

Findings from the interviews and workshops were used to develop the sanitation concepts and solutions from which the models emerged.

2.3.3 Research process

2.3.3.1 Site visits

a) Interviews with users

Users sometimes referred as beneficiaries were interviewed in order to understand their perceptions and views of the sanitation in their respective settlements. The interview mainly focused on key issues related to the sanitation – focusing mostly on the technical factors such as access, accessibility, O&M, functioning, safety, robustness, adequacy of the system, etc.

In addition, after identifying or indicating various problems, the next round of interviews was intended to get the views of users regarding the responses to the identified problems. The questions asked were mainly related to the relevance of the response provided – referring to the technical solutions and its relevance in solving the sanitation problems.

b) Interviews with officials

The officials regrouping municipal engineers, field workers, caretakers and environmental health practitioners were interviewed intentionally to capture their views regarding the sanitation problems in general and specifically focusing on the technical issues. Since the service providers are involved in the daily service delivery and operation, their views were viewed as valuable in shaping a better understanding of the sanitation problem in informal settlements.

c) Other role-players

This group comprises engineers, manufacturers, researchers, CBO, NGO, CSO, etc. involved in the sanitation services. The interviews focused more on the sanitation problems and issues with more focus on the technically issues. The questions were related to the sanitation problems, solutions (success and failures), and relevance of the solutions, innovations and drivers.

2.3.3.2 Visual inspection

To validate some of the information obtained from various role-players (especially users), a visual observation was conducted. This comprised of viewing what has been said and collect evidence related to number of sanitation issues and problems. Some of the evidence collected are the

position and location of facility, number of user /or user ratio, functioning (during and after use), extent of O&M, daily operation, etc.

2.3.3.3 Workshops

a) Presentation and discussion workshop

Having completed the literature review, key findings were clustered and compiled into a discussion document. Additional findings from the interviews and visual observation were also clustered and added to those obtained from the literature. The combined document was presented and discussed during the workshop with the view to capture additional informal and validate the findings and shape the way forward.

b) Validation workshop

Since the research involved literature review and interviews, copious volume of information was collected and translated into data that required a thorough analysis. In order to analyse data, it was deemed important to validate first information. The intention of this workshop was mainly to validate information prior to the analysis with the view to ensure that information collected were valid and is related to the issues being discussed.

- Procedures:

Once the targeted role-players were selected and invited, the workshop was conveyed using the following steps:

- ✓ *Preliminary discussion*: Sanitation problems, response, innovations and drivers
  - Presentation of the project
  - Presentation of the findings from the literature and interviews
  - Discussion, addition and validation of findings
  - Selection of relevant information (related to informal settlements) – technical issues

- ✓ *Sanitation concept*
  - Presentation of the framework
  - Discussion of the framework and refinement
  - Development of the sanitation concepts and solutions
  - Discussion of the sanitation concepts and solutions
  - Selection of the concepts and solutions of relevance to informal settlements

- ✓ *Sanitation solution model*
  - Presentation of the models
  - Explanation of the feature and functioning of models
  - Question for clarity
  - Open discussion
  - Presentation of the models
  - Presentation of the models

- Closing remarks
- Final words

2.3.4 Information management

Information collected during the study period was grouped into appendices according to their sources:

- Literature review – summaries of findings
- Interviews – summary of interviews with various role-players
- Workshops – summary of workshops

2.4 Research framework

Table 1: Research framework

Problem	Questions	Objectives	Methodology	Pointers	Deliverables
There are several sanitation technologies and innovation being developed; however knowledge of this development and trends not being documented and established	What is the current state of knowledge on new and ongoing development of appropriate sanitation solutions for informal settlements?	Consolidate international knowledge on new and ongoing development of appropriate sanitation solutions targeting informal or undeveloped settlements	Literature review of local and international experience on sanitation development targeting IS - Innovative solutions - Key drivers - Drivers translate into innovations - Additional drivers	- Sanitation problems and responses - Success and failures - Solutions & trends - Drivers for innovative solutions - Pointers to the concept	Report: Sanitation technologies approach for informal settlements A review of sanitation solutions trends and drivers for sustainable sanitation systems
There are several sanitation concepts comprising various elements being used; the context of their use may vary according to the settlements patterns and problems. The context of use is often not clarified, thus leading to the development of wrong sanitation options	What are the key drivers (in order of priority) that match the sanitation problems faced by informal settlements	Prioritise drivers for sanitation solutions based on perceptions and opinions (from users, service providers and vendors) in order to outline the emerging concept;	Review of report 1: Drivers for sanitation solutions Literature review: Drivers for sanitation solutions Review: prioritisation criteria	- Drivers for sanitation - Prioritisation framework - Context for drivers prioritisation	Report: Sanitation technology concept
Various sanitation solutions have emerged from the combination of elements of the concept. However, development of these options is not clarified	What options emerge from the combination of various elements of the sanitation concept(s)?	Outline the design specifications and operational requirements of the developed sanitation solutions in order to understand the various design features and their operational requirements;	Literature review and comparison matrix to determine the combination of elements of the concept	- Elements of the concept - Sanitation arrangements - Features - Operational requirements	Chapter: Sanitation technology solutions

From the developed sanitation concepts three technical sanitation solutions have emerged. The social acceptance of these technologies is disputable in terms of their application, context of use and O&M.	What are the key features of the developed sanitation solutions?	Develop the sanitation solution models in order to identify key features and determine their context of application	Assessment of the proposed features from the drawings	- Typical features of a sanitation solution - Relevance of suggested features	Appendix: Features of a sanitation solutions and their relevance in context
Specific operational requirements are to be understood by users	What are the specific operational requirements of these solutions?	Outline the operational requirements of the developed sanitation solutions	Review of literature Stakeholders workshop	- Operational requirements of the sanitation solutions	Appendix: Operational requirements of the sanitation solutions
Limited application of conventional sanitation and number of alternatives	To what extent the developed technical sanitation solutions are applicable in IS context?	Test the models within an IS setting in order to determine the extent of its application	Stakeholder workshop	- Applicability of the sanitation solution - Context of application - General requirements	Appendix: The applicability of sanitation solutions in informal settlements
The extent of application of sanitation solutions not defined	What are the potential limitations of the developed sanitation solutions?	Assess the developed models based on role-players feedback in order to identify gaps for improvement	Stakeholder workshop	- Suitable sanitation solutions - Features - Operational requirements	Appendix: Extent and limitation of technical sanitation solutions in IS.

3. Sanitation technology approaches for informal settlements

3.1 Overview of the sanitation challenges in informal areas

Prior to discuss about the sanitation problems, it was deemed important to understand the meaning of informal settlement and its characteristics as these have a precedent on the problems that are going to be outlined and discussed later.

3.1.1 Understanding of informal settlement

Peri-urban and informal settlements are also commonly referred to as squatter settlements, marginal settlements, shantytowns, urban slums, or illegal settlements (Hogrewe et al., 1993). These informal settlements (figure 2) largely develop outside of government control and do not follow strictly formal and traditional urban planning and development processes. It is important to note, though, that the peri-urban sector is not monolithic and, more often than not, informal settlement development is a hybrid of formal and informal systems.

Generally speaking, informal settlements are characterised by uncertain or illegal land tenure, minimal or no infrastructure, low incomes, and lack of recognition by formal governments. Dwellers build on the cheaper land outside city limits, on land within city limits that is not zoned for housing, on land that has not been urbanised with infrastructure, or on land considered dangerous or environmentally fragile. Many informal settlements begin as land invasions with families illegally squatting on the land (Lagardien et al., 2009; Holden, 2008). Other informal settlements begin with the legal landowner illegally subdividing and selling the land without formal land registration or basic service provisions (Hogrewe et al., 1993).

Figure 2: View of informal settlement

These settlements frequently develop on land that is unsuitable for any other purpose, such as railway reserves, river banks, unstable slopes, swamp land and landfill sites (see figure 2). The choice of site greatly influences the types of services that can be provided. The size, location, condition and resilience of squatter settlements will be determined not just by the characteristics of their residents, but, more importantly, by the political context of official tolerance or intolerance towards them (Holden, 2008).

Informal settlements present unique challenges to sanitation improvement activities. Most challenging are the characteristics that set these areas apart from the urban and rural sectors: poor site conditions, unreliable water availability, high population density, the heterogeneous nature of the population, and the lack of legal land tenure.

Spatially, peri-urban areas are growing much more rapidly than formal urban districts. In many cities, the peri-urban sections are already bigger than the formal areas. Their rapid growth and informal status have resulted in low levels of sanitation services. The lack of these services in particular, inadequate excreta (human waste) management threatens the public health and environment of the peri-urban settlement, as well as the urban area as a whole (Lagardien et al., 2009).

To this end, it can be said that informal settlements are characterised by poor physical site conditions and complicated site layouts, limited water availability, high density population, organisation of communities and lack of social cohesion, lack of land tenure and poor governance; low Income levels and reliance on the informal economy and limited political influence. In addition, informal settlements are characterised by poor sanitation practices including open defecation that are attributed to the lack of adequate infrastructure and limited number of sanitation technologies responding to physical settlements conditions.

3.1.2 Sanitation challenges in informal settlement

It is widely documented that the provision of the sanitation services to informal settlements (IS) is a challenging exercise that requires a holistic approach in terms of the service, technology and management before, during and after the implementation. The sanitation problem in informal settlements as it may appear is not limited to the technology only but include social, economic, institutional and political; the technology being the only the visible part of the problem.

As pointed in the section above, the nature of informal settlements itself is problematic in a sense that the provision of infrastructure may be constrained by many factors presented above. The sanitation problem in informal settlement is multi-dimensional and covers many aspects including social, political, economic, institutional and technical (see figure 3).

From the social point of view, sanitation is considered as a last of the concerns of informal settlements dwellers; the key priorities being (in order of priority) housing, job, electricity, water and then sanitation (Muanda and Lagardien, 2012). Considering these views, it is difficult to adopt any approach for delivering sanitation services to informal settlements as long the understanding of their own problems and challenges (especially those related to sanitation) has not changed.

It is widely acknowledged that informal settlements are characterised by their socio-dynamic structure and diversity of their inhabitant; in most of these settlements, communities are grouped according to their tribal origin, colour, belief, political affiliation, etc. (UN Habitat, 2003).

Figure 3: Service delivery protest

The social cohesion is always fragile thus creating a real disjunction between communities and render the provision of services impossible. Social problems affecting informal settlement are:

- Heterogeneity of the community
- Cultural difference and intolerance
- Traditional and modern beliefs
- Lack of access to basic services (water and sanitation)

Institutionally, the government through municipalities have mandate to provide services to needy citizen. In this context, given the unique situation of informal settlements and the nature of the problems and issues faced residents, the only applicable approach to sanitation delivery is the supply driven. Given the difference of views and agenda, this may not be successful. Since informal settlements are illegally erected on private or government owned land, their legal status is always subject to interpretation, thus making the provision of adequate services quasi impossible. Intuitional problems identified are mainly:

- Uncertain legal status of the land and tenure
- Inadequate infrastructure selection and delivery mechanisms
- Lack of strong partnership between the community and municipalities
- Lack of appropriate management structure
- Lack of health and hygiene education
- Lack of adequate institutional framework of selection and delivery of water and sanitation infrastructure

Politically, decision-makers are using sanitation as their electoral tool to attract informal settlements dwellers through unrealisable promises. These promises add to the existing scepticism of dwellers to accept the planned services. Informal settlements are believed to be populated by a certain population group considered generally as poor, uneducated and easily influenced to gain their support. This attitude has been used by decision makers to provide or not necessary services to communities for the last decade.

Depending on the context, political problems affecting the provision of sanitation in IS are mainly:

- Conflict of interest and goals in the service delivery

- Political motivation and sabotage
- Lack of distinction between public service and political interest
- Lack of civic education

Economically, informal settlements dwellers needs cannot be attended given that sanitation is only one of the least priority for many Governments in developing countries. Kallbermarten (1982) reported that one of the challenges facing developing countries is the lack of available funds to develop and deliver adequate infrastructure to the urban poor. This statement was later echoed by several scholars who added other issues such as:

- Lack of dedicated fund for the provision of adequate and suitable services
- Lack of consideration of the sanitation delivery as an economic priority due to its low investment return
- Lack of interest from public and private investor

Technically, sanitation solutions that can be provided to informal settlements are constrained by various issues related to the physical characteristics of the settlements itself, lack of operation and maintenance, lack of alternative solutions, limited technologies appropriate to the settlements conditions, poor design, non-compliance with the operational requirements, etc.

Focusing on the technical issues, it is known that a sanitation solution can comprise (depending on the technology) a toilet facility, containment/collection, conveyance system, treatment and where applicable disposal. Each of these components may have specific problem (in addition to the general ones presented above). In the context of this study, we have decided to document number of technical problems relation to each of the component of the sanitation solution as follows:

- Toilet facility: robustness of the superstructure, type of pedestal (squat or sit): cleaning, shape, water use
- Containment/collection: type of container (resistance to breakage, rust), ground water protection (moisture and infiltration)
- Conveyance: space , type of piping system, slope
- Treatment: space availability, odour
- Disposal/reuse: handling of excreta or faecal sludge, transport or disposal

Considering all these problems, the sanitation service therefore becomes a problematic issue that should be carefully studied from different perspectives including social, technical, institutional or economic. Unfortunately, this study is not developed to address all these issues and the focus is only to address technical issues with the view to develop corresponding technical solutions while considering other issues (including social) as equally important in affecting the feasibility/applicability of any solution provided.

Informal settlement dwellers view sanitation as a physical infrastructure rather than an overall system that include physical infrastructure, community behaviour, etc. (Lagardien et al., 2012).

From this view, apart the already known and documented informal settlement sanitation problems, additional problems were identified. These include:

- lack of data on sanitation access and common definition of sanitation in urban context; the indifference of those having access to sanitation to the needs of slum dwellers (WSP, 2007)

- unclear responsibility for urban sanitation (due to poor coordination and bureaucracy) and the lack of financial resources and capacity with local government to fulfil their mandate (WSP, 2007)

- lack of land tenure, approaches used to create demand for sanitation often lacking support due to low social cohesion and community spirit; and lastly the lack of health and hygiene education for slum dwellers to adopt good hygienic practices (Schaub-Jones, 2005)

- demand-driven sanitation interventions, political motives, conflict of interest and goals, lack of reliable data on number of informal settlements dwellers and sanitation access, cheap land versus expensive infrastructure, limited technologies appropriate to the settlements, uncertain legal status of the settlement (Hogrewe et al., 1993).

- basic services are prioritised by municipalities rather than sustainable services, lack of sustainable partnership between users and municipality, crisis management as a dominant activity rather than preventative maintenance, lack of budget available to support O&M, low profile of operation and maintenance and lack of appropriate organisation structure within municipalities and communities (Lagardien et al., 2009)

- poor planning and negligence, inadequate community involvement in planning, implementation and post implementation, lack of communication between communities and municipalities

- Inappropriate designs: technologies provided not responding to local context, not taking into account users' needs (Still et al., 2009)

- Lack of consideration, negligence, sabotage, conflict amongst dwellers, poverty, land status, lack of organisational structure, power struggle and conflict of interest (informal settlement dwellers – reported by Lagardien and Muanda (2011).

There are a number of factors specific to urban areas such as lack of tenureship, poverty, lack of a sense of belonging or community, large transient population, high land prices, etc. It is clear (when looking at these problems) that the provision of sanitation to informal settlements is and will remain a challenge that need to be appropriately addressed in order to ensure access to sanitation for all. Not all problems presented above occur simultaneously, their occurrence depends on context and varies from one settlement to another with regard to the type of service provided, organisational level, and density of settlement and level of community involvement.

Addressing the sanitation problems and challenges require designers, manufacturers and other sanitation role-players to consider the institutional, economic and social sanitation related problem as criterion that can be used to develop a sanitation assessment framework. Technical issues may be used to develop sanitation solutions for given informal settlement context.

In response to these issues, several technologies have been developed in order to deal with the problems while existing technologies are being improved or innovated in order to meet users' needs and ensure access to sanitation for all living in informal settlements. However, the innovation responses are often not well understood or qualified and yet need to be elucidated in order to develop a sanitation concept that will guide further research agenda.

3.2 Sanitation services in Informal settlements – Response to the sanitation challenges

The availability of adequate and safe sanitation is a major global challenge, where more than a third of the world's population lacks access to adequate sanitation. This problem is particularly severe in peri-urban areas and urban informal settlements in developing countries, where lack of adequate infrastructure is compounded by poor access to health and education amenities.

Conventionally, most community sanitation problem assessments and project design efforts focus primarily on the technical feasibility of various technical intervention options. Experience to date suggests that these technology-driven projects often fail to meet their objectives; the complexities of peri-urban settlements require that a more comprehensive interdisciplinary approach be used to clarify the problem before attempting to design a project that will address peri-urban community sanitation needs (Hogrewe et al., 1993).

The provision of sanitation services in peri-urban areas can be a challenging exercise given the unique and difficult conditions informal settlements present. Many sanitation solutions may not viable given these difficult conditions discussed above. To create new solutions, project leaders must challenge the status quo at the municipal and national levels, which continue to deal with urban sanitation in a conventional way. The understanding of sanitation has to move beyond a focus on infrastructure provision, which considers only high levels of service and neglecting alternative solutions such as non-waterborne sanitation for example (MDC, 2004). Where a local authority lacks the means to provide a high level of service to all, there are a range of other options which can be pursued to ensure that everybody enjoy their constitutional right to an environment which is healthy. All sanitation interventions should be designed to serve all members of communities (WaterAid, 2011).

3.2.1 Sanitation services in informal settlements of South Africa

Sections 24(a) and 27(1b) of the 1996 Constitution of South Africa implicitly refer to access to basic water and sanitation as a human right. The Water Services Act No.108 of 1997, Section 3(1) states that "Everyone has a right of access to basic water supply and basic sanitation" (DWAF, 1997). Despite being a constitutional right, access to sanitation in informal areas is not being covered adequately; and the low coverage has been attributed to the uncontrolled mushrooming of informal settlements. To fulfil this constitutional right the South African

Government decided to prioritise the provision of basic sanitation services to the poor especially those living in informal areas because of the perceived impact of these services in the reduction of poverty (Mjoli, 2009). This prioritisation has seen the access to sanitation increase from 57.7% in 2001 to about 78% in 2008 and this number is set to increase to increase further in order to meet the 2014 target. However, despite the speedy sanitation delivery, access to adequate sanitation in informal settlements still and remain a challenge for both users and municipalities. These challenges are attributed to several factors including access, physical site characteristics, inadequacy of the sanitation technology to name few.

Number of sanitation solutions (individual and communal) have been developed and implemented in various informal settlements (Holden, 2010; Melo, 2007; DWAF, 2002; Dunstan and associates, 1998; Austin and van Vuuren, 1999) throughout South Africa is response to the sanitation problems faced by needy citizens. The response to these problems are found to be specific to case study sites and the level of services provision is not regulated as technologies to be used are only indicative and not prescriptive; hence giving opportunities to each municipality to determine the level of service relevant to the local context.

3.2.2 Case study responses to sanitation challenges

Sanitation technologies are being developed to improve human health and created conditions that are not harmful to the environment. These technologies should be able to ensure the safe disposal of human excreta, greywater and wastewater that may be generated by households. In South Africa, the most commonly preferred and used sanitation technology is the water borne sewerage (Austin et al., 2005). There are other intermediate technologies such as VIP, UDS (Duncker et al., 2006), ablution facilities, Enviroloo (Scott, 1998), septic tank, and recently MobiSan (Lagardien et al., 2009) that has been tried but users of all background prefer the top range (reference to full waterborne sanitation) without considering various implications that may rise from the application. There is no single solution that can be applied as universal panacea and the situation will continue to worsen unless new approaches are adopted (Austin and Duncker, 2002). Considering the argument by Austin and Duncker (2002), municipalities (as service provided) have decided to respond to the sanitation problems in different way – some looking at the most feasible technology, while other looking at the cheapest options (in terms of O&M, running cost, purchase, etc.) and constraints related to each technology option. In any case, there was no indication of municipalities looking at users' needs.

Sanitation technologies can be broadly categorised according to their use or the operational requirements. This includes individual and communal sanitation; waterborne and non-waterborne. Individual sanitation system refers to a sanitation technology provide to individual or a family and can be used only a dedicated person and his/her family. In this category number of technologies such as VIP, UDT, bucket, porta-potty, etc. are available.

Communal sanitation refers to a sanitation technology dedicated for a number of users within a defined precinct – it should not be confused with public toilet (which refers to a facility accessible for all). Technologies available include communal ablution block (CAB), MobiSan, Kayaloo, etc. and can be classified according to their operational requirements – this includes

dry and wet sanitation system. Each municipality has its own requirements in terms of technology choice and provision.
Responding to the sanitation problems faced by informal settlement dwellers, municipalities have adopted various measures with regard to the approach to be used, technology choice (Parkinson et al., 2008), management and organisational structure at community and municipal levels. Three municipalities were used to illustrate their response to the sanitation problems in informal problem. It should be noted that illustration below covers only the sanitation technology options provided.

a) eThekwini

eThekwini is widely recognised as one of the most progressive South African municipality that strategically provides and manages the sanitation services to urban, peri-urban and rural areas. For the purpose of this study, the focus is on the urban and peri-urban informal settlements only. In the past 10 years, this municipality provided various sanitation technologies to various informal settlements within its jurisdiction the latest being the CAB.

According to the city officials, the provision of these technologies was based on the context of each settlement and more importantly the local conditions (in terms of topography, access, etc.). For instance, informal settlements situated in less accessible zones were provided with VIP toilets, those situated in areas accessible were provided with UDT. New areas such as Shembe were provided with CAB (Gounden and Sibiya, 2011). This response to the sanitation issue was widely applauded by users (see Lagardien et al.; 2010; Roma et al., 2010) and seems producing expected results. However, the dry sanitation technologies (VIP and UDT) are giving few operational problems related to the management of faecal sludge.

b) City of Cape Town

The provision of sanitation services is one of the priorities set by the City officials. The last ten years have been characterised by an increase on the sanitation provision throughout the City and more than fifty different technologies were used. To date, the number of sanitation technologies has been reduced to about fifteen (Grootboom, 2011) and this number is expected to be reduced further. The reduction was attributed to the wrong choice, lack of user acceptance and more specifically the inadequacy of provided solution to respond to the sanitation problems. Despite making access to sanitation one of the development priorities, the provision of sanitation services to informal settlements still a challenge for officials for number of reasons including increasing number of informal settlements, sabotage and vandalism, political motive, lack of alternative technologies as well as inadequacy of existing solutions to name few.

c) Stellenbosch

Given the increase in number of informal settlements and dwellers, the municipality adopted a supply driven-approach to deal with the sanitation problems. Various technologies including ablution block, Kayaloo, bucket toilet, container, chemical toilet and Enviroloo were provided to various informal settlements mushrooming within the Stellenbosch municipality. However, despite the provision of sanitation as response to the sanitation problems, access to sanitation

still not adequately covered due to number of issues such as inadequacy of certain technologies, low number of facilities, lack of adequate O&M, poor management, misuse and vandalism, etc.

In view of the approaches used by the three case study municipalities, it is clear that the response to the sanitation problems is specific to each case study. The technology itself may not be sufficient to respond to the users' needs and solve the problem but a starting point in preventing health risks and environmental pollution. Some municipalities have adopted other support measures such as user education/awareness programme, liaison and communication and monitoring and evaluation system (M&E). Where these support measures are implemented, the sanitation problems and issues have been addressed satisfactorily despite some sporadic constraints.

The responses to the sanitation are being slowed by several issues such as the lack of technical innovations and consideration of the informal settlements conditions, sanitation delivery approach, political interference, etc. With regard to the technical solutions, various technologies are not meeting their intended purposes while others have been successfully implemented. The appropriateness of each of the solutions provided is understood as the ability of the sanitation technology/solution to respond adequately to the sanitation problems – the key one being a barrier to the spread of sanitation related diseases and protection of the environment.

3.2.3 Appropriateness of responses to the sanitation challenges

According to WHO (2007) 747 million people have gained access to sanitation facilities (equivalent to 205,000 people every day) since 1990. Despite this huge achievement, a further 1,089 million rural and 1,085 million urban dwellers will need to gain access in the coming 15 years if the 2015 target is to be realised" (Ibid.). The reality is that sanitation delivery has proven to be a challenge for many governments worldwide especially in developing countries. In 2000 it was realised that sanitation delivery would have to be doubled in order to achieve universal goals. Doubling sanitation delivery requires addressing sanitation challenges not only from technical perspectives as it is the case currently but also looking at social, economic and institutional perspectives.

In the international sphere, South Africa signed the millennium development goals (MDG) agreement that aimed at halving the proportion of people without sustainable access to basic sanitation. Although, this goal may not be achieved by the year 2015 despite the progress made in this regard, 12 Million people still not have access to adequate sanitation (Ministry in the Presidency, 2012). Towards meeting this challenge South Africa is amongst many of the countries which have adopted well-intentioned programmes for providing subsidised basic sanitation services. In practice many projects have failed due to the lack of proper use of infrastructure despite the associated 'health and hygiene awareness' programmes that are attached to service delivery. Questions of whether delivery has failed because of inappropriate technology, not meeting the actual needs of communities, or because of a lack provision for O&M, continue to be points for discussion in the sanitation sector.

Bearing this mind, it should be noted that the appropriateness of a response to sanitation issues should be measured in terms of the produced impacts; and these should be visible. The visible signs indicating the appropriateness of a sanitation solution are viewed differently and depend on the goal and intention of each role-player. For user, adequate response is reflected through free access to the sanitation, cleanness and comfort; what happens beyond is not a priority. In contrast, the service provider understands the appropriateness as the ability of the technology to function adequately at all times, with least maintenance, low cost and less interruption.

In the context of this study, it was found that institutional, economic and social issues are key indicators of the appropriateness of a sanitation response. These issues (as indicated above) can constitute criteria and indicators of a technology assessment framework. Other issues technical related issues can be used to develop sanitation solutions for a given context.

This section of the report intends to document failures and success of sanitation technology innovations in informal settlements. Success and failure are being explored intentionally to identify key area of innovations and related drivers. We should bear in mind that success or failures may depend on several issues. Amongst these are technology types, dynamic of the settlement, users' awareness, etc. For the purpose of this research the focus is on technical issues only.

a) Success

An analysis of several case studies shows that community-driven sanitation projects were more successful because local people were actively involved in the selection of sanitation options and day-to-day management of the sanitation project implementation processes. In this approach, the external implementing agents provided support and project management while local leaders took all day-to-day management decisions (Still, 2009).

Sanitation can only be sustained when O&M services are budgeted for, when provision is based on a partnership with local authorities and supported consistently (Brikké, 2000). At this time there is broad consensus that basic sanitation services in particular are sustainable when they are:

- functioning and being used;
- able to deliver an appropriate level of benefits;
- continue over a prolonged period;
- managed institutionally and do not affect the environment negatively
- at a local level, or by alternative mechanisms, costs are covered
- at a local level is provided with technical assistance, including training, monitoring and systems of reporting (Brikké, 2000).

Looking at few examples, the success of sanitation technologies is very often context based and may depend on the level of community awareness and types of technology provided. In Kitui-pumwani (Kenya), shared toilets were constructed; households were allocated a shared cubicle within the toilet block and were responsible for the cleaning of the facility. Initially the system worked well, however, increased tenancy led to a reduction in commitment to cleaning of the

facilities. As a result, it became increasingly difficult for committees to enforce, and many of the toilets fell into disrepair (Wegelin, 1997). Also, the committees found it increasingly difficult to collect funds to pay for the pits to be emptied.

The Orangi Pilot Project in Karachi (Pakistan) shows that community orientated planning and the adoption of appropriate urban technologies can yield significant successes (Sijbesma et al., 2008). Likewise, the slum mapping and enumeration work pioneered in Indian cities acted as the precursor of large-scale improvements in sanitation facilities, especially when they are community (as against local authority) managed.

The community toilet movement in India has undoubtedly been a success providing almost half a million toilets in some of the most densely packed urban areas. Success has also been demonstrated in the eThekwini (South Africa) approach where ablution blocks (comprising toilet blocks, showers and handwash basin as well as laundry points) were provided to peri-urban settlers. The caretaker (a volunteer) designated by the community was handed the responsibility of looking after the facility. To date, these facilities are in good working condition and their O&M cost are less compared to those not having a caretaker (Lagardien et al., 2009). As Eales (2008b) points out communal toilet blocks are proving highly effective, because they concentrate usage in one place and so make sewer connections, management and operation financially viable". However, it is not the technology that determines these successes but the governance arrangements and the attention paid to making them work. "These blocks readily lend themselves to partnership arrangements, where the skills and the strengths of different partners can be leveraged to best effect" (Ibid.).

Similar situation was observed in Cape Town (Pook se Bos informal settlement) where the MobiSan facility is provided to a community of about 400 people. The caretakers (a municipal official and other designated by the community but paid by the municipality) are responsible for the daily O&M of the facility. The technology is amongst successful sanitation being operated in informal settlement context; this success is mainly attributed to the joint management (city of Cape Town and community forum), the continuous user awareness programme (held at the facility), and the high level of compliance amongst users and sense of ownership (Lagardien and Muanda, 2011).

In view number of successful sanitation technologies in informal settlement, Teun-Jan & Wells, (2007) states that that success is equally contingent on projects being relevant, satisfying perceived needs and desires, and feasible in respect of resources. Sustainable solutions require the right combination of technologies, approaches and enabling factors to match the environmental, socio-economic, institutional and legal context.

A study by IRC (2007) shows that the success of a sanitation solution (regardless of the technology) will be defined by the number of drivers including political support and institutional leadership, sustainable financing programme, partnerships across sectors, tailored technology choice, hygiene promotion and sanitation marketing and empowering community centred approaches. In this line, the assessment of sanitation solutions in eThekwini, Cape Town

and Stellenbosch, has shown that factors underlying the success of the sanitation services are related to the following factors:

- Level of community organisation
- Compliance with basic use and operational requirements
- Willingness of community to accept the facility and take care of it
- Level of awareness programme
- Community engagement and involvement before, during and after the deployment of the sanitation,
- Adequate community and municipal structure deal with informal settlement problems,
- Use of local labourers for the O&M,
- Joint management of the facility, Bottom up management structure
- Location of the facility within an acceptable walking distance,
- Continuous health and hygiene programme,
- Regular monitoring of the facility,
- Short response time to reported problems and issues, etc.
- Adequate design of the components (to meet local conditions)
- Appropriateness of the solution to the local conditions

These factors are often used by sanitation role-players to assess the performance of the sanitation services. It was noticed during the course of this research that the factors underlying the success of sanitation services are case specific and may change over time. This implies that success can temporal and turn to failure when dispute emerges between municipal officials and users or when political interference is high. This situation often happen is informal settlements where political activism is high (example of Kayelitsha and Harare in Cape Town).

b) Failure

Providing adequate sanitation to in informal settlement dwellers continues to present many problems globally and in South Africa. International experience of subsidised sanitation programmes showed that supply driven sanitation delivery approaches led to unsustainable sanitation services because they focused on toilet construction without considering hygiene education, community mobilisation and meeting sanitation demands of the beneficiary communities (Brikké, 2000).

Several international and local studies have outlined many causes of sanitation technologies failures in informal settlements. These causes are classified as technical, social and institutional. To illustrate this, Baken (2008) has shown that the regular, government-constructed community toilet blocks constitute examples of hopelessness; construction and maintenance agencies showed no accountability to the communities concerned, meaning that they developed no sense of ownership. As result, most toilets became blocked, dirty and in serious disrepair within three months of construction, leaving people with no alternative but to defecate in the open". Moreover communal toilets are not a panacea since they do not address issues of personal safety adequately, especially for women and children at night (Eales, 2008b).

In Quetta (Pakistan) the condominium sewer was successfully tested in informal settlements. However, in the absence of a well-functioning sewerage network and treatment facilities, faecal sludge is being dumped in ravines in the vicinity of the city (Qutub et al., 2008). Mjoli (2009) pointed out the inadequacy of the O&M, low users' satisfaction due lack of involvement in the planning, implementation and post-implementation process, lack of users' awareness and poor adherence to operational requirements as the causes of failures of sanitation technologies. These findings were echoed by Lagardien et al., (2009) adding the lack of sustainable partnership between users and municipality, crisis management as a dominant activity, poor planning, lack of communication, lack of budget available to support O&M, lack of appropriate organisation structure as causes of failures.

In addition, the same study found that the lack of distinction between the responsibilities of households, community and municipality and ineffective planning, monitoring, evaluation and interventions are cited as core problems to failure of sanitation technologies. Still et al., (2009) added the lack of ownership and negligence, irregular cleaning of the facility, distance walk to reach the facility, use ratio (number of people allocation per toilet) especially during peak hours and inaccessibility to the facility amongst problems that cause failure of sanitation technologies.

- Provision of greywater disposal: greywater shall not be considered as drainage but rather a sanitation problem that need to be integrated in the overall sanitation system. Most sanitation technologies (targeting informal settlements) ignore the greywater problem, thus leading to total failure of the entire system.

- Handling of human waste: there is a controversy regarding handling, reusing and management of human waste where dry sanitation systems are provided. Dry sanitation systems are failing mostly due to general beliefs (especially in Africa) where people are reluctant to touch, even look at human waste after defecation.

- Soil conditions: this is a limiting factor for number of technologies, especially those relying on sun and air for hydration. Due to the nature of land where informal settlements are located, several technologies are failing due to problems related to high water table, flood prone areas, low lying and steep slope, etc.

- Stringent operational requirements: some technologies (such as UDT and its derivatives) require certain level of understand of operational requirements in order to ensure adequate functioning. Lagardien et al., (2010) reported that the non-compliance with operational requirements has been the most common cause of failure of sanitation technologies in informal settlements.

- High O&M cost: Mjoli (2009) stated that failure of sanitation systems in informal settlements is attributed to the lack and high cost of O&M. The insufficient or lack of O&M budget has driven several municipal to abandon the O&M of certain sanitation systems.

- Blockages caused by use of inappropriate anal cleansing materials usually caused by misuse, negligence and vandalism. Level of poverty led many people to use inappropriate anal cleansing materials that often cause problems to the entire system.

- High reliance on permanent water source: technologies provided in water scarce areas may fail due to lack of permanent water supply for their operation. This may result in severe blockage and total failure of the system.

- Unavailability of important parts locally: usually, municipalities tend to provide sanitation services that are originally designed abroad. Recent research by Parkinson et al., (2008) has shown that the unavailability of important parts and inability to mass produce sanitation system locally has led to abandonment of number of sanitation options; thus reverting communities to eradicated system due to lack of appropriate sanitation.

- Slow response and lack of communication: the level of communication and response time to fix a sanitation related problem is amongst challenges informal settlements dwellers are facing. The slow response to breakdown has left communities without a choice than using available facilities or practice open defecation. According to Lagardien et al., (2010) it may take up to 3 days to see a simple blockage being fixed. In this regard, the bottom-up and top down approach and organisational structure within municipalities have been blamed for poor response to maintenance requirements.

From the review of a number of literature and personal experience during the course of this study, it was found that the failure of sanitation solutions in informal settlements are the same as the (sanitation) problems identified in the previous section of this report. These causes may be of social, institutional, technical or financial character and mainly include the following:

- Lack of community involvement and buy-in of the deployed technology,
- Lack of trust and dialogue amongst key stakeholder involved in the sanitation provision,
- Supply driven approach used for delivering sanitation in informal settlements,
- Lack of adequate monitoring and O&M structure,
- Poor management,
- Lack of users education and awareness programme,
- Inadequate sanitation technologies (that do not match the local condition),
- Political interference, etc.

Technically, most of sanitation solution fails because of inadequate O&M, inappropriateness of the solution, poor design, lack of understanding and compliance with operational requirements as well as inappropriate use. In addition to this, the lack of understanding of drivers for the development and delivery of sanitation solutions in informal settlements may lead to wrong choice and application. Hence, drivers should be clarified and established prior to embark into the development of any sanitation solution concept and model.

The solution to the sanitation problem often requires a far more holistic intervention than simply providing technology. Technology does not fail humans but humans fail technology if this later cannot be sustained in the socio-economic, personal or cultural environment. The users are often blamed for the failure but the reality is that failure occurs because the technology is inappropriate to the circumstances.

The success of a sanitation technology is compounded by a number of requirements that need to be considered. Regardless of the level of sophistication of the technology, if these requirements are not complied with, the likelihood of failure is high. In addition, it should be noted that every technology has a specific set of operation, maintenance and institutional requirements for ensuring adequate and sustainable functioning. These requirements need to be considered at the design phase and tested prior to the implementation.

The design of appropriate sanitation technologies should take into account the documented success and failure of each sanitation technology in order to move forward towards solving the sanitation problem. Success and failures should be thoroughly analysed in order to identify positive elements and draw lessons that could be used to inform the sanitation concept.

From this review, it was found that the understanding of the success and failure of the sanitation technology (mainly from technical perspectives) can adequately inform the innovation and related drivers that can be further used to develop the sanitation concepts and solutions. Success and failure should be documented as a mean of finding innovations and drivers that can further explored to develop the sanitation concept(s) and solution(s).

c) Way forward

From a technical point of view Toubkiss (2008) pointed that the main challenge for ensuring access to adequate sanitation is to find sanitation solutions that are appropriate to local conditions, affordable, easy to operate and maintain and viable. Affordability and viability includes the feasibility of keeping the technology running effectively. It should be noted that every technology has a specific set of operation, maintenance and institutional requirements for it to operate on a sustainable manner; these need to be considered during the design process.

The only way adequate responses can be given to the sanitation challenges and issues is to draw lessons from the success and failure, develop or suggest innovations that respond adequately to the sanitation problems (by considering not only technical issues but many other indicated in the previous section), and most importantly understand the drivers for the development of these innovations.

The understanding of drivers is believed to be a determinant factor of the success or failure of the technology. The intention of the design engineer or manufacturer can be easily reflected on the driver leading to any innovation. Therefore the innovation holding potential to respond to the sanitation problems (in informal settlements) and related drivers should be documented and understood in the context of informal settlements. The understanding of these innovations and related drivers is believed to inform the development of the sanitation concept.

3.3 Sanitation solution and options – relevance to informal settlement context

3.3.1 Innovative sanitation solutions and options

It is acknowledged that the sanitation problems facing or faced by informal settlement have triggered the development and deployment of several sanitation technologies. Having identified the sanitation problems in informal settlements, innovative solutions are needed to deal with the identified problems. To each of the sanitation challenges and issues outlined in the previous section of this report corresponds an innovative solution that mainly depend on the context of application, types of technology and the approach used for the provision of the technology to the settlement.

Bearing this in mind, an attempt was made to outline key innovative solutions emerging from the sanitation options provided to informal settlements. In the light of this, a key question that needs to be answered is that "… *what are the innovative solutions to the sanitation challenges in informal settlements?*"

The interviews conducted during the research period, it was noticed that the responses to the sanitation challenges are of various motives including technical, environmental, social, institutional and financial. For the purpose of this research, only technical solutions that are related to the components of the sanitation options (referred as collection, containment, transport, treatment and disposal) are discussed.

Learning from successes and failures (in the light of sanitation problems identified in the section above), several innovative sanitation solutions have been developed, others being developed or piloted. In this context, the key questions that may be asked are:

…" *What makes the existing sanitation and new innovative solutions different"?*
…"What is new compared to the previously developed and deployed sanitation technologies"?
…"What is an innovative sanitation solution"? Can we consider these new technologies as innovative solution"?

The literature review provided an outline of the sanitation problem and technologies provided to informal settlements. The analysis of these sanitation technologies has outlined number of innovative solutions and related drivers which were found in most cases related to the component of the sanitation options. Despite the large number of technologies provided to informal settlements (case of the City of Cape Town for example), the number of people without access to adequate sanitation is set to increase, thus indicating the failure of most of sanitation systems.

Due to the failure of current conventional sanitation systems and the increase of number of people without access to sanitation, several organisation such as BMGF, SusanA, IRC, WRC, etc., and many researchers have embarked in the quest for alternative solutions to the sanitation problem; hence triggering the need for developing appropriate sanitation technologies within a given context while meeting users' needs. Given the nature and dynamic of informal settlements, the new sanitation concept pioneered by large number of organisation does not

look at the traditional concept of sanitation that categorise it as dry or wet system, conveyance or non-conveyance systems, etc. To illustrate this, several research are being undertaken in order to find appropriate sanitation technology arrangements for urban poor in peri-urban and informal areas.

According to BMGF (Undated), the improvement of the quality of sanitation services for billions of people requires a next generation of sanitation. With the current number of people living without adequate sanitation, there is an urgent need to expand the suite of technologies for decentralised, non-waterborne sanitation across the service delivery chain (capture and containment, extraction and transport, treatment, disposal, and reuse of excreta) in urban areas. To achieve this, BMGF identified the need for appropriate sanitation solutions for peri-urban areas. Through a call for innovative ideas that was made, several proposals were submitted, reviewed and the most innovative selected (appendix A). Trends emerging from the review of selected innovative solutions proposed include the following:

- *Sanitation capture and containment technologies: improvements or alternatives to pit latrines. Desirable solutions may offer:*
  - Lower pathogen load of materials to enable safer servicing/removals;
  - Minimal or no user involvement in operation and maintenance of containment facilities;
  - Technologies useable in a wide variety of contexts.
- *Solutions to menstrual management and safe disposal of child faeces.* Desirable solutions may offer safe, biodegradable and/or low bulk/reusable materials (i.e., no use of chemicals/materials that are potentially dangerous to the environment and human health).

- *Extraction and transportation innovations for hauling faecal sludge to transfer or disposal points. Desirable solutions may offer:*
  - Treatment and/or water separation that commences during transport;
  - Increased ability to extract solids as part of extraction from pit latrines and other containment devices;
  - Durability in unstable and unpaved roads situated in densely populated urban environments;
  - Increased personnel safety during extraction and/or transport.

- *Advancements in decentralised treatment technology for use at community, apartment block, town, and/or city scales. Desirable solutions may offer:*
  - Decreased time requirements to reduce the mass or volume of faecal sludge / sewage;
  - An ability to site and maintain the system directly in communities;
  - Pre-fabricated / off the shelf sale possible for community or apartment block level use;
  - Remote sensing capacity for centralised monitoring / controls.

- *Innovations in re-use of waste for agricultural, energy or industrial purposes at community and/or city level. Desirable solutions may offer:*
  - Cost effective in comparison to waste treatment;
  - Competitive with existing sources of fertiliser, energy or industrial inputs;
  - Effective with the reduced nutrient load found in developing countries.

- *Other sanitation innovations, including but not limited to:*
  - Improved temporary toilets that do not use chemicals requiring special disposal;
  - Low cost composting facilities requiring minimal user interaction with composted material.

Conversely to BMGF, the sustainable sanitation alliance (SusanA) promotes appropriate sanitation technologies with an emphasis on the sustainability. According to the SusanA, a sanitation technology is appropriate only if socially, environmentally and financially viable. Trends emerging from the review of innovative sanitation solutions and proposals are related to the sanitation solutions making use of locally available materials, easy to use and accessible to all. Still (2011) and WRC focus on developing a sanitation system that use less water for its operation, requires connection to a septic tank or an existing sewer and using locally available materials. The innovative solutions are related to the flexibility and adaptability of the design to the local context. Gyampo (2011) provides a simplest way of dealing with environmental pollution caused by septic tanks, sewer and other type of sewage conveyance system.

Table 2: Innovative sanitation solutions and the components of relevance

	Innovative sanitation solutions	**Component(s) of relevance**
1.	Conversion of excreta to valuable products	Treatment
2.	Algae for the effective and economical treatment of waste	Treatment
3.	Decentralised next generation sanitation for diarrheal pathogens	Facility and treatment
4.	Hybrid anaerobic digester-microbial fuel cell for energy & nutrient capture	Treatment and reuse
5.	Design of microorganisms with semiconducting membranes	Treatment
6.	"Lego-Like" sanitation system: pit latrines made of bio-compost	All components
7.	A low-cost decentralised sanitary system	All components
8.	Fortified excreta pellets for use in agriculture	Treatment and reuse
9.	Ecological sanitation	All components
10.	Prototype micro-flush-biofil toilet facilities	Facility and treatment
11.	The earth auger toilet: innovation in waterless sanitation	Facility and treatment
12.	An energy-producing waterless toilet system	Treatment
13.	Turning latrines into fly traps	Facility
14.	Universal slum sanitation with 100% safe reuse of nutrients	All components
15.	Urban sanitation solutions for high-use, flooded, & difficult-to- serve areas	All components
16.	The lotus throne: a self-cleaning solution to sanitation	Facility
17.	A simple auger die assembly that treats faecal waste	Treatment
18.	High-efficiency sanitary toilet with sewage treatment	All components
19.	Integrated mobile sanitation solutions in peri-urban setting	All components
20.	Safe sludge	Treatment

The key innovative solution emerging from this sanitation is related to the non-use of chemical, self-cleaning or purification (that do not necessitate conveyance or centralised treatment work), micro-biological decomposition of human waste and potential reuse of treated effluent. The University of Potsdam alongside a South African consortium designed the communal water house (currently piloted in Ikwezi local municipality). Emerging innovation trends are related to on-site containment and processing of human waste to generate water and energy while reducing carbon emission. It includes on-site water recycling for high water service water, water heating by solar energy, solar air conditioning and modern toilet systems.

The analysis of these sanitation solutions (proposals) suggest that most these innovative solutions are being developed for specific needs in response to an identified challenges and issues; and the solutions are related to the components of the sanitation technology and are not specific to a particular context. Drivers for these innovations are mainly of social, institutional, economic and environmental nature; and to lesser extent on key technical issues. The table above provides an illustration of innovation proposals and the components of relevance. From this table, it becomes clear that the proposed innovative sanitation solutions are related to the components – with the facility and treatment being the main focus. This confirms that the sanitation challenges described in the previous section of this report are mainly reflected on the components of the sanitation; and the sanitation innovations should focus more in areas where most problems are occurring.

3.3.2 Innovative sanitation solutions

a) Overview of innovative sanitation solutions

The analysis of various innovative sanitation solutions has provided a baseline for understanding each of these solutions and categorise those holding potential. It emerges from this analysis that innovative solutions that address sanitation challenges for urban poor or peri-urban settlements are (but not limited) to the following:

- Decentralised system (with separate collection and treatment of human excreta to recover water and energy
- Self-containment sanitation that can be used to break down human waste into useful gases
- Sanitation systems that take into account settlements patterns, provides job opportunities through O&M and other activities
- Sanitising human waste for beneficial reuse (energy, fertilisers, etc.) for achieving zero waste generation
- Optimum use of sanitation systems to harvest rainwater, on-site greywater treatment, processing of faeces and generating energy.

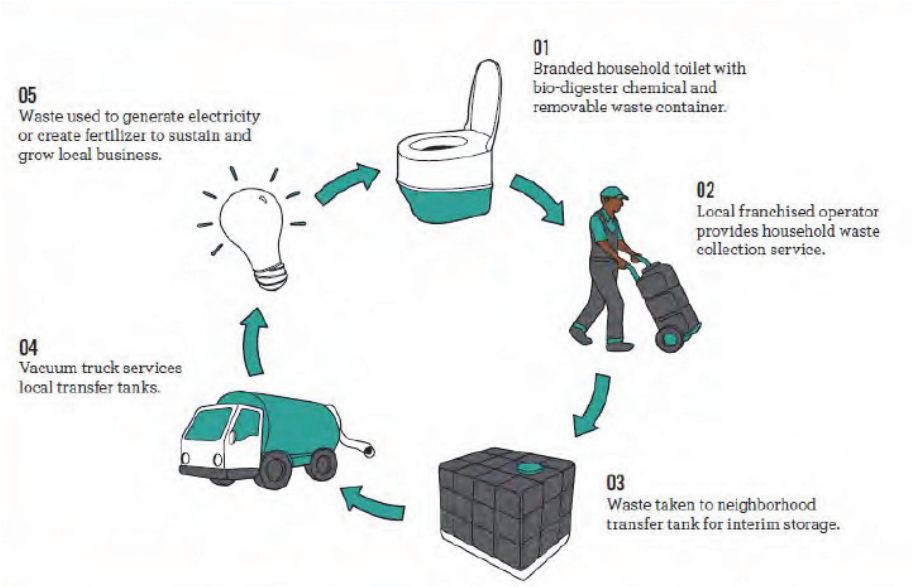


Figure 4: Example of emerging trend for innovative sanitation (Source: Roma & Curtis, undated)

Interestingly, all innovative solutions tend to promote sensitive issues such as water conservation, generation of energy from waste; on-site processing, reuse and maximal use of the natural potential offered by the Mother Nature. For example, a bio-digester toilet equipped with removal waste container can provide opportunity for waste collector (local franchised operator), waste storage and transport, treatment to generate energy or create fertiliser. This implies that, the trends emerging in the sanitation sector focuses more on transforming waste into useful products (energy or fertiliser) while promoting business at various scale.

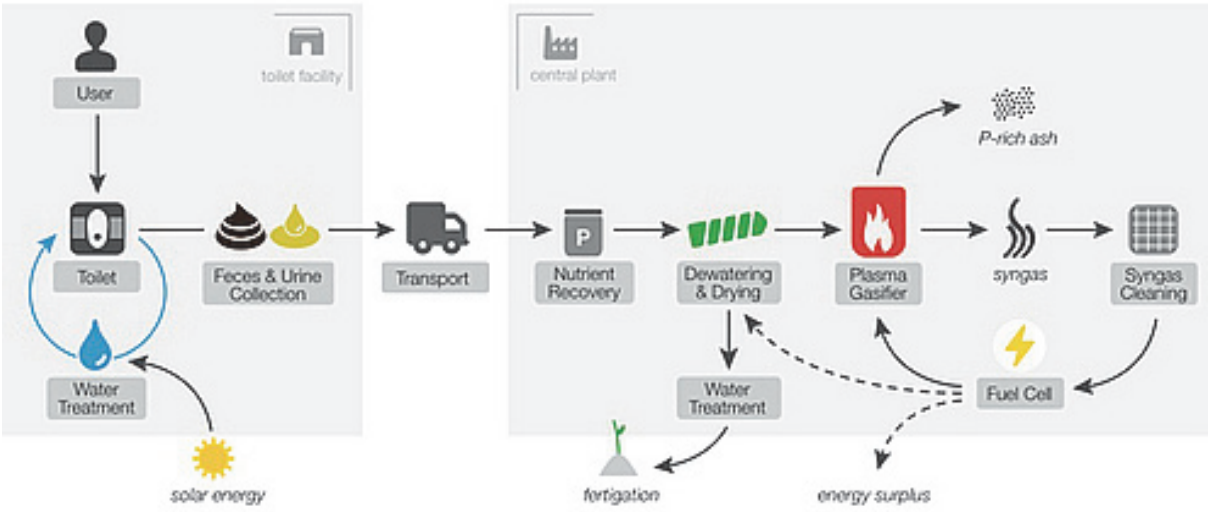


Figure 5: Innovative sanitation solution (Source: TU Delft)

Drawing from figures 4 and 5 emerging innovative sanitation solutions are mainly developed to address number of challenges including density, energy shortage, water conservation and job opportunities, etc. Each of these innovations is linked to one of more components of a sanitation system. Using figure 5 above as illustration, the innovation sanitation solution proposed by TU Delft suggest smaller community facility scattered around the settlement comprising toilet facility with a self-cleaning squatting ceramic pan. The content of the toilet can be collected and

transported to a processing plant to recover nutrient and generate energy. In addition, transport, nutrient recovery and energy recovery can generate business opportunities for informal settlement residents such as local waste collectors and transporters for example.

However, from the review of sanitation different sanitation technology options, it was found (as indicated in previous section) that the innovative solutions addressing sanitation challenges are context based and are factor of the settlement patterns (that includes community dynamic, type of settlement: location, topography), level of service and political motivation. Focusing of the developing sanitation solutions, an extensive literature review covering available innovative solutions was undertaken in order to highlight the emerging trends and their relevance to the sanitation problems in informal settlement. In addition, interviews with design engineers, manufacturers and sanitation vendors were conducted.

From the literature and interviews, it emerged (from technical perspectives) that the innovative sanitation solutions are tied to each of the potential component of the sanitation solutions. These innovative sanitation solutions are responding generally to specific issues (as indicated in appendix A).

Referring to the sanitation problems discussed in the previous section, the responses provided, success and failures, the emerging innovations (BMGF, IRC, Sanitation compendium, etc.) are mainly focusing on each of the components of the sanitation solutions. Some innovative sanitation solutions trends are illustrated as follows:

- *The toilet facility*

The manner by which water is being used in informal settlement has led to the development of the micro flushing system where waterborne (flush toilet) is being used. This solution addresses water conservation. Another emerging trend is the water repellent pedestal with a pedal which is related to the cleanness of the toilet vault given the number of users, cost of O&M while reducing the volume of water required for cleaning toilet. In the context of informal settlement, these innovations may respond better the water scarcity issue, cleanness of the facility and reduce the cost of labour related to the daily cleaning of the facility.

- *Containment /Conveyance*

Depending on the types of the sanitation solution, containment or conveyance may be applicable. Generally, containment is often found when using dry system while conveyance is most for wet/flush system but these concepts are subject to changes according to the context and designs.

- Containment – the emerging trends suggest the introduction of double vault or rapid desiccation of faecal sludge in order to reduce the holding period. Various innovations are being suggested but their application still to be proven in the context of informal settlement.
- Conveyance – in the context of informal settlement, it is suggested that small diameter pipe should be used for conveying wastewater and inspection chambers should be used

at very 20 m instead of actual conventional 100 m; pipes should be laid at shallow depth to allow easy access during the maintenance.

- *Treatment*

There is a general trend today to turn green by ensuring that waste generated by human activities is converted into usable resources. With this vision in mind, several innovative sanitation proposals tend to convert (using different techniques) urine or faeces into resources that can be variously used. For example, faecal sludge produced by dry sanitation systems can be converted into pellets that can be easily handled (collected, transported and disposed where applicable); mixed human excreta can be used to generate biogas.

Other solutions suggested include:

- Conversion of human faeces into compost that be easily handled and safely use in agriculture. This solution is intended to remove safely and in an environmentally sound manner the faecal sludge from urban areas while providing the farming industries with compost.
- Rapid drying of human excreta for easy handling or disposal. Given the density of informal settlement and the number of sanitation users, the access to the sanitation may requires large number of infrastructure and the collection, treatment or disposal of produced excreta may be challenging. The solution to this issue is a rapid drying of excreta that can be converted into reusable materials such as pellets or compost.

Treatment of human excreta can offer business opportunities (SMME, CBO, etc.) and create jobs amongst sanitation users (as referred in figures 4 and 6).

- *Disposal/Reuse*

The current drive in the sanitation field is to generate zero waste and make waste useful by generating energy and nutrients for various applications. In view of the emerging innovation trends, disposal is seen as a last option while reuse is being encouraged.

- In terms of disposal – it is believed that dry or wet sanitation solutions may produce substantial volume of faecal sludge, greywater that need to be treated and safely disposed. Greywater is produced where handwash or shower facilities are provided. In the context of informal settlement, the number of users and the volume of faecal sludge and greywater may be higher than expected; hence to ensure adequate functioning, a rapid treatment of faecal sludge is an option.

- Reuse – it is well documented that human excreta and greywater contains pathogenic organisms and should be handled with due care. Treated faecal sludge and greywater can be useful sources of nutrient and water. However, the reuse should be controlled in order to prevent health risks and environmental pollution. For example, biogas generation and composting are suggested as a reuse options. Innovative solution here is related to the time taken to convert the faecal sludge into useful products that can be reused safely.

Innovative solutions are related to the components (or functional elements) of the sanitation solution; and their application is context based and depend mainly on the settlement types and the dynamic of users. The analysis of solutions presented in section above shows that innovative sanitation solutions evolve around the facility (toilet) and treatment. Conveyance, containment and disposal are not being explored and no innovative solution has been so far suggested. The economic aspects (with reference to business models and its sustainability, etc.) are also scarcely addressed. The relevance of these solutions is not often proven given that they are not being developed without considering key sanitation issues related to informal settlements.

b) Relevance of innovative solutions in the context of informal settlements

It is well known and documented that the conventional sanitation systems comprising waterborne and conveyance systems have failed for various reasons and is not often suitable for informal settlements. In this line, several innovative solutions have been or are being developed including those reported in the previous section. Their relevance and applicability may be context based in terms of types of settlements serviced.

Technical sanitation solutions are developed to respond to number of issues including human health and environmental protection. According to Tilley et al. (2009) a technical sanitation solution may comprise two or more of the following components (depending on the context): toilet, collection and containment, treatment, disposal or reuse (where applicable). The types of settlements to be serviced include informal and formal settlements which have different characteristics, challenges and problems. Informal settlements are generally considered as problem areas where basic infrastructure is lacking, people living anarchically and less control over the population. Innovative solutions are being developed in response to some of these issues; and become options only when successfully implemented, adopted by users and have track record in terms of operation, maintenance and capabilities to respond to the users' needs.

The analysis of the innovative technical sanitation solution (presented in appendix A) was intended to assess the applicability in the context of informal settlement, the cost-implication (in the context of developing countries), the O&M (in the context of informal settlement) and manufacturing, availability, etc. in the light of identified problems faced by informal settlement dwellers.

The following findings emerge from this analysis:

- The solutions provided are not considering informal settlement problems, thus not responding to the needs of informal settlement dwellers and the context of these settlements;
- Beneficiation emerges as a key driver followed by environmental protection (which is the aim of the sanitation itself);
- The solutions (as presented) in isolation cannot respond to the sanitation problems in informal settlement; however, the combination may provide a solution that respond better to the conditions.
- Proposed innovative sanitation solutions are related to the components (or functional elements) of a sanitation system.

From this analysis, innovative solutions holding potential (in the context of informal settlement) are mainly related to the following:

- ✓ Easy and safe collection of human waste
- ✓ Resource recovery and energy generation
- ✓ Low O&M and water saving
- ✓ Portability and mobility of the facility
- ✓ Rapid hydration of faecal sludge

The relevance of an innovative solution may be viewed differently by various role-players. For the purpose of this study it was therefore decided to determine the context by which the proposed solutions are relevant. The context presented below is related to the approach for developing technical sanitation concept and solution (discussed in the previous sections of this report). The following parameters were used to determine the relevance of the innovative sanitation solutions in the context of informal settlement:

- Density (user ratio, access and number of facility)
- Operation and maintenance
- Health risk and environmental protection
- Affordability

Table 3: Innovative solutions and their relevance to informal settlement (BMGF, undated)

Innovative sanitation solutions	Relevance
Bio-solid treatment	Large volume of bio-solid produced Lack of space Physical characteristics of the settlement
Rapid dehydration of human faeces	Large volume of bio-solid produced Lack of space Physical characteristics of the settlement
Easy and safe collection and disposal	Large volume of excreta produced Collection and disposal method Handling mechanisms Access
Resource recovery and energy generation	Excreta can be treated on-site for beneficial use given the constraint for collection and disposal
Low O&M cost	The occurrence of breakdown, vandalism, misuse, etc. increase the O&M costs of sanitation in informal settlement
Portability and mobility of the facility	The land tenure may not offer potential for permanent infrastructure; reuse of existing infrastructure is an option if relocation of users is envisaged
Decentralised system	Physical characteristics of the settlement may be a constraint (for access, construction, etc.)
Waterless and micro-flushing systems	Water conservation given the lack of accountability amongst users in informal settlement
Alternative building materials	Beneficiation – job creation
Double containment (reception and treatment) and cartridge	Beneficiation, safety for handling and faecal sludge management
Rapid desiccation/dehydration of FS	Density
Smoothness of the toilet and water repellency	Number of users and density
Pedal operation	Density and number of users (flushing mechanisms failure)
Mechanical mixing	Due to large number of user, enhancing the drying process
Wind driven systems	Enhance the drying process and reduce odour
Processing of combined waste	Beneficiation

The proposed innovative sanitation solutions (table 3) address number of sanitation problems despite being more focus on the facilities and treatment (resource recovery). It is important to note that innovation should be focusing on specific problem solving than general assumptions. With reference to informal settlement, the key relevance of the suggested innovation trends and solution is related to number of issues including the density (referring the large volume of human excreta produced, access and functioning of the facility), poverty, affordability and cost of operation and maintenance.

Having identified innovative sanitation solution and emerging trends, the key question that should be explored is "*what is driving these innovative solutions*?' and "*to what extent these drivers respond to the sanitation problems in the context of informal settlements*?"

3.4 Drivers for the development of innovative sanitation solutions

3.4.1 Overview of drivers for innovative sanitation solutions

The identification of the sanitation problems in informal settlement, factors contributing to the success and causes of failures provide an opportunity to investigate and identify the drivers for the sanitation technology innovations. Since the sanitation problems in informal settlement are classified into category (known as social, technical, institutional, social, financial, etc.), the success or failures of these technologies are linked to the way these problems are dealt with. Drivers for the sanitation technology innovations are believed to be drawn from these problems.

The main drivers for developing sanitation solutions for informal settlements were basically the need to improve public health and hygiene of urban areas. To a large extent these drivers are context based and are dependent on number of factors including:

- The level of awareness of the service of the individual involved in the design or service delivery,
- The knowledge of the area and related sanitation problems,
- The knowledge of the dynamic of the settlement,
- The knowledge of the level of service (intended to be provided),
- The background of the individual involved in the service

Using these factors, several drivers were identified and their relevance was found to be subject to personal feeling, level of awareness and knowledge of the sanitation problems as well as the nature and dynamic of informal settlements. It is worth noting that each settlement may have its own issues that should be carefully studied and translated into drivers; generalising drivers to all informal settlements may not provide expected result. In this line, some drivers are discussed below in terms of their relevance.

a) Water conservation

It is known that South Africa is a water scarce country facing water shortages in coming years if current resources are not well managed. Water conservation strategies are being put in place to deal with looming water crisis. Amongst these strategies, reuse, wise water use and technical solutions that enhance less water use are being implemented or explored. Due to water scarcity status of the country, the utilisation of waterborne sanitation is seen unrealistic. For this reason

dry sanitation systems, low and pour flush toilets were amongst many other technologies that were introduced to deal with water conservation. These sanitation technologies require less or no water at all for its functioning and have been successfully implemented in several parts of the country and have produced intended impacts on water use.

b) Environmental protection

The main objective of sanitation technologies (in their traditional forms) is to get rid of human waste. The environmental protection was not an issue, thus given least considerations. Due to the increasing pollution to the environment that causes threat to human health and the environment, manufacturers and designers attempted to develop technologies that may positively respond to the problem. Several sanitation technologies were or are being developed taking into account environmental protection as key factor; amongst these technologies are full water borne sanitation and its derivatives, UDT and many others.

c) Elegance

Sanitation is not only a place used for defecation but should be considered as a restroom that need to please users. Sanitation is a system – not just a technology; its primary focus is to discard human waste in order to prevent environmental pollution and threat to human health. Therefore, the sanitation system should be elegant, attractive safe and clean. The elegance of a sanitation technology will therefore provide confidence to users and cut off the contamination chain and environmental pollution.

Looking at the pour flush toilet example, Still (2011) stated that this technology is used in Asian societies where water is mostly used for anal cleansing and users prefer squatting. This technology was adopted by the Western culture in region where water is scarce. Due to the sanitation habit, the technology was innovated and made more comfortable for use (through the provision of toilet seat similar to the full flush toilet), easy to clean and elegant for users.

d) Operation and maintenance cost

Lagardien et al., (2012, 2009) study has shown that inadequate operation and maintenance is a major sustainability barrier for the sustainability of sanitation technologies. There is little appreciation of the long-term financial implications of operating the various sanitation systems. As a result, communities and local governments are currently choosing technical options that, in the long term, are unaffordable and unsustainable (DWAF, 2002).

Mjoli (2009) indicates that the inadequate capacity for O&M of sanitation systems in most municipalities is apparent; and 73% of municipalities only performed reactive maintenance while 78% of the municipalities did not have any O&M plans. The choice of high maintenance sanitation systems such as waterborne sanitation and low flush on-site sanitation technologies should be made with full consultation of the beneficiary households to make sure that they understand their responsibility for operation and maintenance costs.

e) Upgradability

The Government of South Africa is working towards the eradication of sanitation backlog by accelerating the sanitation services through the provision of adequate sanitation facilities. For instance, intermediate sanitation technologies such as Kayaloo and CAB are being provided with a possibility of upgrading in near future. Due to the nature of sanitation technologies, an adequate sanitation should provide a space for future upgrade without causing much damage to temporary infrastructure. The need for upgradable sanitation should be considered as it will reduce the cost of constructing new facilities.

f) Impacts of climate change

In recent years, the effects of climatic change have impacted in many sectors of human life; and the most affected being the water sector. Technical sanitation solutions should consider the impacts of climate change when deciding on options. In water scare areas, care should be taken to ensure that the technology being designed, selected or provided will work accordingly regardless of the external impacts that may be caused by the climatic change.

g) Resource recovery and reuse

The MDG 7 goal is to ensure large access to water and sanitation by the year 2020. Energy requirement may be a limiting factor that may slow the sanitation delivery in many parts of the world including South Africa. According to Willetts et al., (2010) important nutrients such as nitrogen and phosphorus are contained in human waste; and should be recycled and sold as fertiliser.

The approach is driven by concern about the loss of finite reserves of phosphorus for manufacturing commercial fertiliser and the damage created by introduction of excessive amounts of nutrients (nitrogen and phosphorus) from wastewater into waterways. It presents the possibility of an income stream from wastewater treatment. Given the current energy crisis, technical sanitation solutions are to be designed by considering human waste as source of energy rather than waste.

h) Rate of urbanisation

It is known that the lack of exact data on number of people living in informal settlements is a problem to the provision of sanitation. A number of sanitation solutions have failed previously due to a lack of consideration of this driver; as results community in informal areas have reverted back to unhygienic sanitation behaviour that cause diseases and even death especially amongst children. Therefore, considering the rate of urbanisation (in terms of population growth) will respond to the issues related to large number of users and density which is one of biggest challenges for servicing informal settlements.

i) Adaptability

Through the assessment of innovative sanitation solutions outlined in appendix A, it emerges that the adaptability was the most important driver across all technologies. Given the temporary status of informal areas (despite staying longer than planned), innovative solutions should focus on alternative ways of adapting technology to local contexts. Several solutions have failed due to static /inflexible design, adapted to certain needs and not considering local conditions.

Flexibility in design requires leaving room for improvements and adaptation as this may save money, time and need for building new infrastructure.

j) Affordability and willingness to pay

Financially restricted communities cannot afford certain types of sanitation systems due to high cost of operation and maintenance (Mjoli, 2009; Paterson, 2007). In the majority of cases, the poor status of communities living in informal areas make some types of sanitation unaffordable especially when users are not willing to pay. Due to the poor status of communities living in informal areas, willingness-to-pay surveys also help identify technologies that are acceptable and affordable to a community.

k) Effectiveness and suitability to local conditions

- *Effectiveness*
  - An effective sanitation refers to a whole system of which toilets are just one component. The effectiveness of a sanitation system should comply with the following requirements:
  - Respectability and hygienic: the system should meet the health and functional requirements for all users
  - The system should not pose risk of pollution to the immediate environment
  - The system should provide dignity and privacy to all users
  - The system should require minimum or no water for its functioning
  - The system should require low O&M

- *Robustness/durability and safe containment (during rain and flood events)*
  - Robustness and durability: due to the nature and dynamic of informal settlements, sanitation technology innovations should be robust to handle large number of users and vandalism; it should be functional for the design period.
  - Light weight for easy handling and transport: the land tenure and dynamic of informal settlements are issues that should be considered when designing a sanitation system. Knowing that informal settlements may be moved to suitable areas, care should be taken to ensure that sanitation infrastructure should be displaced to prevent wasting resources and money.
  - Watertight (for safe containment): the technology should not cause problems to the environment through leaks, seepage into ground or emission of objectionable smell.

- *Locally available components*
  - Availability of parts: care should be taken to ensure that parts are locally available and easily obtainable.
  - Ability to be mass produced: preferably, parts and components of the sanitation technology should be locally produced in order to prevent high cost of shipping and reduce waiting period for delivery.

- *Ease of operation, maintenance and service during productive life*
  - Ease of operation: sanitation innovations should be easy to operate; complicated operational requirements may create dissatisfaction or reduce users' confidence.
  - Ease of maintenance: traditional or conventional sanitation technologies require certain level of skills for their maintenance. Care should be taken to consider options that require less significant maintenance in order to reduce the cost and ensure continuous functioning.
  - Ease to service: sanitation options should be easily accessible for service as complicated design may render the facility unusable. Provision should be made to ensure that the facility can be serviced without altering or destroying existing structure.

l) Sustainability

The functional sustainability of technology requires that people value, utilise, finance, care for, repair, improve and eventually replace the technologies on which they rely. It is important that technologies must be easy to operate, manage, and maintain. Understanding the context of technology assists in careful design that must be based on a better understanding of what end-users really want in the first place.

m) Accessibility/location

The location of the sanitation facility is a most important factor that needs to be considered. The sanitation technology innovation should be designed in such a way that its location provides access to all (including children elders and disabled persons) (Lagardien et al., 2009). Further, the same study shows a high level of abandonment of sanitation and an increase of people reverting to unhygienic sanitation habits.

From this study, it can be said that as long as the location of the sanitation technology does not provide access to all user groups, the probability of failing is high regardless of its elegance. Hence, the technology innovations should be made to be accessible and positioned on an appropriate location suitable for all user groups.

n) Cost effectiveness

The costs of sanitation solutions increase in proportion to advance/complicity in techniques. Usually construction costs are less in rural areas because simple solutions can be applied instead of sewerage and water treatment systems. Conversely to conventional technologies (which life cycle cost increase with time) sanitation technology innovations should have lower life cycle cost for the entire operational period.

o) Scale of use up and uptake

Sanitation technology innovations are developed to meet specific needs. Once developed, it is recommended to pilot the technology in order to understand how it works in practice, and refine by fixing problems that may emerge from the short term use, etc. After this, the innovation should be marketed, scaled up for further application.

Apart from the literature, sanitation role-players suggested additional drivers that include poverty and density. It is generally understood that informal settlements are populated by the low income category of the population and their living conditions are characterised by the lack of basic infrastructure, lack of access to basic needs, low or no income and high rate of criminality. Hence, the innovative sanitation solutions should consider this aspect; as high tech solution may not be affordable and difficult to maintain.

Concerning density, the high living cost and poverty has left vulnerable population with no alternative choice than invading private or municipal lands for settlement purposes. These settlements took place in an uncontrolled and unstructured manner; squatters occupy spaces without adequate planning and control, thus the available space becoming lesser than the number of squatter and dwellings. The lack of available space for implementing basic infrastructure impact severely on the service delivery and can be seen as a limiting factor in terms of technology choice. Therefore, innovative solutions should consider density as it may severely impact on the functioning of the sanitation with regard for example to access, emptying, transport, etc.

3.4.2 Drivers and their relevance to informal settlement

Research by Lagardien et al., (2009) revealed that the failure of a number of innovative sanitation solutions is due to the lack of interaction between manufacturer, vendor and users, inadequate marketing and scaling up. For instance, Paterson (2007) suggested municipalities to investigate and promote innovative sanitation solutions in all settlements in order to broaden choice to communities. In today's context (of informal settlement) drivers for innovative sanitation solutions are increasingly becoming more complex. The major drivers have expanded beyond those of the traditional concept and delivery models that focused on the protection of public health and urban hygiene, environmental protection (and preservation of ecological integrity), to a more business model adding efficient use of scarce resource, potential markets and products (water, nutrients and energy).

The current tendency to achieve successful sanitation in informal settlements requires holistic and innovative approaches that can take into account various factors (of relevance to these settlements). From the analysis of the drivers outlined above, we have identified key drivers that are believed to respond to the sanitation challenges in informal settlements. Depending on the service provider, manufacturer, design engineer and other stakeholders involved in the development or provision of sanitation to informal settlement, drivers for innovative sanitation are of various motives. Lagardien and Muanda (2011) attempted to outline various drivers that emerged from the literature and interviews with certain manufacturers or design engineers, these include (but not limited to):

- ***Protection of public health and maintaining urban hygiene***: this is the first driver identified and still remains one of the major drivers. Water borne diseases are among the most causes of public health hazard, which are mainly attributed to the lack of proper management of the urban water system. Emergence of resistant microorganisms and toxic/carcinogenic chemicals have triggered the introduction of advanced technologies and improved management of wastewater.

- ***Protection of the environment and preservation of ecological integrity***: expansion of urban centres and unregulated waste disposal has deteriorated the natural environment and endangered ecological integrity. Most of informal settlements (when starting) do not have adequate sanitation systems in place. Open defecation, use of bucket system and other available methods to collect and discharge excreta is practiced. Untreated wastewater is discharged into recipient water bodies (streams, wetland, ground or river). Recipient water bodies are increasingly impacted by the pollution loads and their ecological values (fauna and flora) are deteriorating.

- ***Efficient use of scarce resources***: the wastewater streams are treated and the recycled water is kept in the loop and used in appropriate applications.

- ***Water conservation***: the use of potable water for disposing human excreta should be kept as minimum as possible; reuse of wastewater effluent is encouraged at all levels.

- ***Efficiency***: it is widely known that informal settlements are often located in a challenging environment that requires specific attention when planning the provision of services. The provision of a technical sanitation solutions to informal settlement should therefore consider the cost effectiveness, O&M cost, affordability& willingness to pay, sustainability of the selected option, effectiveness of the selected option for the particular context, robustness/durability & safe containment (during rain and flood events).

- ***Flexibility and adaptability***: the context offered by informal settlement requires flexible technical solutions that can be adapted to local context and future planning. For example, informal settlements are being developed through the provision of intermediary water and sanitation services in lieu and place of basic ones. So, technical solutions should be designed in such a way that the transition from rudimentary level of service to the intermediate or full service should be as smooth as possible.

- ***Functionality:*** the technical solution for informal settlement should be reliable and operational at all times. The accessibility and location should be made easy for all users; the components of the system should be locally available and lastly the technology should be easy to operate and maintain and service during its productive life.

- ***Elegance and aesthetic***: while planning to deploy a technical sanitation solution to an informal settlement, we should consider the elegance (referring to internal and external appearance, aesthetic, attractiveness, pleasance and comfort) as most of informal settlement communities prefer flush toilets as a suitable option.

- ***Resource recovery***: all components of urban water (drinking water, wastewater, storm water including solid waste) could be viewed as economic goods and their proper handling and utilisation has cost implications. As much as costs are incurred in managing them, recovery plans must be incorporated. It is therefore important to embrace a holistic view of integrated waste management to reduce costs of operation

and to maximise benefits by exploiting the opportunities for reclamation and reuse. Some of the resources that can be tapped from waste streams include energy (from solid biomass and liquid waste) and nutrients (phosphorus and nitrogen).

- ***Economic*** (in terms of cost, O&M, manufacture, etc.)*:* the sanitation technology should be viable in terms of its cost, O&M. In addition, it should not be beyond the capability of local service providers or user to supply or operate the facility.

These findings were confirmed and validated during the stakeholder workshop (refer to appendix B) during which additional drivers were presented. In view of the large number of drivers presented and argued as being relevant to the informal settlement sanitation innovations, it was decided to consider only those drivers having a technical connotation while others are being used to develop the technology assessment framework.

3.4.3 Classification of drivers

The analysis of these drivers in the light of the sanitation challenges and innovation proposals /solutions discussed in the previous section suggests that drivers for sanitation innovation can be categorised as general or technical.

- **General or primary drivers** refer to a category of drivers that may describe the status or condition of the sanitation within the settlement and other general factors. This category of drivers emerges from social, economic and institutional issues. It should be noted that these general are a translation of the impacts of the sanitation challenges issues, and are in most of cases apparent. It can reflect immediately on the conditions of the sanitation solutions.

- **Technical drivers** refer to the category of drivers that may impact directly into the functioning of the sanitation; these drivers are referred as approach, method or process used to respond to the general drivers with the view to find a solution.

Therefore, for the purpose of this research it was decided to focus on technical drivers while general drivers were used to develop the technology assessment framework for assessing the relevance of the proposed sanitation solutions.

a) General or primary drivers

As indicated previously, the key factors leading to the formation of informal settlements are related to the long term failure of government to implement structural plans to enforce development control and provide adequate infrastructure, in-migration, poverty and lack of income, etc. The analysis of these factors suggested the following general drivers as related to the sanitation solution innovations in informal settlements:

- Poverty and Affordability: the level of income should be considered as it may influence the affordability of the sanitation in a particular context;
- Density and Access: impact on the access to sanitation and should be regarded as key determinant factor;

- Dynamic of the settlement (mobility): may have impacts on the sanitation in terms of investment;
- Political interference – political support should be in place to ensure the buy-in of the innovation;
- Disorganise landscape – the nature and conditions of the settlement should be considered;
- Social and cultural disparities – users' needs and cultural differences should be addressed;
- Inadequate education level – the innovation should consider the level of education of users in terms of understanding the operational requirements;
- Unequal access to available resources – available resources should be assessed prior to develop a sanitation solution;
- Negligence, vandalism and theft – the innovation should consider these issues as their impacts may be damage severely the sanitation solution;
- Sanitation being a least priority – user intention and demand should be assessed and addressed; hence the sanitation solution should take cognisance of this issue;
- Lack of accountability – the innovation should be developed in such a way that the lack of accountability does not affect the functioning of the sanitation;
- Money market: the development of sanitation systems may be considered as a business opportunity rather than a service that needs to be provided to needy users;
- Safety (for certain user groups): since informal settlements have history of violence, vandalism and offer an insecure environment, the safety of user is believed to enhance adequate use of the facility;
- Economic benefits: this driver was found to be disputable as most of services provided to informal settlements are free. The economic benefit of the sanitation technology in this context is often nil for the service providers, while benefiting on the designer/manufacturer or vendor;
- Local employment opportunities: this driver may be applicable only if the service provider provides opportunity for local (users) to undertake certain tasks to keep the facility in good working conditions. With the current drive of outsourcing service providers for the O&M of these facilities, this driver may be disputable and its application may be context based.

These general drivers are considered as primary as it occur naturally. These primary drivers have other ramifications that should be explored further. For more details regarding the general drivers, refer to the role-players workshop (appendix C).

b) Technical drivers

Following the identification of general drivers, role-players suggested the following drivers related to the technical capabilities of the sanitation solutions:

- Cost of the facility;
- Local decentralised: decentralising the sanitation systems may provide easy control, maintenance and accessibility while generating resources and local employment for local users;

- Extent of operation: this defines the types of technology and its reliability in terms of use;
- Maintenance cost: defines the types of technology to adopt and its context of use, level of service provision and investment return;
- Environmental protection: zero waste generation;
- Beneficiation: generating resources from waste;
- Cost of O&M and construction;
- Rapid and easiness of treatment of human excreta.

These technical drivers were found to be context specific and related to the type of innovation solutions. These drivers were found to be related to the key functional elements of the sanitation.

c) Prioritisation of drivers

The drivers for the development of sanitation technologies are prioritised according to:

- Their attribute and adequacy in responding to the sanitation problem
- Their impact on the general informal settlement environment

Since the development of sanitation technology required an understanding of the sanitation problem and innovation trends occurring at local and international levels, it is advisable to consider both user and municipal views when prioritising drivers. Users as a primary beneficiary should have say with regard to what they consider as a priority. This will determine the level of awareness and how they consider sanitation. Municipality as a service provider should also prioritise drivers considering some key aspects such as budget, extent of O&M and general settlement patterns. The business (referring to sanitation manufacturer, seller and contractors) and engineer may not have suitable opinion in this regard given their focus. Their opinion may be considered only if there is a rationale behind the selection of some of these drivers. There should be evidence of prior investigation showing their involvement with users and municipal officials to determine the needs.

The selection criteria for prioritising these drivers are mainly:

- ✓ The nature and relevance of the driver (in relation to the sanitation problem)
- ✓ The extent by which the driver play is solving the sanitation problem
- ✓ The alignment of driver with the core aim of the sanitation
- ✓ The innovative character of the driver (with reference to the sanitation problem)
- ✓ The focus of the driver

Drivers in this context were prioritised using these criteria while considering the grouping discussed in section c) above (technical and general). Despite requesting stakeholders to differentiate technical and general drivers, it was observed that the group, especially those with social background, still persisted to not dissociate drivers according to the suggested grouping. According to them, the most influential drivers in order of priority are:

- ✓ Health and environmental protection
- ✓ Convenience (elegance, accessibility and suitability for all users group)
- ✓ Effectiveness and adaptation to local physical conditions (upgradability)

- ✓ Low operation and maintenance costs
- ✓ Sustainability (economic benefit – energy generation, resource recovery, reuse, local business and job opportunities)
- ✓ Water conservation

In contrast, the engineer and municipal official groups agreed that the proposed grouping was relevant to the context of informal settlements and suggested the following order of priority:

- ✓ Operation and maintenance cost
- ✓ Beneficiation (resource recovery)
- ✓ Water conservation
- ✓ Effectiveness and adaptation to local conditions
- ✓ Convenience (which include health and environmental protection)

Given the difference of views between the social and technical groups, it was suggested to characterise the identified drivers (regardless of their order of priority) by assigning indicators (that can be used to identify each driver). It should be noted that some drivers such overcome the impacts of climate change, rate of urbanisation scale of use and uptake were considered not relevant in the context of informal settlement by the role-players despite being a topical issue. However, it is believed that these drivers should be considered in the light of the current changing environment and dynamic around informal settlement and the physical conditions of the soil and the number of unused or failing sanitation technologies.

Table 4: Drivers and related indicators

Drivers	**Category of Indicators**	
	General	**Technical**
Health and environmental protection	- Odour/smell, - No illness,	- No indication of pollution (spillage, leaks, blockages, overflowing, etc.);
Convenience (elegance, accessibility and suitability for all users group):	- Attractiveness, - Comfort, - User satisfaction, - Time of use;	- Accessibility, - Location,
Effectiveness and adaptation to local physical conditions (upgradability	- Usage, - User perception, - Extension,	- Robustness, - Location, - Handling, - Connection - Design,
Low operation and maintenance costs	- Reliability and availability, - Period / time of use;	- Functioning, - Cleanness - No major breakdown,
Sustainability (economic benefit – energy generation, resource recovery, reuse, local opportunities	- Robustness, - User perception, - Accessibility, - User ratio,	- Functioning, - O&M - Cleanness, - Treatability and reuse
Water conservation	- Reuse	- No leak, - Less or no water use

The reluctance of the group to classify drivers according to the two categories (technical and general) was attributed to the fact that the group in general believe that the general drivers have strong influence on the technical drivers. Further, the groups added that general drivers can be used as assessment criteria as it can give an indication of the applicability or relevance of the technical drivers in a given context.

d) Drivers and emerging components

Given the reluctance of sanitation role-players to classify drivers according to the two major categories (referred as general and technical) and knowing that the drivers for sanitation are related to the sanitation components, it was found important to associate relevant component(s) to each of the identified drivers (table 5 below). The assignment of the components to each the driver identified was intended to inform the development of the sanitation solution (discussed later in this report). These drivers (as presented in table 6) are attached to the components of the sanitation solutions in a general manner – and each of these components may have various sub-components depending on the context.

Table 5: Drivers and related components

Drivers	**Solution – General component**
○ Reduction of FS volume ○ Zero waste generation ○ Reuse and Resource recovery ○ Safety (health and environmental protection) ○ Reduction of FS volume	Treatment (on or off-site) Reuse
○ Health & environ. protection ○ Job creation	Treatment and disposal (on or off-site)
○ Zero waste generation ○ Energy and nutrient recovery	Treatment and reuse (on or off-site)
○ Poor physical sites characteristics ○ Cost recovery (through reuse)	Toilet and containment
○ Space availability ○ On-site treatment ○ Cost of transport ○ Health risk & environmental protection ○ Cost effectiveness (O&M)	All components
○ Water conservation ○ Low cost O&M ○ Robustness	Toilet
○ Health risk & environmental protection ○ On-site treatment ○ No energy requirement	Containment Treatment (on or off-site)

It should be noted that each of these components may be designed differently to respond to the specific context of a particular case study. Taking the example of water conservation, a toilet facility can be designed taking into account the water scarcity status of South Africa. Hence, a toilet facility (equipped with a squatting or sitting pedestal) can be waterless, can use micro-flushing or low flush device. The design of the components should be based on the local conditions (with reference to the sanitation problems) in addition to being related to drivers.

3.4.4 Drivers for innovative sanitation solutions

The stakeholder workshops have indicated that drivers for the development of sanitation solutions are derived from various motives. During these workshops, stakeholders identified various drivers ranging from health and environmental protection to the money market. The level and value of each driver suggested were context based and dependent on each individual. A key lesson emerging from the workshop suggests that drivers are chosen according to the level of knowledge and awareness amongst stakeholders and more specifically their understanding of the sanitation problems.

Having identified and grouped drivers, and referring to the sanitation problems and innovation trends and solutions, an analysis of various drivers was conducted to determine and select drivers holding potential and applicable to informal settlements. For the purpose of this study, the research team decided to select rapid treatment, operation and maintenance and beneficiation from the list of drivers identified by stakeholders. These drivers were selected mainly for relevance in most of informal settlements with specific reasons:

- *Rapid treatment of human waste*

Informal settlements are characterised by high density of a large number of inhabitants over a small space that is usually unsuitable for housing. As per constitutional obligations, basic water and sanitation services should be provided to sustain the life of those living in these informal settlements. However, various constraints such as access, physical characteristics of the settlements and lack of other essential infrastructure can make provision more difficult than expected. Conventional sanitation solutions may not be suitable, hence alternative solutions that consider on-site treatment and rapid treatment of human excreta can adequately respond to these issues.

- *Operation and maintenance*

Several studies (Lagardien et al., 2009; Mjoli, 2009; Still, 2009) have indicated that the O&M is one of the causes of failure for number of sanitation solutions especially those provided to informal settlements. Given the ratio of users to facilities the imbalance is apparent. In some case, over 120 users share one facility where a ratio is estimated to be 1:50. In these conditions, frequent breakdowns should be expected, thus making the O&M crucial as an activity intended to ensure adequate functioning of the facility. With reference to expected breakdowns, O&M requirements should be as minimal as possible given the lack of available and dedicated budget for this purpose.

- *Beneficiation (energy recovery and reuse)*

The review of local and international sanitation innovation solutions has pointed to resource recovery and reuse as key trends toward achieving sustainable sanitation solutions. Given the lack of disposal infrastructure, access and cost of transport, etc. and considering the nutrient values of human excreta, beneficiation emerges as key driver that is worth being pursued as the reuse of treatment human excreta can contribute to job creation, food security while reducing to a large extent the environmental pollution and health risks associated with unsafe sanitation practices.

In the context of this study, these drivers are believed to cover all types of informal settlements. The concepts to be developed will be related to these drivers and the examples provided can be customised to other areas.

Summary

It is recognised globally that informal settlements often develop on land unsuitable for housing purposes and in most of cases lack basic infrastructure such as water and sanitation. The lack of these basic services is often associated with poverty, lack of governance, negligence and other issues that have direct or indirect impacts on the wellbeing of the communities and the service provision. The sanitation problems in informal settlement are multi-dimensional, ranging across social, institutional and technical aspects. Inadequacy of the technology provided relates to lack of alternative technology, poor design, use ratio, the service provision approach, limited technologies appropriate to the settlements conditions, operational dysfunction where basic service is available, lack of O&M plan and guidelines.

In response to these challenges, municipalities have attempted to provide sanitation services by implementing various sanitation technologies and solutions. Despite these efforts, many have failed while others have succeeded. The failure is often attributed to poor management, inadequacy of the solution provided, lack or inadequate O&M, etc. Factors underlying success are often related to the level of community awareness and organisation, adequate design (that consider the local conditions), O&M, etc.

Given the growing number of people living without adequate sanitation, designers and engineers have developed alternative innovative solutions. These innovative solutions emerge from lessons learnt from success or failure of existing sanitation solutions and to some extent the sanitation challenges occurring in informal settlements. The innovative solutions suggested are related to the treatment and use of human excreta, water conservation, and environmental protection with more emphasis on beneficiation, rapid treatment of excreta for reuse, micro-flushing (water conservation), low O&M costs, conversion of human excreta into reusable energy, etc. while considering business opportunities that may emerge from the collection, transport, treatment or reuse of waste products (such as energy and fertilisers).

The idea behind the development of innovative sanitation solutions was to respond to sanitation challenges through the provision of alternative. The discussion with sanitation role-players reveals that drivers for developing innovative sanitation solutions are mainly motivated by health and environmental protection, money market, beneficial use of human excreta, low cost technology affordable to all, operation and maintenance cost, water conservation, etc. These drivers can be grouped into two broad categories namely general or primary and technical drivers related to the given conditions of the settlements and the functioning of the sanitation.

For the purpose of this study, drivers for sanitation innovations are technical (O&M, reuse, zero waste generation, portability, low cost O&M, etc. while density and environmental protection emerged as general drivers. These drivers were further clustered into functional facility and

components innovation (based on the focus of the research) and further discussed in section 5.10.

4. Approach towards developing sanitation concepts and solutions for informal areas

4.1 Overview of sanitation concepts

The aim of sanitation is to ensure that human excreta and greywater are disposed in an environmentally sound manner which is not harmful to both human and the general environment. In the past the occurrence of various sanitation related diseases prompted communities to develop various concepts intended to protect themselves against disease. Bearing this in mind, various concepts including the conventional waterborne sanitation concept and related alternatives emerged. These concepts were designed assuming that human excreta and greywater should be moved from the source where it is generated to another place where it can be disposed without impacting on human health. Overtime, it was found that the conventional sanitation concept just moved a problem from one place to another and the cost of related operation and maintenance was high and unaffordable for developing countries.

The failure of the conventional sanitation concept opened ways for alternative concepts including mobile sanitation, ecological sanitation, waterless sanitation, closed loop and many more. Broadly speaking, the intention behind the development of these alternative concepts was mainly to respond to the failure of the conventional sanitation concept and proposing a simple, low cost and affordable concept that could respond to the aim of the sanitation (Tilley et al; 2007).

There is a great need for sanitation practitioners to plan with a more holistic perspective, by considering the sanitation problems and response within the settlements and the sanitation chain in order to come up with an overall sanitation concept. A holistic perspective includes components such as technical, (socio-) economic, institutional and financial feasibility studies, consultation with the users in which the whole life cycle of different sanitation options are presented and discussed, quality assurance during implementation, and ongoing institutional support during the O&M phases.

Since the design of the conventional sanitation concept was based on assumptions that resources are unlimited (despite belief by certain scholars as appropriate solution for a particular problem) and the waste produced from the resources at household is only suitable for disposal in the environment where it could be assimilated by nature, the development of alternative~~s~~ sanitation concepts is becoming increasingly indispensable for both economic and ecological reasons.

The literature outlines various concepts that have been developed following the failure of the conventional waterborne sanitation concept (especially in developing countries). Some of these alternative concepts include “Don’t mix – faeces, urine, water concept” of Uno Winblad (1997), “closing nutrient and water cycle concept” (Esrey et al., 1998) and decentralised communal managed systems to name few, etc. Most of these alternative concepts are based on resource recovery principles, water conservation or decentralised nature of operation and maintenance

and, have their merits. However, their application in informal settlement contexts has not yet been proven and may be subject to various constraints presented by each unique environment.

4.2 Drivers for development of sanitation concept

The development of alternatives sanitation concepts is mainly intended to respond to several sanitation challenges, failure of conventional sanitation concepts and needs to develop alternative low cost and viable solutions (Roy, 1984) that can be applicable in difficult contexts including informal settlements. On the basis of these facts, new sanitation concepts (see appendix C) have been developed and made available for choice. However, drivers for developing these concepts vary according to the individuals and their motivation. Drawing from our interaction with different sanitation practitioners, it appears that drivers for the development of the sanitation concept are similar to those used for developing innovative sanitation solutions. These include for example development of alternative solutions, reduction of O&M cost, money market, reduce waste through resource recovery and energy generation and water conservation.

It emerged from the interaction with sanitation practitioners that sanitation innovations and solutions are being developed without any elaborated concept as most of them were unable to provide or explain the link between the innovative sanitation solutions and the concept or how their proposed solutions are being developed. Sanitation practitioners often pointed to failure of the conventional sanitation concept, protection of human health and environmental and the need to attain hundred per cent sanitation coverage as key drivers for developing alternative sanitation concepts. However, they were unable to indicate neither the way the sanitation solutions are being developed nor the concepts that were used, despite revealing some of the drivers for the development of sanitation concept. A clear and documented approach for developing the sanitation concept and solutions was lacking, hence prompting the need for developing one.

4.3 Approach for developing sanitation concepts and solutions

The development of a sanitation concept is a pre-requisite for developing technical sanitation solutions. Without adequate concepts the possibility of developing appropriate technical sanitation solutions is reduced substantially. The concept is understood as a guiding tool that should drive the development of sanitation solutions that are appropriate to a specific context. This implies that the concept must be established prior to developing sanitation solutions.

It is widely acknowledged that the conventional (waterborne) sanitation concept is not a suitable option for developing countries. An adequate sanitation concept is one that responds better to the sanitation challenges in a particular context and offers opportunities for innovation. The r Review of number of alternative sanitation solutions has shown that numbers of sanitation concepts being used are not relevant to informal areas and are lacking foundation. Therefore, drawing from the findings of this study, it was deemed important to develop an approach for developing sanitation concepts and solutions that can be adapted or customised to respond to a given context.

In this regard, various design theories were reviewed to identify key elements and pointers applicable to informal areas. The proposed approach evolves from the design theories suggested by Suh (1988) and Phal & Beitz (1993) used in engineering industry to design processes. This theory suggests stages that include identifying problems/challenges (from different perspectives) as a starting point and evaluate the responses to these problems/challenges; identify emerging innovation in terms of their relevance and assess and prioritise drivers for these innovations, to develop the concept. This theory was adapted by adding stages and key pointers to develop the approach presented below.

Table 6: Approach to developing technical sanitation concepts and solutions

Stages	**Key pointers**
1. Identify and assess the sanitation problem in context	1.1 Investigate and identify the sanitation problem 1.2 Outline the extent of the problem and its impacts 1.3 Identify the factors underlying success 1.4 Identify the causes of failure
2. Identify and evaluate existing technical solutions	2.1 Investigate and document the technical sanitation solutions 2.2 Investigate their advantages and disadvantages in context 2.3 Outline technical characteristics 2.4 Highlight the relevance to the settlement context
3. Identify and explore innovative solutions and emerging trends	3.1 List current innovative solutions (at local and global levels) 3.2 Explore innovative solutions in terms of their relevance in response to the sanitation problems 3.3 Evaluate innovative solutions and select those responding to the sanitation problems (in a particular context)
4. Identify and evaluate drivers for the development of the sanitation	4.1 Identify drivers for the development of sanitation solutions 4.2 Cluster drivers (into technical and general) 4.3 Evaluate each driver according to its importance and relevance 4.4 Select drivers that hold potential according to their relevance
5. Select and prioritise drivers appropriate to the settlement context	5.1 Select a group of drivers (technical or general) 5.2 Assess each drivers in terms of its value and relevance 5.3 Rank drivers according to their value and relevance
6. Develop the sanitation concept based on prioritised drivers and innovative solutions	6.1 Match the drivers to the corresponding innovative solutions 6.2 Assess emerging concept in terms of its response to the sanitation problem 6.3 Evaluate each concept in terms of relevance to the settlement context
7. Identify the technical sanitation solutions	7.1 Assess the concept to identify its characteristics 7.2 Use the characteristics of the concept to determine the components of the sanitation solutions 7.3 Assess each components (in terms of its relevance) to identify the technical sanitation solutions
8. Develop the sanitation technology assessment framework	8.1 Select the general drivers identified previously (section 5.1) 8.2 Examine each general driver in term of relevance and applicability 8.3 Assign indicators to each driver
9. Develop the model based on the selected option	9.1 Consider the functional elements (components) of the sanitation option 9.2 Outline the requirements of each components 9.3 Assign features to each components 9.4 Build the model based on the components and their requirements

Drawing from this theory, a draft working document (presented in table 6 above) was developed and discussed during the stakeholder workshop (see appendix C). The draft working

document suggests that the development of the sanitation solution (regardless of the approach and process used) should take into consideration the following stages:

4.3.1 Identify and assess the sanitation problem

Sanitation solutions are developed in response to number of issues and problems that should be identified prior to decide on the approach or process that should be used. To achieve this, the approach suggests investigating and identifying problems related to sanitation and their extent and assesses the conditions of existing solutions (where applicable). The assessment of the conditions of existing solutions should focus on the factors that contribute to the success and causes of failure in order to draw lessons and find the way forward. Identified sanitation challenges should be grouped into two categories namely technical and general (include social, institutional and economic). The general challenges will constitute the technology assessment framework while technical challenges will be used to inform innovation solutions.

4.3.2 Identify and evaluate existing technical solutions

Having identified specific problems, the approach suggests that identifying and evaluating the existing sanitation solutions, by outlining their advantages and disadvantages as well as their technical characteristics and their relevance in terms of response to the sanitation problems identified should follow. Evaluation of existing sanitation solutions provides additional information related to the success and failure and direction for issues to be addressed.

4.3.3 Identify and explore innovations solutions and trends

Prior to developing any solution, it is advisable to review and explore existing solutions to identify their uniqueness and trends. Doing so will assist designers or manufacturers to understand local and global trends in sanitation and to align with other endeavours. This can be achieved only by identifying and listing the current innovation solutions and trends (at both local and international levels), explore their potential in terms of uniqueness and feasibility in the context of informal areas. Further, the guidelines suggest that selected innovation solutions and trends should be analysed using a matrix – by matching each to the sanitation problems.

4.3.4 Identify and evaluate drivers for the development of the sanitation

During the workshop, it was agreed that drivers for development of sanitation solutions are of various motives. Some of these motives were found to be irrelevant to the sanitation problems and not responding to the aim of the sanitation (example of money market). Bearing this in mind, the approach suggests that drivers should be identified and grouped according to their specifications (referred as general or technical). Technical driver refers those related to the functioning of the sanitation while general drivers refer to evaluation criteria and indicators. These drivers can vary from one settlement to another and should not be generalised to all informal settlements.

Each driver should be evaluated based on certain criteria including relevance to informal settlement conditions and sanitation technology option; ability to address or respond adequately sanitation challenges specified for a particular context.

4.3.5 Select and prioritise drivers appropriate to the settlement context

Since several drivers have been identified, the guideline suggests selecting only those holding potential in terms of responding to the sanitation problems. For the purpose of this study, only drivers related directly to the functioning and components of the sanitation solution are selected. Drivers should be selected according to the context of the study, prioritised according to their values and ranked accordingly. It should be noted that prioritisation and ranking may be case specific as related to the sanitation problems.

4.3.6 Develop the sanitation concept based on prioritised drivers and innovation trends

A concept is defined as a general idea that corresponds to some characteristics and features (Wikipedia, 2013). It is broad ideas based on observation of real phenomena or problems with the intention to respond to certain issues. Bearing this in mind, the approach suggests that the development of the concept should first consider matching the prioritised drivers to innovative sanitation solutions. As suggested by the approach the grouping of innovative sanitation solution and related drivers will constitute the concept that should be assessed in terms of responding to specific sanitation problems and relevance to particular informal settlements. This implies that to each innovative sanitation solution is attached a number of drivers clustered according to their priority order (as indicated in section 4.3.5) to develop a sanitation concept.

4.3.7 Develop sanitation solutions

Technical sanitation solutions are developed by assigning to each sanitation concept relevant innovative solutions. To each innovative sanitation solution key components (toilet, containment/conveyance, treatment, reuse or disposal) are assigned as applicable. The emerging combination constitutes technical sanitation solutions.

It should be noted that from one concept several solutions can be developed encompassing a technology, a process or an approach that can be used to respond to specified sanitation challenges. The emphasis is to ensure that the proposed solution is sustainable, user friendly or low cost.

4.3.8 Develop the sanitation technology assessment framework based on local conditions

Access to water and sanitation entails the provision of technologies that are reliable and responsive to user needs. A study by Lagardien et al., (2012) of user acceptance and functioning of communal mobile sanitation facilities suggested that sanitation technologies should be assessed to ensure their suitability for each given context. The assessment should be undertaken at planning, implementation and post-implementation phases using certain criteria (Lagardien et al; 2012). These criteria are various and range across social, institutional, economic, environmental and technical perspectives.

In this study, it was pointed that sanitation issues covered under technical perspectives should be used to develop sanitation solutions while remaining issues (referred as primary or general drivers) constitute the technology assessment framework. In this regard, many drivers were identified and their relevance assessed (appendix C); further, indicators were assigned to each of these criteria to develop a technology assessment framework.

For the purposes of this document, each criterion is accompanied by simple and easily interpretable indicators. The indicators will allow planners and end-users to describe the technical, social, financial requirements as well as the impacts and benefits obtained by application of a sanitation system. Table 7 below presents general drivers, criteria and their relevance and indicators used during a process of assessing sanitation solutions based on those issues which strongly affect the choice of sanitation.

Table 7: Example of a sanitation technology assessment framework

Drivers	Criteria	Relevance	Indicators
Convenience	User satisfaction	A sanitation facility should provide certain level of convenience to users; this will enhance the acceptance and adequate functioning (Lagardien et al., 2012)	- comfort - personal security - privacy/dignity - smell - noise - attractiveness/ status
Appropriateness	Adequate design	A sanitation facility solution should be appropriate to local conditions and users groups	- location - accessibility
Job creation	Employment opportunity	Job opportunities should emerge from the O&M of	- community involvement - income generation
Money market	Business opportunity Income generation	Business opportunities should emerge from the sanitation solution	- local business - income generation
Affordability	Number of facilities Access to sanitation	Sanitation solutions should be affordable in terms of costs and O&M	- access - number of facilities - cleanness
Health and environmental protection	Attractiveness	Protection of human health and environment	- odour - smell - no indication of pollution
Reliability	Adequate functioning	Sanitation solutions should function at all time	- continuous access - no signs of breakage or leaks
Safety	Access Security	Safety of users	- no theft or vandalism - no report on violence

The final choice of sanitation solution to be implemented will be the decision of the users and planners who will select those parameters relevant to their community's profile and local conditions from the given set of criteria. Furthermore, it is open for the decision makers to select a rating system that better suits their local framework. It should be noted that this framework is not prescriptive; additional drivers and criteria may be developed and incorporated depending on local conditions.

4.3.9 Develop models for further discussion

The models consider the functional elements (components) of the sanitation option developed in section 4.4.6. To each of these components is assigned features based on the operational requirements. The models are built by outlining each specific component, its features and provide an outline of specific operational requirements.

Summary

Sanitation concepts are based on broad ideas that have emerged from the observation of a given situation. These ideas can be translated into a concept only by matching existing or available innovations or solutions to the drivers that address these problems. In so doing, concepts are being developed.

Review of available literature and interviews with various sanitation role-players provided an indication of the level of understanding of the sanitation concept. From this review and interviews, various sanitation concepts (different from the conventional) were identified. However, there was no evidence of an existing tool that could be used to guide designers, engineers and other sanitation role-players to develop the sanitation concept. Further, none of the sanitation role-players interviewed was able to explain how their sanitation solutions were developed nor the concept used and the context of its application.

Bearing this in mind, a draft approach for developing sanitation concepts and solutions was developed. This approach outlines steps that to guide designers and engineers in developing adequate sanitation solutions. Through this approach, various sanitation concepts were developed by matching the innovative sanitation solutions to relevant (prioritised) drivers.

For the purpose of this study, the beneficiation, water conservation and decentralisation – low cost sanitation concepts were selected based on their potential to address the sanitation problems in informal areas. These concepts are explored further in the next chapter and used to develop sanitation solutions and models.

5. Development of technical sanitation solutions for informal areas: Illustrative example

This section of the report outlines the development of technical sanitation using the approach discussed in the previous section. Three case studies namely Pook se Bos, Masiphumelele 1 and Enkanini were selected and used to illustrate the sanitation problem, examine existing sanitation solutions and develop sanitation concepts and solutions as well as models.

5.1 Sanitation problems

The first step suggested in the approach was to investigate the sanitation problem, its extent and document failure and success of sanitation interventions. To do so, we decided to investigate each of the case studies indicated above. Outcomes are presented below.

a) Investigate and identify the sanitation problem

The sanitation problems encountered in each of the case studies were different and context-based. Each of these problems was investigated from general and technical perspectives. The general perspective covered social, institutional, and economic issues while technical perspectives covered issues related to the functioning of sanitation technologies.

Table 8: Identified sanitation problems at case study settlements

Pook se Bos	Masiphumelele 1	Enkanini
High density (overcrowding) Poverty Limited access (use ratio of 1/40) Inaccessibility to settlement Poor housing – low income Location of the facility Collection of faecal sludge Drying of faecal sludge Disposal of faecal sludge Night soil disposal Greywater disposal High water table (humidity)	High density (overcrowding) Poverty Limited access (use ratio of 1/70) Inaccessibility to settlement Poor housing – low income Frequent blockages Night soil disposal Greywater disposal High water table (humidity)	High density (overcrowding) Poverty Limited access (use ratio of 1/80) Inaccessibility to settlement Poor housing – low income Location of the facility Frequent blockages Misuse/vandalism/theft Night soil disposal Difficult physical site conditions

b) Outline the extent of the problem and its impacts

The problems encountered at all three case studies have certain impacts on the functioning of the sanitation technologies. For example, high density and overcrowding create limited access to sanitation services for many people, thus causing a reversion to use of buckets (night soil) or adopt open defecation. From a technical perspective, lack of adequate O&M, difficult access to the site and misuse severely impacted on the functioning of the sanitation technology.

c) Identify factors underlying success and causes of failure

Factors underlying success of sanitation solutions at each of the case studies were identified through interviews with different sanitation role-players. These factors were found to be related to the technology in terms of the operational requirements and management (see table 9 below for details).

Table 9: Factors underlying success and failure of sanitation solutions

	Pook se Bos	Masiphumelele 1	Enkanini
Success	Adequate management (caretaker) Compliance with operational requirements Regular O&M and M&E Continuous awareness campaign Safety of user Positioning of the facility Provision for night soil disposal	Predefined number of users Zone of the area (per facility) Community monitoring	Robustness of the facility Adapted design (of the facility) Zoning of the area (per facility)
Failure	Lack of greywater disposal Increasing number of users Misuse over weekends Night soil hamper drying process Saw dust not enhancing drying of faecal sludge Difficult handling of faecal sludge Difficult transport and disposal of faecal sludge Air pollution during mixing and transposing of faecal sludge	Misuse Vandalism Theft toilet seat and drainage pipes Frequent blockages Large number of users No dedicated facility for night soil disposal Infrequent O&M and M&E Bureaucratic management Lack of sense of ownership High water table during winter	Misuse Vandalism Theft toilet sit and drainage pipes Frequent blockages Large number of users No dedicated facility for night soil disposal Infrequent O&M and M&E Bureaucratic management Lack of sense of ownership

Table 9 shows that the success of sanitation solutions is limited to management and compliance with operational requirements. Failure in contrast has many underlying factors which can be technical, social or institutional. Both success and failure have certain impacts on sanitation services and should influence the development of innovative solutions.

5.2 Existing sanitation solutions

This stage of the framework requires identifying existing sanitation solutions in place, assessing the performance (or functioning), outline technical characteristics (meaning operational requirements) and examine their relevance to the case study site. Each of the case study sites was provided with different sanitation technology. Pook se Bos has MobiSan – a communal dry sanitation, while Masiphumelele and Enkanini are provided respectively container toilet and waterborne full flush communal sanitation systems.

- MobiSan

MobiSan (figure 6 below) is a portable dry sanitation facility that was developed by Vitens (a Dutch company) and implemented in Pook se Bos with the support of the city of Cape Town

officials. This technology has been developed to respond to number of sanitation issues related to land tenure, accessibility, lack of water and sewer networks, etc. MobiSan comprise toilet facility, urinals, handwash basin, night soil disposal; containment (two chambers underneath for raw and treated faecal sludge), and a mixer. This technology is relevant to settlements where the water table is high, not flood prone and can serve as emergency sanitation solution (Castellano, 2011). However, its operation requires continuous users' awareness, regular O&M and M&E as well as aeration and use of products such as saw dust to enhance the drying of faecal sludge.

One of the challenges of this sanitation solution is related to the drying, handling, collection and disposal of faecal sludge. This may require the use of drying agent such as saw dust, aeration while handling and transport may not possible if access to the settlement is not guaranteed.

Figure 6: MobiSan unit

- Container toilets

This type of sanitation comprises a block of standalone toilet units fitted with a removable container (removable 100 litres plastic bucket) installed in a concrete cast superstructure containing 10 litres of chemicals (to neutralise odours and dissolve human faeces). This type of sanitation solution requires frequent cleaning and removal of container contents. More often, the cleaning is done every two to three days which cannot control overuse, misuse and vandalism. In addition, the use of bulk anal cleaning materials such as newspapers, baby wipers and disposal of sanitary pads and nappies has contributed to the need for frequent emptying (see figures 7 and 8).

This sanitation solution remains a suitable option (according to Mels et al., 2008) for informal settlements situated in private lands, inaccessible areas and wetlands or flood prone lands. However frequent emptying; misuse and vandalism have made this option more expensive in addition to high O&M cost and not being children and disabled friendly.

Figure 7: View of container toilets (source: Mels et al., 2008)

Figure 8: Collection and transport of container toilets (source: Mels et al., 2009)

- Kayaloo

Kayaloo (figure 9) is a mobile sanitation unit comprising 10 full flush toilets connected to a sewer. Each cubicle measures approximately 1,2 x 0.9 m with own lockable outside door. The base infrastructure is made of steel tube with a galvanised corrugated iron roof. Each block of sanitation is equipped with standpipe and laundry point. The flushing mechanism is located between toilet in a middle closed compartment to prevent vandalism and theft.

Figure 9: Kayaloo sanitation facility (Source: Absolute ablution)

Kayaloo has been used for years in Kayamandi informal settlements where the municipality appointed a private service provider for the cleaning of facility. However, despite these arrangements, the main O&M tasks (such clearing blockage, replacing faulty parts or fixing

leaks, etc.) are undertaken by the municipal services. Due to high occurrence of vandalism and misuse, many facilities do not function properly.

Sanitation solutions provided at each of the case studies have their advantages and disadvantages. Their suitability is dependent on many factors include the level or extent of O&M and M&E, awareness amongst users and ability of the service provider to respond to issues related to the functioning of the facility. Improvement of sanitation services requires addressing negative issues outlined above to inform or inspire designers to develop solutions that respond better to the local context.

5.3 Innovative sanitation solutions

This stage of the approach suggests that before developing or proposing any innovative solutions, we should first investigate developed or proposed solutions at local and global levels. Once identified, these solutions should be explored to determine their relevance to specific sanitation problems, evaluate and select those holding potential. If not responding to the sanitation problem, the approach suggests building from existing solutions (that have been implemented) to develop new ones.

During the course of this research, the Bill and Melinda Gate Foundation (BMGF) innovative sanitation solutions (or proposals) were identified and discussed (see appendix A for details). The advantages and disadvantages of innovative sanitation solutions were explored to select and further evaluate those holding potential. Evaluation was based on the relevance and feasibility of each innovative sanitation solution to respond to sanitation problems and sustainability or implementation in informal settlement setting.

Table 10: Innovative sanitation solutions relevant to each case study

Case study	Innovative sanitation solutions/proposals			
Pook se Bos	Dehydration of faecal sludge	Easy and safe collection and disposal of human excreta	Conversion of human excreta	Zero waste and energy generation On-site treatment
Masiphumelele 1	Decentralised treatment Managed communal systems	Low O&M cost	Self-cleaning	Multipurpose Resource recovery
Enkanini	Micro-flushing	Low or no water consumption	High pressure – vacuum flushing	Self-cleaning Bio-solid treatment

5.4 Drivers for innovative sanitation solutions

Having identified current sanitation solutions provided to the case studies, this stage comprises: identify, cluster, evaluate and select drivers for developing sanitation solutions relevant to each context. It should be noted that drivers are categorised as technical and general as applied for each of the case studies.

a) Identification and clustering of drivers for the development of sanitation solutions

Drivers for developing sanitation solutions are variable and may differ from one individual to another depending on levels of awareness and knowledge regarding the specific sanitation problems and challenges as well as feeling and motives of business, money market or any other. Drivers for developing innovative sanitation solutions were obtained from interviews with different sanitation role-players and grouped (see table 11 below). These drivers are further discussed in the next section.

Table 11: Identified drivers for development of innovative sanitation solutions

Drivers	Pook se Bos	Masiphumelele 1	Enkanini
Technical	Access to the settlement Water conservation Adaptability/upgradability Mobility of the infrastructure Enhancing faecal sludge drying Cost recovery Resource recovery	Extent of O&M Access to the settlement Sustainability Reliability Operating cost Upgradability	High water use Water conservation Sustainability Upgradability Frequent blockages
General	Misuse Density (increase of users) Environmental protection Health risk Attractiveness /Elegance User friendly	Density (long queue) Misuse Environmental protection Health risk Attractiveness /Elegance User friendly	Density (long queue) Misuse Vandalism and theft Environmental protection Health risk Attractiveness /Elegance User friendly

b) Evaluation of driver according to its importance and relevance

Drivers are discussed according to their relevance. Opinions may differ regarding the relevance of these drivers depending on the level and understanding of the sanitation problems or the importance/value of the drivers in responding to the sanitation problems. For the purpose of this research, the relevance of identified drivers (table 12 below) emerges from the discussion with sanitation role-players. For more details regarding the evaluation of drivers see appendix B sections 4 and 5.

Table 12: Evaluation of drivers

	Drivers	Relevance
Technical	Access to the settlement	Lack of access may impact the collection, transport or disposal of faecal sludge
	Adaptability/upgradability	Sanitation solutions should be adapted to local conditions and upgraded in according to informal settlement changing environment (see slum upgrading programme)
	Mobility of the infrastructure	The mobility of infrastructure is important in areas where permanent infrastructure cannot be implemented and can serve as emergency sanitation system
	Enhancing faecal sludge drying	Faecal sludge contains pathogens and when dried, the amounts of pathogens is reduced, thus protecting human health and environment
	Resource recovery	Reduction of waste through treatment and reuse
	Extent of O&M	High cost O&M may render the technology useless
	Water conservation	To protect water resources by using less water as possible
	Cost recovery	To ensure sustainability
	Sustainability	To ensure that the facility remains indefinitely in good conditions
	Reliability	To ensure that the facility functions all time
	Operating cost	To be as low as possible to facilitate sustainability
	High water use	Reduce water use as much as possible
	Water conservation	Reduce water use as much as possible
General	Density (increase of users)	Ensure that the facility can accommodate large number of users
	Health risk	Protect human against disease
	Environmental protection	Protect the environment against pollution
	Attractiveness /Elegance	Internal and external look of the facility should attract users
	User friendly	Accommodate all user groups
	Misuse	Able to work all time despite misuse
	Vandalism and theft	Able to stand and function despite vandalism or theft

c) Selection of drivers according to their relevance

Drivers are selected according to their relevance in terms of the manner and extent to which it addresses the sanitation problems, all drivers outlined above are relevant to a particular context and are not generalised to all case study sites. Looking back at the sanitation problems discussed in the previous section, the following drivers were selected for each case study site:

- Pook se Bos: density, resource recovery, operating cost, extent of O&M, environmental protection, user friendly
- Masiphumelele 1: density, access to the settlement, extent of O&M, environmental protection
- Enkanini: density, access to settlement, misuse and vandalism/theft, high water use, extent and O&M cost.

As indicated above, density as one of the biggest challenges hampering the provision of sanitation services in informal settlement was agreed to be a leading driver in developing sanitation solutions due to impacts on access to the settlement, use, and extent of O&M, etc.

5.5 Prioritisation of drivers

Referring to innovative sanitation solutions (refer to table 10 above), drivers for their development were identified, discussed (refer to table 11) and grouped into technical and general categories. After this grouping, these drivers were evaluated (see table 12) in terms of their relevance and response to the sanitation problems in informal settlements.

Drivers are ranked according to their relevance and value at this stage. It should be noted that ranking is subject to many factors which include personal perception and feeling of the researcher, level of awareness and in depth knowledge of the sanitation challenges and may be subject to discussion and debate. The ranking suggested in the example below emerged from the field observation and discussion with municipal officials and informal settlement residents.

Table 13: Ranking of drivers for development of innovative sanitation solutions

Drivers	Pook se Bos	Masiphumelele 1	Enkanini
Technical	(1) Mobility of the infrastructure (2) Enhancing faecal sludge drying (3) Resource recovery (4) Cost recovery (5) Water conservation (6) Adaptability/upgradability (7) Access to the settlement	(1) Extent of O&M (2) Sustainability (3) Operating cost (4) Access to the settlement (5) Reliability (6) Upgradability	(1) Water conservation – High water use (2) Sustainability (3) Upgradability (4) Reliability (5) Upgradability
General	(1) Density (increase of users) (2) Misuse (3) Environmental protection Health risk (4) Attractiveness /Elegance (5) User friendly	(1) Density (long queue) (2) Misuse (3) Environmental protection – Health risk (4) Attractiveness /Elegance (5) User friendly	(1) Density (long queue) (2) Misuse and vandalism and theft (3) Environmental protection – Health risk (4) Attractiveness /Elegance (5) User friendly

From this table above, drivers are ranked according to specific sanitation challenges. For example, land tenure and increasing number of users were selected as key issues hampering sanitation provision in Pook se Bos; hence mobility of the facility was selected as priority driver. In other cases, the extent of O&M and water conservation are viewed as priority in addition to density.

5.6 Development of sanitation concept (s)

Sanitation concepts development was achieved through the application of the approach presented in section 4.4 above that suggested matching the prioritised drivers to innovative sanitation solutions. During the workshop, the sanitation role-players were requested to match the prioritised drivers to the corresponding and relevant innovations proposals or solutions. Through this exercise, several concepts (presented in appendix C) ranging from energy recovery and reuse to low operation and maintenance and water conservation emerged. Some of these developed concepts were general while others were found to be specific to the sanitation problem. In the context of this study, only concepts of relevance to informal

settlement sanitation problems were selected. The intention of this stage of the approach is to develop the sanitation concepts using the case study examples discussed above.

a) Match the drivers to the corresponding innovative sanitation solutions

Given the number of drivers that emerged it was decided to select only priority drivers for each case study and relevant innovative solution (from the appendix A) applicable to each context in order to develop the sanitation concept. From this combination, number of sanitation concepts emerged and those of relevance to each case study were selected (see table 14 below).

Table 14: Development of sanitation concepts

Case study	Driver		Innovative solution	Emerging concept
	Technical	General		
Pook se Bos	Mobility Resource recovery	Density	Rapid drying of faecal sludge Bio-processing Resource recovery (fertiliser)	Beneficiation
Masiphumelele 1	Extent of O&M	Density	Low cost O&M CB O&M	Community management
Enkanini	Water conservation	Density	Micro-flushing	Water conservation

- *Beneficiation (resource recovery and reuse)*

Global trends in the sanitation field move towards achieving zero waste by considering waste as resource, recovering energy from waste, and reusing waste products maximally. The beneficiation concept is based on the general understanding that waste contains useful nutrients that can be recovered and reused in a variety of ways. Given the large number of informal settlement dwellers and volumes of excreta and solid waste generated daily as well as other factors such as lack of access to the site, lack of electricity or other source of energy and disposal infrastructure, the beneficiation concept constitutes an adequate option.

Table 15: Development of the beneficiation sanitation concept

Innovative solutions	Prioritised drivers	Concept
o Bio-solid treatment & reuse; o Rapid dehydration o Easy and safe collection and disposal o Low O&M cost	o *Bio-solid treatment* o *Resources recovery and reuse* o *Safe handling of human excreta* o *Extent of O&M and costs* o *Water conservation* o *Upgradability and adaptability*	- Beneficiation : treatment and reuse of waste product

This concept was developed by considering the innovative sanitation solution proposals and prioritised drivers presented in the table 15 above. This concept is based on the idea that suggests that human excreta can be treated and used in various contexts to enhance food production or generate energy. While focusing on the treatment and beneficial use of the sanitised human excreta, this concept also addresses issues such as water conservation, O&M, upgradability and adaptability to the local contexts.

This concept can make use of both water and non-water reliant sanitation systems and the key components of relevance can be the toilet/collection conveyance or containment (depending on system), separation/treatment, disposal or reuse. Adopting this concept can:

- contribute to food security (through use of waste product for gardening)
- create jobs amongst informal settlement dwellers (collection, handling and transport of waste)
- generate energy that can be used for cooking
- reduce the volume of waste generated
- improve the life of informal settlement dwellers (safe environment)
- decrease the occurrence of sanitation related diseases and pollution

➢ *Decentralised and low operation and maintenance costs*

The failure of centralised sanitation as a concept has prompted designers to adopt alternatives. In recent years, the decentralisation concept has emerged as suitable in areas where access and space are key constraints. This concept was developed from a general idea that consider informal settlements as isolated areas lacking basic services, characterised by poor households, lack of access and difficult physical site characteristics.

Bearing this in mind, the concept is based on the assumption that decentralisation of the services (contrary to the conventional sanitation concept) can respond to these issues. Innovations trends and prioritised drivers sustaining this concept are presented in table 16 below. With reference to informal settlements, the decentralised sanitation concept can address:

- lack of space (density of the settlement, access, housing types)
- difficult physical site characteristics (topography, water table, etc.)
- number of users vs. number of facility

Table 16: Development of the decentralised – community managed sanitation concept

Innovative solutions	Prioritised drivers	Concept
o Decentralised treatment o Multipurpose o Resource recovery o Managed communal systems o On-site treatment	o *Decentralisation of services* o *Extent & cost of O&M* o *Sustainability* o *Adaptability & upgradability* o *Water conservation* o *Resource recovery*	- Community managed sanitation systems: CB O&M with technical support of the service provider (training, materials and equipment)

The concept of decentralisation associated with low O&M can also further address the issues associated with high cost of O&M, job creation, reuse and localised management of the sanitation facility as whole.

These three concepts were further discussed in the light of the sanitation problems to select those holding potential and determine their relevance in the context of informal settlements. Analysis suggested that the proposed concepts are context based and not one size fits all. Relevance to a given context should be based on certain factors including the settlement patterns, the level of service to be provided, the availability of the options, the level of awareness (with regard to the sanitation problems) amongst users and the way municipal

officials consider the sanitation matters and their impacts on the general public and environment.

- *Water conservation and resources protection*

Water should be considered as scarce resource that should be used sparingly and protected in South Africa, classified as 30st driest country in the world with an average rainfall of 450mm per year. The basic services provided by municipalities that include water, sanitation and other services have been criticised mainly due to the lack of accountability amongst beneficiaries. In informal settlements for example, vandalism, theft, misuse of these services (especially water) have been widely reported.

In view of this alarming situation, a sanitation concept based on water conservation and environmental protection can respond much better to relevant issues in informal settlements, summarised as follows:

- reduction of greywater flow
- decrease of environmental pollution caused by greywater
- reduction of water consumption for sanitation (conservation of water resources).
- reduction of ground water contamination

Table 17: Development of the water conservation sanitation concept

Innovative solutions	Prioritised drivers	Concept
o Low or no water consumption Micro-flushing o High pressure – vacuum flushing o Self-cleaning o Energy generation o Zero waste generation	o *Water conservation* o *Zero waste generation* o *Resources recovery & reuse* o *Robustness, effectiveness & suitability to local physical conditions* o *Operation and maintenance* o *Upgradability & adaptability*	- Water conservation: less or no water use; vacuum flushing

In addition to water conservation, this concept addresses issues related to the O&M, water use mechanisms, zero waste generation, robustness of the system and upgradability as relevant where the land tenure and upgrading of current services are on the agenda. Hence, any concept addressing these issues can be of relevance to informal settlement. Further assessments were undertaken to determine the relevance of each selected concept in order to determine the key components of sanitation solutions. With reference to the study's aim, it was decided to explore the developed sanitation concepts (table 17 above) and select those responding adequately to the sanitation problems in informal settlements.

For the purpose of this study, beneficiation, low operation and maintenance cost and water conservation were selected as key concepts to be discussed further and used to develop the technical sanitation solutions. The rationale for the selection of these concepts is provided below.

b) Assessment of developed concept

This assessment was intended to understand the way the developed concept addresses the sanitation problems and to examine the relevance to informal settlement (in terms of application).

- *Beneficiation (resource recovery and reuse)*

This concept was introduced years ago with the idea of converting human waste into useful resources. Various technologies such as UDT, MobiSan, and Enviroloo, etc. were developed based on this concept. The conversion of human excreta into usable products may be achieved through the use of available technology such as biogas digester, septic tank, drying bed or any other available technology. However, the technologies for converting human excreta may be subject to many factors including the physical settlement characteristics (water table, slope, sensitivity of the environment, etc.), the cost, O&M requirements and the skills required for operation.

The beneficiation concept, considered one of the most innovative, is applicable to both dry and wet sanitation technologies focusing on the treatment components mainly. Other components of importance can be (depending on the context) the collection, conveyance (where applicable), containment and storage (where applicable). This concept can be applied to any type of settlement given availability of and required for construction of the treatment facility, storage and access for transport of the waste products (if used off-site). If on-site reuse is envisaged, potential users should be identified to avoid long storage and inconvenience it may cause to the public and the environment.

- *Water conservation concept*

This concept can broadly cover only sanitation systems using water for either conveyance or treatment of human excreta. It can be applied in areas where water supply is available and misuse is being identified or reported. The concept is based on the general idea that suggests the use of less or no water for flushing toilet (referring to waterless systems), use of low or micro-flush, self-cleansing or high pressure vacuum flushing system. In informal settlements, given the large volume of water lost through misuse, vandalism, theft of components, water conservation concept can suit these conditions. The use of micro-flushing, waterless or vacuum pressure can substantially reduce the volume of water required for toilet flushing.

- *Decentralised and low operation and maintenance costs*

The conventional centralised sanitation concept reportedly fails due to high costs of O&M, conveyance system and construction, etc. Alternative decentralised concepts find favour mainly due to the low O&M, local management, and on-site treatment. The decentralised sanitation concept with low cost O&M and community management can be applied to any type of settlement (including informal) and technology (dry or wet system).

In general, the decentralised concept is understood as an approach towards achieving sustainable sanitation. Its application may be subject to the level of organisation amongst users, support provided by municipalities and level of user's awareness. The decentralised concept

can cover both beneficiation and water conservation concepts. Many technologies can emerge from the combination of these 3 concepts. The sanitation components covered by the decentralisation concepts are the toilet, conveyance/containment, treatment and storage prior to reuse.

5.7 Development of sanitation solution(s)

Having developed sanitation concepts, the next stage is to develop sanitation solutions by outlining defining elements and identifying components that correspond to each defining element.

a) Identification of defining elements of the sanitation concept

Defining elements of each of the concepts are presented in table 18 below. Each of these elements plays certain role in the development of sanitation solution. For example, defining elements of water conservation concept are low or no water use, micro-flushing, self-cleaning or water recovery and reuse. Hence, defining elements should be adapted to local conditions and tied to the concept.

Table 18: Development of sanitation concepts

Case study	Emerging concept	Defining elements of the concept
Pook se Bos	Beneficiation	- Collection and containment of excreta (mixed or separate) - Rapid dehydration of faecal sludge - Transport/transfer from one containment vault to another - Collection of urine - Treatment (on or off-site) of faecal sludge and urine - Bio-solid treatment (mixing organic waste with faecal sludge) - Reuse or disposal of human excreta - Low O&M
Masiphumelele 1	Community management	- Communal ablution facility managed by community - Dry or wet sanitation system - Presence of a caretaker - Multi-purpose facility - Decentralised treatment (on-site) - Resource recovery (biogas)
Enkanini	Water conservation	- Low or no water use - Vacuum flushing - Self-cleaning - Micro-flushing - Resource recovery

These defining elements are subject to change depending on the conditions of the settlement, extent of use and compliance with the operational requirements.

b) Identification of the components to defining elements of the sanitation concept

Defining elements are tied to certain components of a typical sanitation system. For example collection and containment are key defining elements of the beneficiation sanitation concept. These defining elements can be further translated into solution by designing specific features.

Many examples are available (TU Delft squatting pan or micro-flushing for example – refer to BMGF proposals).

Table 19: Sanitation options emerging from sanitation concepts

Concept	Defining elements of the concept	Components
Beneficiation	- Collection and containment of excreta (mixed or separate) - Rapid dehydration of faecal sludge - Transport/transfer from one containment vault to another - Collection of urine - Treatment (on or off-site) of faecal sludge and urine - Bio-solid treatment (mixing organic waste with faecal sludge) - Reuse or disposal of human excreta - Low	- Toilet - Containment - Separation/Treatment - Reuse
Community management	- Communal ablution facility managed by community - Dry or wet sanitation system - Presence of a caretaker - Multi-purpose facility - Decentralised treatment (on-site) - Resource recovery (biogas)	- Containment - Collection - Conveyance - Treatment (on-site) - Transport - Reuse - Community centre
Water conservation	- Low or no water use - Vacuum flushing - Self-cleaning - Micro-flushing - Resource recovery	- Collection - Containment - Conveyance - Treatment (on-site) - Transport - Storage

c) Assessment of each component (in terms of its relevance) to identify the technical sanitation options

Components identified above are arranged in certain order depending on their functions in the sanitation chain. This arrangement gives place to a sanitation options. For example: the combination of toilet facility-containment-separation/treatment-storage or reuse point directly to a dry sanitation system that can be a UDT. This combination and emerging sanitation option do not specify the exact type of dry sanitation (in terms of use – communal or individual; operational requirements – emptying, etc.).

Table 20: Emerging sanitation options

Components of the options	Emerging options	Case study
- Toilet - Containment - Separation/Treatment - Storage/Reuse	- Dry sanitation system	Pook se Bos
- Containment - Collection and Conveyance - Treatment (on-site) - Transport and Reuse	- Managed communal systems - Decentralised system - Water or non-water reliant systems	Masiphumelele
- Collection - Containment - Conveyance - Treatment (on-site) - Transport and Reuse	Communal: - low flush or - dry system	Enkanini

5.8 Assessment of sanitation solutions

The approach suggests that reflecting back on general drivers identified in section 5.1, to assign indicators and outline the relevance of each driver in response to the sanitation problems and settlements characteristics. The assessment is made by comparing sanitation options for each case study to the assessment framework.

Table 21: Sanitation technology assessment

Drivers	Criteria	Relevance	Indicators
Convenience	User satisfaction	A sanitation facility should provide certain level of convenience to users; this will enhance the acceptance and adequate functioning	- comfort - personal security - privacy/dignity - smell - noise - attractiveness/ status
Density	Number of users	Accommodate number of users and	- Functioning - Reliability
Misuse/vandalism	Robustness	Strong enough to resist vandalism	- Functioning
User friendly	Accommodate all user groups	To be used by all user groups (children and disabled)	- Accessibility - Comfort
Appropriateness	Adequate design	A sanitation facility solution should be appropriate to local conditions and users groups	- location - accessibility
Job creation	Employment opportunity	Job opportunities should emerge from the O&M of	- community involvement - income generation
Money market	Business opportunity Income generation	Business opportunities should emerge from the sanitation solution	- local business - income generation
Affordability	Number of facilities Access to sanitation	Sanitation solutions should be affordable in terms of costs and O&M	- access - number of facilities - cleanness - extent of O&M
Health and environmental protection	Attractiveness	Protection of human health and environment	- odour - smell - no indication of pollution
Reliability	Adequate functioning	Sanitation solutions should function at all time	- continuous access - no signs of breakage or leaks
Safety	Access Security	Safety of users	- no theft or vandalism - no report on violence

The assessment using these criteria and indicators provided an indication of the suitability of the sanitation options and their relevance to the case study. Findings suggest that:

- Dry sanitation systems are convenient, safe and reliable (in terms of functioning), affordable; can generate jobs and income or business opportunities through collection, handling, treatment, disposal or reuse of waste products. However, handling, transport and treatment of human waste may be hazardous unless appropriate measures are in place.

- Community managed sanitation systems can be convenient, less prone to vandalism and theft, appropriate and reliable (if well designed and maintained), can generate business and job opportunities (if resource recovery is envisaged). However, safety, density and reliability can be amongst limiting factors that can restrain the use of this sanitation option in informal settlement.

- Communal low flush sanitation systems are convenient where water and sewer are available; can accommodate large number of users (provided sufficient number of facilities are in place, adequate O&M and compliance with operational requirements), can generate business opportunities, job creation. However, the safety of users, vandalism and misuse as well as availability of water can limit the application of this option.

The proposed sanitation options are context specific and have advantages and disadvantages that can be overcome through adequate design. Models can therefore be developed by assigning features to each of the components. These features can be changed, refined or redesigned to overcome some of disadvantages of the proposed solutions.

5.9 Development of the model(s)

Models can be developed to illustrate and discuss the sanitation options. The intention is mainly to show how a concept can generate many options and how an option can have number of components and features. Some example of sanitation solution models emerging from this research are presented below:

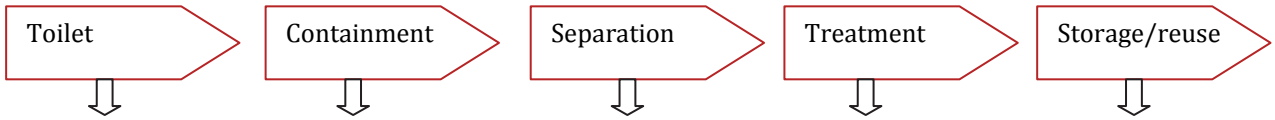
Example 1: MobiSan (Pook se Bos)

The dry mobile sanitation system (MobiSan) can comprise toilet, containment, separation/treatment, storage and reuse. Innovative solutions proposed here concern number of components (as indicated above). The model emerging can be as follows:

- Toilet: urine diversion pan (self-cleansing pedestal will be ideal given large number of users)
- Containment: two vaults (collection and storage) –
- Separation: mixing and triage of dried and semi-dried faecal sludge
- Treatment: mixing of semi-dried faecal sludge with bulking agent (saw dust for example)
- Storage: urine and dried faecal sludge storage containers
- Reuse or disposal: can be on-site (where applicable) or off-site (so require handling/packaging, transport)

Additional features required here will be:

- Filter (underneath the nightsoil disposal container) to allow excreta (mixture of urine and faeces) that is often discharged early in the morning to separate liquid and solid portions;
- Underneath the filter, a portable-removable container should be placed to remove the liquid portion of nightsoil for disposal;
- Given the frequent misuse or non-compliance with operational requirements (especially over weekends when the caretakers are not present at the facility), it is suggested to perforate the two containment containers in order to allow liquid waste to trickle and incorporate a removable-portable container to collect the liquid.



Self-cleaning pan	Double container	Manual mixer	Natural ventilation	Drying bed
UD pan	Filter (night soil)		Use of bulking agent	Moveable container
Male urinal (waterless)	Filter (containment container)	Waste separation	Rapid dehydration	
Night soil disposal	Removable cartridge	Bio-waste grinding	Composting faecal sludge with bio-waste	

Cleaning of the facility, collection, transport of urine or dry faeces and treatment offer job and business opportunities for informal settlement residents.

Example 2: Masiphumelele 1

The solution for this settlement is communal multi-service community managed sanitation system that comprises toilet facility, collection/conveyance, and on-site treatment. The product from the treatment is to be stored, transported and reuse (where applicable). The model emerging should have the following features:

- Toilet: squatting and sitting pedestal – self-cleaning porcelain; micro-flushing (high pressure vacuum), pedal flushing mechanism, 2l cistern and sanitary pad and nappy disposal bin.
- Collection: shallow sewer of diameter higher than 110mm; inspection chamber every 50 m (instead of recommended 100m), minimal slope to ensure self-cleansing velocity (depending on the topography of the area);
- Conveyance/collection: septic tank (for collection of mixed excreta), soakaway for greywater
- Treatment: biogas digester and greywater treatment
- Storage facility: biogas storage and distribution hub; and treated greywater pond
- Transport: where applicable, treated excreta or greywater can be transported to the point of use (within or outside the settlement)
- Multi-purpose hall: can be used for community meetings, parties or other event;

It should be noted that this model can generate job and business opportunities. Since this is a community managed system, number of jobs such as caretaker, cleaner or security can be generated. Business model emerging here can be related to CB O&M, treatment and transport of

human excreta (using container, wheelbarrow or small truck – example of Ubuntu sanitation), selling of biogas or waste products, etc.

Self-cleaning pan	Shallow sewer	Septic tank	Waste product storage
Micro-flushing	Large diameter pipes	Bio-digester	Biogas storage
Pedal flushing	Short distance between inspection chambers	Oil and grease trap	Biogas distribution hub
		Greywater filtration Soakaway	Greywater storage pond
		Constructed wetland	

In addition to the suggested solution, the design of this option suggests a multi-purpose hall that can serve for community meetings or shop close to the toilet where basic goods such as toilet paper, sanitary pad, etc. can be purchased by users. Transport of treated usable waste (fertiliser for example), distribution of biogas, treated greywater, O&M of the wastewater conveyance can generate business and job opportunities of local informal settlement residents

Example 3: Enkanini

The proposed solution here is based on the existing technology that has been upgraded to address number of sanitation problems including vandalism, misuse, wasting of water, etc. The solution presented in based on water conservation concept and has number of components including collection, conveyance, treatment (on-site), transport (of treated waste) and reuse.

This option is similar to the one above (example 2) in terms of components and their purpose and opportunities the sanitation solution may provide. However, the design of features is different as this solution is dealing with issues related to vandalism, misuse and theft; excessive water use and greywater disposal.

Self-cleaning pan	Shallow sewer	Septic tank	Greywater storage pond
Sealed pan	Large diameter pipes	Oil and grease trap	
Micro-flushing		Greywater filtration Soakaway	
Panelled flushing mechanisms	Short distance between inspection chambers	Constructed wetland	
Lockable cubicle		Greywater treatment using lava gravel	
Portable structure			

These three examples illustrate the application of the approach in developing sanitation solutions for informal settlements. This approach can be customised to any context and the outcomes (meaning solutions) may vary from one case study to another. It should be noted that many sanitation solutions can be developed from a given sanitation concept. The number of sanitation options developed depend more on the specific problem being addressed and the

way it is addressed. Most importantly, innovative sanitation solutions are related to the components of the sanitation system and innovative sanitation solution can be tied at one or more of these components.

Referring to the proposed innovative sanitation solutions (See appendices A and B), it clearly appear that none of these cover all components of a sanitation system in isolation; if combined, these innovations can easily address sanitation problems and provide alternative solutions.

5.10 Technical sanitation solutions for informal settlements

Findings from this research suggest that "…Unless context specific drivers for a functional sanitation facility and related technical innovations are established and documented, we will not be able to develop appropriate technical sanitation solutions for informal settlements..."

Bearing this in mind, drivers chosen for the sanitation concept are central to the functioning of sanitation solution, technical innovations (with reference to components) and are related to technology assessment framework for testing appropriateness of innovations. Gaps and issues emerging from functioning of the facility, technical drivers and technology assessment framework constitute the research agenda that should be further pursued.

5.10.1 Drivers

This study established based on interaction with sanitation stakeholders and field observation that drivers for sanitation concepts for informal settlements are related to the functioning of the facility and component innovation. These drivers address mainly key sanitation challenges that include access, night soil and greywater disposal, decentralised management of the facility. While component innovation drivers address issues related to beneficiation, water conservation and low operation and maintenance (O&M). The section below illustrates the value of the approach of selecting and using context specific drivers to refine current technical sanitation solutions to informal settlement sanitation realities in South Africa (see table 1 and 2 for details).

a) Drivers for a functional facility

Functioning of a facility regardless of the technology is a key defining attribute of an appropriate sanitation solution. Functioning is an indication of the reliability and adequacy of the facility to operate optimally. However, in the context of informal settlement waste streams tend to mix, and may either bypass or directly undermine the functionality of sanitation solutions that are viewed in isolation.

Sanitation concepts that derive from a narrow understanding of the function of a facility to the exclusion of sanitation-related domestic waste management (other than urine and faeces) will inevitably fall short of context-bound requirements. Related systems intended for the safe collection and disposal of domestic waste are key feature of a particular context. Drawing from study findings, it was established that drivers for functional sanitation facilities in any informal settlement context include:

- Location & safe user access
- Night soil and greywater disposal
- Decentralised facility & user management

Taking these different drivers into account, the research developed a number of concepts to locate within an approach for addressing sanitation challenges based on an established concept. Gaps in current approaches that have emerged over time and across a range of informal settlement contexts are outlined. Comments that are summarised in the table assist in shaping key pointers for research agenda (see table 1 below for details).

Table 22: Outline of drivers for a functional sanitation facility

Concept for IS	**Current approach**	**Gaps**	**Comments**
Facility drivers			
Location & Access	Demarcation for servicing – access to external support dominates location rather than access to users.	Access to households for sharing does not account for public use. Leaving some doors open and others locked is a voluntary solution devised by user neighbourhoods.	Optimum location within a settlement relies on criteria as accessibility affects user practices that impact on the functioning of a facility, especially if located in public spaces.
Night soil disposal	Stormwater drains as shared flush toilet units generally overburdened	Scarcity of collection facilities – shared toilets are usually overburdened. Open defecation contaminates and contributes to sanitation failures.	Dumping of nightsoil into stormwater drains suggests nightsoil disposal as a component of design of the sanitation facility, based on specific conditions. Inadequate access prevents use of toilets for disposal as sewage.
Greywater disposal	Stormwater drains generally used for dumping domestic food and kitchen waste Blockage of drains next to shared toilets units is common.	Scarcity of disposal facilities – laundry and domestic washing points are created next to stormwater drains for practicality of disposal. Dumping is a norm. Solid waste in greywater pooling is characteristic.	Localised treatment and reuse of greywater may be designed as community-based solutions for in-situ treatment of greywater for re-use, such as for irrigation or toilet flushing.
Decentralised Facility and User management	Casual cleaners are rotated. Monitoring leans on reporting of blockage or breakdown – depends on departments to rapidly respond in order to prevent serious breakdowns.	Dealt with as a technical repair issue. Learning from past experience to build on past successes is an ongoing gap. Monitoring responses are not exclusively about external skills as many are minor repairs.	Technical lens on functionality. O&M remains off-site despite past successes of local level servicing (local volunteers and contractors). Identify local caretaking and janitorial services that may function as models to learn from.

Location and access are related to the functionality of any facility as these factors influence behavioural norms in informal settlements. Toilets are directly affected when used to compensate for inadequate, related domestic waste disposal systems, which are best taken into account as a component of design for an appropriate and adequate sanitation solution.

Daily disposal of night soil, greywater and solid waste in stormwater drains has become a norm in informal settlements due to inadequacies of sanitary systems for domestic waste in general. The banks of stormwater drains also commonly serve as convenient pathways. Stormwater drains are generally more accessible for direct “dumping”, due to their length and transversal placement between clusters of dwellings across dense neighbourhoods.

Sanitation facilities are directly affected, for example, by disposal of used disposable nappies in toilet bowls. Blockages and recurring disrepair result from misuse, which is often due to other waste disposal systems, but are also a consequence of insufficient on site management and caretaking.

Decentralised facility and user management incorporate issues related to the functioning and operation and maintenance of the facility. This study has established that ensuring adequate functioning requires the management of the facility at lowest level as possible for number of reasons including:

- Inability of municipalities to respond timeously and adequately to reported functional problems;
- Long waiting period to respond to reported issues (e.g. vandalism, leaks or blockages);
- Line of communication between different department involved in operation and maintenance of the facility;
- Lack of management liaison between different services and communities;
- Fragmentation of responsibilities amongst different services involved in sanitation provision and operation and maintenance;
- Job opportunities that may be generated through beneficial use of waste products generated from the treatment or processing of human excreta.
- Lack of adequate janitorial services that led to vandalism, misuse and users to adopt certain sanitation practices including open defecation.

Sanitation solutions extend to factors that affect the functioning of specific facilities in a context that includes systems for other domestic waste. The functionality of sanitation specific facilities is clearly somewhat dependant on related domestic waste infrastructure and services in informal settlements.

b) Technical Drivers for the component innovation

Drawing from findings of this research, it was established that technical drivers* (outlined below) translate into innovation drivers in the context of the components of the sanitation system (toilet, collection, treatment, reuse/disposal); meaning that innovations are reflected on the components of sanitation system. Key drivers for component innovation established by this research are:

- Water conservation*
- Beneficiation*
- Low O&M costs*

The table below suggests that innovation relevant to each driver is key to develop prototypes. Emerging innovative solutions are related to components that are pointing potential options and way forward for further research agenda.

Table 23: Outline of technical drivers for component innovation

Technical drivers	Components	Innovation (solutions)	Comments /Potential options*
Water conservation	Toilet: flushing system	Micro-flushing	Communal sanitation facility (wet): micro-flushing and pressure vacuuming – this can reduce the volume of water used for flushing
		Water repellent pan	Self-cleaning pan that prevent sticking of human faeces
	Collection	Small diameter sewer and inspection chambers	Shallow depth sewer equipped with inspection chambers every 50m and at each intersection with the main sewer. CB O&M (cleaning and unblocking sewer). This can reduce the volume of water and provide self-cleansing velocity, hence reduce blockages.
		Rainwater harvesting	Rain water can be harvested from the rooftop, treated using fabric filter and used for toilet flushing, cleaning of the facility or handwash
	Treatment	Tank system for wastewater treatment	Tank system for pre-treating wastewater and generate gas that can be used to provide electricity at the facility, for geyser or communal cooking hub. Anaerobic treatment is required in order to produce gas, while effluent can be polished through aerobic process (cascade aeration) or ponding system and used for irrigation
		Greywater treatment	Greywater from laundry and communal ablution block is collected into a buffer tank and treated using 3 stages filtration (coarse screening – straining, primary filtration and secondary filtration using crushed lava rocks). Treated greywater can be used for dust suppression or cleaning the facility
	Reuse/disposal	Greywater storage tank	Specially designed that allows greywater to remain longer (over 2 days) as to prevent re-contamination. Greywater reuse can be subject to the level of treatment and the extent of treatment and treatment process should consider the intended use (purpose), safety or containment. Stored greywater can also be reused.
Beneficiation Dry system	Toilet	Water repellent pan	Dry sanitation system fitted with a squatting or sitting pan – repelling water to avoid mixing with faeces, thus reducing the volume of water for cleaning purpose.
	Containment	Double containment - Primary dehydration - Secondary treatment (mixing with saw dust or bokashi for example)	Collection container where human faeces and urine are separately collected; second contained where dehydrated faeces is collected and further dried. This will allow the facility to run while human faeces are being dehydrated in secondary container. This will ensure continuous operation of the facility.

	Treatment	Rapid dehydration Anaerobic and aerobic treatment	Mixing with drying agents, or forced aeration to avoid moisture. The container is equipped with moveable cartridge for collecting leaching wastewater and vertical and horizontal aeration for infusing air. Conversion of faecal sludge into fertiliser by mixing with food waste (composting); treated human faeces can be easy handled, further treated and transported off-site (where applicable). Treatment of faecal sludge (by composting) can be anaerobic or aerobic depending on context. In both cases the intention is to prevent environmental pollution (odour, leaching wastewater, etc.). Treated faecal sludge can reduce the volume of sludge to be disposed while providing fertiliser that can be reused.
	Reuse/Disposal	Pelletisation: stabilised faecal sludge Handling, storage and transport	Stabilisation of faecal sludge for easy handling and transport; conversion of treated faecal sludge into granular or powder for easy use in agriculture. Treated faecal sludge can be mixed with household organic waste and converted into compost
Wet system	Toilet	Water repellent pan and urinal	Dry sanitation system fitted with a squatting or sitting pan – repelling water to avoid mixing with faeces; thus reducing water use for cleaning purposes.
	Collection	Shallow sewer with inspection chamber	Reduce significantly high tech sewer cleaning, reducing the cost of O&M, low volume of water required for conveying excreta and provide opportunity for local resident to work and generate income.
	Treatment	Greywater treatment using 3 stages filtration Septic tank systems	Greywater collection and treatment using 3 stages filtration (coarse screening – straining, primary filtration and secondary filtration using crushed lava rocks) Wastewater is treated into septic tank to generate energy (biogas) and treated sludge as fertiliser. Generated gas can be used for illuminating the facility and cooking purposes while fertiliser can be used in agriculture
	Reuse/disposal	Fertiliser from faecal sludge Treated wastewater effluent	Excess treated effluent can be disposed into drainage system (where available), leachfield or infiltration trenches (if available); Wastewater effluent can be treated using septic tank system to generate gas. Treated wastewater effluent can be further treated and polished using wetland or pond system and further used in irrigation
Low O&M costs	Toilet	Community Based O&M	To allow community to undertake certain tasks such as cleaning, unblocking, etc. so as to reduce O&M costs, create business and job opportunities for users

		Self-cleaning pedestal/pan	Designed to reduce high O&M costs (related to cleaning), while preventing misuse by keeping the facility clean.
	Containment/collection	Removable cartridge (for dry sanitation)	To allow easy removal and handling of leaching wastewater. This reduces the cost of manual removal of dehydrated faecal sludge. This will allow community to deal with O&M issues (related to collection and handling or transportation of faecal sludge).
		Shallow sewer with inspection chamber	Reduce significantly high tech sewer cleaning; provide self-cleansing velocity, thus reducing blockages caused by bulk materials build up. In addition it provides opportunity for local resident to work and generate income.
	Treatment	Localised on-site CB treatment using local materials	Use of local labour, materials and expertise to treat human waste
	Reuse/disposal	CB initiative – storage and reuse centre	Initiative include community centre where products of human waste (gas, fertiliser) are being collected, stored and distributed (where applicable)

* Solutions suggested are communal and emerging options are either dry or wet

Innovative sanitation solutions are related to the components of a typical sanitation system (and are either tied to the toilet/containment, collection, treatment or reuse/disposal). These innovations are context specific in terms of design and functioning. An appropriate sanitation solution is the one that combines a number of innovative solutions in response to particular sanitation challenges. Innovation solution cannot address sanitation challenges in isolation; their combination can respond better provided a technology assessment framework is in place.

Drawing from the table above, it emerges that communal dry sanitation solutions (based on beneficiation concept) respond adequately to the conditions pertaining in informal settlements provided adequate physical site characteristics. From this perspective, innovative solutions should address number of issues related to functioning of the facility and components in order to ensure the appropriateness of the solution in a given context. Some of the issues that should be addressed are related to:

- Collection, treatment and disposal or reuse of greywater
- Operation and maintenance
- Rapid dehydration of human faeces
- Containment of raw and dehydrated faecal sludge to ensure rapid dehydration

5.10.2 *Technology assessment framework and sanitation solution prototypes*

This study established that technology assessment framework evolves from the functioning of the sanitation and components innovation. It comprises criteria that can be used to assess the functioning and appropriateness of a sanitation solution for a particular context. In contrast, sanitation solution prototypes evolve from technical drivers that translate into sanitation facility and related components.

a) Technology assessment framework

Criteria for assessing sanitation technology can vary according to the types of sanitation system and settlement characteristics. Dry and wet sanitation being commonly used systems, this study suggested assessment criteria that may be similar or different in some context. The tables below suggest the technology assessment framework for dry and wet sanitation systems.

Table 24: Emerging technology assessment framework for dry sanitation system

	Dry sanitation systems
Location	- The facility should be located far from flood prone - No water table or ingress of storm or ground water - Optimal location (centred as possible in order to ensure equitable access and walking distance for all users. - In case of high density settlement, zoning is proposed to facilitate access - Security: safety of users (day and night) - Number of user that can be accommodated (during peak hours) - Reliability (continuous functioning)
Nightsoil disposal	- Dedicated nightsoil disposal point (design and functioning) - No spill of night soil at the disposal inlet - No smell
Greywater disposal	- Greywater disposal point - No ponding or pooling of greywater
Decentralised system	- Handling, transport, on or off-site treatment of faecal sludge and disposal to be

	a localised function of users - Employment opportunities - Business opportunities
Water conservation	- Reuse of rainwater for cleaning of the facility - Potential for greywater treatment and reuse
Beneficiation	- Treatment of faecal sludge to acceptable quality for safe handling, transport or reuse (where applicable); - Treatment of greywater to acceptable quality for reuse or discharge - Generation of fertilisers from faecal sludge - Job opportunities
Low O&M	- Use of locally available materials (for undertaking certain tasks) - Frequency of breakdown and repairs

Table 25: Emerging technology assessment framework for wet sanitation system

	Wet sanitation systems
Location	- Facility to be located close to a sewer line (if available) or septic tank system as to reduce the cost of sewer and frequent maintenance work in case of blockages or leaks
Nightsoil disposal	- Separate night soil disposal (equipped with a disposal inlet funnel) to be provided
Greywater disposal	- Collection sewer and tank for greywater (laundry and handwashing) to be provided. Sewer to be equipped with oil, grease and sand traps
Decentralised system	- Local O&M activities undertaken by local communities (users). - Employment opportunities - Business opportunities
Water conservation	- Collection of rainwater for handwash and cleaning purposes - Water savings devices - Treatment and reuse potential for grey and blackwater
Beneficiation	- Generation of energy from human excreta - Use of energy generated from human excreta - Reduction of waste stream
Low O&M	- Use of locally available materials (for undertaking certain tasks) - Frequency of breakdown and repairs

b) Sanitation solution prototypes

South African experience in sanitation suggests that communal sanitation systems are the most suitable option within the context of informal settlements. This choice is mainly driven by many factors including lack of sense of ownership, the settlement density and physical site characteristics that are not permitting the provision of individual facilities. Communal and shared (rows of units) in "dry" or "wet" systems are common, depending on space, settlement (soil)conditions, availability of water, sewer collection and treatment system.

- *Dry sanitation systems*

Based on suggestions made with regard to innovative solutions (refer to tables 1 and 2 above), the prototypes suggested cover both dry and wet sanitation system. These prototypes are evolved around water conservation, beneficiation, low O&M and functional facility drivers.

- *Water conservation*

As indicated above water scarcity is one of the reasons for adopting dry sanitation systems. Dry systems save water and are suitable for areas where water is scarce or not available. However, dry sanitation still needs water for other use including cleaning of the facility, handwashing and dust suppression (where applicable). In this line, the solution proposed includes rainwater harvesting,

collection and treatment of greywater generated for reuse or disposal (depending on local context and needs) (table 26).

Table 26: Dry sanitation solution prototype based on water conservation driver

Innovative solution	Description
Rainwater harvesting	- Rainwater is collected from rooftop - Collected rainwater is filtered and stored - Collected rainwater is used for handwash and cleaning of the facility
Greywater collection and treatment	- Greywater generated from handwashing is collected into a soakaway/tank - Greywater is treated using 3 stages filtration (coarse screening, straining and filtration using crushed lava) - Treated greywater can reused for dust suppression in the settlement or irrigation

- *Beneficiation*

Dry sanitation systems (mainly urine diversion toilet) are developed based on assumption that waste can be converted into usable products. This implies beneficial use of waste products for many purposes including conversion into fertilisers, pellets and other products that can be safely used without harming human health or the environment.

Table 27: Dry sanitation solution prototype based on beneficiation driver

Innovative solution	Description
Nightsoil disposal	- Separate from toilet block (on side of facility) - Strainer (filter to trap faeces allow liquid trickling) - Liquid sludge collection (moveable container) - Aeration (horizontal and vertical) to prevent odour and enhance dehydration process
Greywater collection and treatment	See water conservation above
Faecal sludge treatment	- Collection and containment: double vault (collection of raw faecal sludge and drying vault) - Aeration (horizontal and vertical) for enhancing dehydration process - Fortification of dried faecal sludge (in drying vault by mixing with drying agent such as saw dust) - Co-composting: mixing of faecal sludge with biodegradable waste
Faecal sludge handling, transport and reuse	- Dried faecal sludge is removed from portable cartridge from the drying container - Dried faecal sludge is fortified in drying container by injecting air and mixing with saw dust or other drying agent - Dried faecal sludge can be handled from the portable cartridge and discharge into wheelbarrow and taken off-site (if access for truck is not feasible)

The proposed solution prototype has the following features:

- Nightsoil disposal point separate from the toilet block to facilitate early morning disposal and prevent long queue for those want to use toilet during peak hours;
- Greywater collection and treatment to prevent ponding/pooling that can enhance breeding of mosquitoes and rodents; thus causing environmental pollution;
- Faecal sludge treatment – two containers equipped with strainer to allow drying of wet faeces (trickling leachate). One vault serves for collection while other serve for dehydration.

- Further drying and fortification of faecal sludge is done by adding saw dust or other bulking agent for easy handling, transport and disposal or reuse (where applicable). Each container is equipped with moveable/portable cartridge where faecal sludge is dried. This is purposely designed for easy handling and transport.

- *Low O&M cost*

Appropriate sanitation solutions (dry or wet) should have low O&M cost in order to ensure continuous and reliable functioning. In this line, the innovative solution suggested here is related to some components of a sanitation system:

- Toilet: self-cleaning pan (squatting or sitting) – smooth to prevent sticking of faeces
- Containment/collection: portable/removable faecal sludge cartridge – easy to handle, transport and dispose. Access chamber to the containment vault for maintenance.
- Treatment: use of locally available materials and tools (broom, rod, brush, etc.)
- Handling/Transport/Disposal or reuse: wheelbarrow, tri-cycle or pulling using a rope (to reduce cost of transport, difficulty of access to the site or use of expensive alternative.

- *Wet system*

Wet sanitation systems require water for its functioning and substantial volume of greywater may be produced from laundry, handwash and even ablution bock (where available), thus requiring certain level of treatment before reuse or disposal, reuse or disposal.

- *Water conservation*

The main reason for the solution proposed below is water conservation; since South Africa in water scarce country, collecting and using of rainwater for handwash of cleaning the facility.

Table 28: Wet sanitation solution prototype based on water conservation driver

Innovative solution	**Description**
Rainwater harvesting	- Rainwater is collected from rooftop - Collected rainwater is filtered and stored - Collected rainwater is used for handwash and cleaning of the facility
Greywater collection and treatment	- Greywater generated from handwashing is collected into a soakaway/tank - Greywater is treated using 3 stages filtration (coarse screening, straining and filtration using crushed lava) - Treated greywater can be reused for dust suppression in the settlement or irrigation

In addition, given substantial volume of greywater generated from various activities such as laundry and handwashing, collection and treatment is deemed important simple for reducing pollution load, prevent ponding and to some extent encourage reuse for many purposes including dust suppression or small backyard garden irrigation.

- *Beneficiation*

There is a general trend to encourage beneficial use of waste products in order to reduce pollution load on the environment, prevent spread of diseases and reduce the volume of waste. Given the fertilising value of human excreta, reuse is a suitable option that can improve livelihood of communities.

In this line, the proposed solution includes collection of human excreta through shallow and small diameter pipe for easy operation and maintenance; rainwater harvesting tank for collection and treatment (using filtration) of rainwater and use for handwash and cleaning of the facility. Greywater is collected and treated for local application (dust suppression, irrigation or avert ponding that can result in breading of rodents and mosquitoes).

Table 29: Wet sanitation solution prototype based on beneficiation and low O&M drivers

Innovative solution	**Description**
Collection of human excreta – shallow and small diameter sewer	- Shallow sewer (small diameter pipe) to collect human excreta - Inspection chambers at junction and every 50 m - Traps for capturing large objects
Rainwater harvesting tank	- Collected rainwater is filtered and stored - Collected rainwater is used for handwash and cleaning of the facility
Greywater collection and treatment	- Greywater generated from handwashing is collected into a soakaway/tank - Greywater is treated using 3 stages filtration (coarse screening, straining and filtration using crushed lava) - Treated greywater can reused for dust suppression in the settlement or irrigation - Treated greywater can infiltrated into ground

- *Low O&M cost*

Low cost O&M is achieved when certain tasks such as cleaning, small repairs such as unblocking, fixing leaks, sweeping and disinfecting the facility are undertaken by local communities or users (Lagardien et al., 2009). Therefore, it is suggested that for wet sanitation systems, the following tasks should be undertaken by users with support (in terms of materials and equipment) by municipalities:

- Cleaning and sweeping of the facility
- Unblocking and leak fixing
- Replacement of parts (such as taps, toilet handle, etc.)

In both cases (dry and wet), the cost of O&M is one of key determinant factors that should be looked at in order to ensure adequate and reliable functioning. In addition, the operation of the facility, treatment and reuse of waste product can generate employment to local residents while decreasing the cost of O&M and offering a sense of ownership.

6. Further research for the development of sanitation solutions

The development of sanitation solutions is intended to address particular sanitation challenges in a particular context (informal settlement for example). Despite attempts to develop sanitation solutions, it is nevertheless recognised that there is no one size that fits all as a model solution that can be used to respond to the range of sanitation challenges, as depicted during this research. Through discussion between various sanitation role-players, it was agreed an adequate sanitation solution approach is needed to align design with policy and the needs of users. Despite the emergence of the approach from which technical sanitation solutions and models are discussed in this report, many of issues were identified through the review of literature and interaction with various sanitation role-players and captured as gaps that need to be addressed.

Having suggested innovative solutions and outlined their importance in addressing sanitation problems, further research should address the following issues related to:

c) Functional facility

- Location – access to sanitation is often subject to adequate location of the facility within the settlement. Despite principles that suggest that a sanitation facility should be located with 250 m of households, this study established that many facilities are not adequately located within this limit. Hence, prompting users to adopt certain sanitation practices including use of night soil, bucket or open defecation. In this line, it is suggested to investigate criteria for determining the optimum sanitation location within a settlement and the extent to which location impacts on the use of a facility and imparts change on sanitation practices.

- Nightsoil disposal – many sanitation solutions do not make provision for nightsoil disposal. The lack of adequate nightsoil disposal often results in the use of either a toilet block (that reduces number of unit at a facility) which results in long queue especially during peak hours. The other issue is the illegal dumping of nightsoil into stormwater drain or sewer (where available), in the bush, catchpit (along main roads). Therefore, this study suggests to investigate the design of a nightsoil disposal facility based on conditions pertaining to informal settlements (referring to density, distance) while considering operation and maintenance aspects.

- Greywater disposal – one of the biggest sanitation challenges in the disposal of greywater in informal settlements. Several studies have addressed this issue looking at localised solutions, engineering and community based solutions. To date, little has been done to promote localised treatment and reuse of greywater within informal settlements. This study suggests the development of localised community-based greywater treatment solutions using locally available materials and to investigate the potential reuse of locally in-situ treated greywater for irrigation or toilet flushing.

- Decentralised system – Lagardien et al. (2009) guidelines suggested that to ensure adequate functioning of sanitation facility certain tasks should be performed by local community living in the settlements. Despite making these suggestions, technical lens on functionality and O&M are still outsourced despite success of local level servicing. In

this line, this study suggests piloting of the guidelines in informal settlement context in order to determine the context of application and identify gaps.

d) Component innovation

- Water conservation
  - Toilet – conserving water is one of biggest challenges hindering wet sanitation systems in informal settlements. Several studies have focused on toilet structure, suggested use of rainwater or dual system (rainwater – treated greywater), low flush, etc. However, little has been discussed about the way of conserving water while reducing the need for frequent cleaning. Bearing this in mind, this study suggests investigating water conservation devices/systems for sanitation facilities in informal settlements.

  - Greywater treatment (see section a above)

- Beneficiation
  - Greywater disposal or reuse (when dry sanitation system is provided) – treated greywater may be used for many purposes including dust suppression or cleaning of toilet facility (sweeping floor for example). The beneficial use of greywater is often subject to the level of treatment and needs; but generally greywater is treated or disposed to prevent environmental and health related issues. Several studies have addressed these issues and many solutions have been developed. For this study, further investigation should address the development of localised greywater treatment system to meet non-potable reuse standards.

  - Rapid dehydration of human faeces using natural bulking agent – faecal sludge is another challenge faced by informal settlements. Handling, treatment, disposal or reuse of faecal sludge has been widely addressed by several studies; and to date many challenges regarding appropriate technologies, health issues related to handling and transport of faecal sludge as well as emerging business opportunities are scarcely addressed in the context of informal settlements. In this line, further research should address the following:

    - Investigation into faecal sludge dehydration process – efficiency of aeration in stabilising faecal sludge;
    - Extraction and handling of faecal sludge from communal mobile sanitation facilities in informal settlements;
    - Management of faecal sludge from mobile or permanent structure sanitation in densely populated informal settlement;
    - Development of an environmentally friendly transport mechanisms for faecal sludge from dry sanitation systems in densely populated informal settlements;
    - Development of sustainable business models for managing faecal sludge from dry sanitation systems in the context of urban informal settlements

- Low O&M costs
  - Operation and maintenance of sanitation facilities in informal settlements – assessing viable options from community perspectives.

In addition to the above, further research should be addressing the following:

- Development of technology assessment framework for sanitation solutions provided to informal settlements – given the large number of sanitation technologies that are available in the market and those being developed worldwide, there is a need to understand how they have been developed and the context of their application. Bearing this in mind, this research developed an approach for developing sanitation concepts and solutions. Developed technologies should be adapted to certain conditions and respond to certain challenges in order to be considered adequate for the purpose. In this line, this research suggest the development of a sanitation technology assessment framework for dense informal settlements where basic services are lacking – the focus should be on both dry and wet sanitation systems, communal, shared and individual.

- Decentralised management: community based operation and maintenance has been proven efficient in ensuring the long term sustainability of sanitation facilities. This has been proven by the study by Lagardien et al. (2009) (see section a) above for details). In this regard, it is suggested to investigate the extent to which community-based operation and maintenance impact on the long term sustainability of sanitation in informal settlement context.

Conclusions

The provision of adequate sanitation solutions is a challenging exercise due to the changing nature and dynamic of informal areas. Technical challenges such as operation and maintenance, relevance of the technology, design and the physical site characteristics are key elements that should be carefully considered when planning to develop appropriate solutions. Other challenges considered as general can be used to assess the sanitation solution.

The success and failures of a number of sanitation solutions to informal areas, are attributed to number of issues that can be clustered as technical (referring to those related to the components of the sanitation solutions) and general (referring to the challenges that can be used to assess the technology). Success can be replicated while failure can be used to inform innovation and further refinement of the solution. Emerging innovation solutions and proposals and their respective drivers are general and should be considered in the context of informal settlement based on their relevance to address specific and particular sanitation challenges. Drivers for these innovations should also be aligned within the same context and prioritised according to their relevance.

It is important to note that the innovation solutions may not provide the expected solution to the sanitation challenges as such; each solution should be carefully explored and the context of its application established prior to decide on the selection. This study has shown that there is mismatch between the sanitation solutions and concepts; as most sanitation solutions investigated were found to be developed without established concept. This mismatch can be seen as one of the causes of the failure of sanitation solutions; hence the understanding of the innovations and drivers are key to developing adequate/appropriate sanitation concepts and solutions.

Innovative sanitation solutions and drivers must be established and understood prior to developing sanitation concept. The approach (presented in this report) suggests stages and pointers that

should be followed to develop sanitation concept and solutions. Therefore, knowledge of sanitation concept can inform the development of sanitation solutions for a particular settlement context.

To sum it up, the approach developed addresses the way that innovations are developed and incorporated into a technical solution. The intention behind developing this approach was to enable sanitation role-players to develop appropriate sanitation concepts and solutions for a specific context. The approach is a starting point intended to provide guidance for how to tackle sanitation issues in a particular context, and it is flexible for different contexts. The aim is to inform sanitation role-players on how to develop sanitation concepts and solutions relevant to the context and conditions of informal areas.

Key findings of this research are summarised as follows:

- Innovation solutions and proposals suggested that are not relevant to informal settlements given the difficult and changing nature of these settlements, can be customised to meet local conditions by means of a thorough assessment of number of factors (referred in this study as general drivers).

- Sanitation concepts developed are based on personal feeling, level of awareness and understanding of the sanitation problems. Most of these concepts are lacking a scientific base to justify their relevance to particular sanitation problems or innovation proposals and drivers.

- There is mismatch between sanitation solutions and concepts. It therefore recommended that sanitation solutions should be developed based on a determined concept. As most sanitation solutions investigated were found to be developed without an established concept, this mismatch is one cause of failure.

    - Individual sanitation solutions are viewed by informal settlement residents as meaning that local government/municipality escape their legal obligation to provide and maintain basic services.

    - Communal sanitation solutions (dry or wet systems) were believed unlikely to be the most accepted solution so that individual waterborne sanitation attracted more attention amongst users and sanitation experts.

    - The choice of communal sanitation solutions was attributed mainly to various factors including design features to accommodate municipal responsibility for O&M and more importantly localised socio-economic dynamics and conditions for sanitation solution.

- Technical sanitation solutions cannot be developed without an adequate sanitation concept.

- Technical sanitation solutions for informal areas should consider water conservation and beneficiation and should be community managed as this can reduce the cost of O&M.

- Drivers for the sanitation concept are central to the functioning of sanitation solution and technical innovations (with reference to components); and are both related to technology assessment framework for testing appropriateness of innovations.

It is should be noted that no technical sanitation solutions cannot be developed without adequate knowledge of particular sanitation challenges; and no sanitation concept can be developed without adequate knowledge of sanitation innovations and related drivers. It is important for sanitation role-players to understand the sanitation challenges in a given context prior to developing solutions; doing so is believed to ensure long term sustainability of the sanitation solution.

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APPENDICES

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Appendix A: Technical sanitation solutions (BMGF sanitation grant) and their relevance to IS context

Technical solution	Description	Relevance of the technology	Innovation trends	Relevance in IS?
1. Technology to Convert Excreta to Valuable Products	**Anaerobic micro-digesters and micro-combined heat/power thermoelectric** generation units—into a single portable unit that can consume human excreta to generate electricity, heat, methane, fertiliser, and water. Each device will be designed to serve a single extended family.	Individual system: Biogas generation Treated effluent for potential reuse	Portability Energy generation Water generation	Lack of space Access FS management
2. Algae for the Effective and Economical Treatment of Waste	**Algae-based waste treatment system**. Cyanobacteria (blue-green algae) will treat waste and produce two forms of renewable energy: nutrient-rich fertiliser to enhance agriculture and bio-methane to power the facility and local communities.	Bio-remediation: Waste treatment using algae - Generate energy - Effluent reuse (in agriculture)	Use of algae Energy generation Bio-conversion (fertiliser)	Algae growth requires space
3. Decentralised Next Generation Sanitation for Diarrheal Pathogens	**A wind turbine-driven sanitation system** for its ability to raise and maintain temperatures in an insulated container that removes pathogens in human waste. This decentralised system is intended for 20-50 people and will test maintenance of the temperatures and timespans required to reduce pathogens.	Communal system: - Dessication (pathogen killing)	- Wind driven system - Timespan to reduce pathogens	Density (may not provide sufficient wind) Maintenance of temp.?
4. Hybrid Anaerobic Digester-Microbial Fuel Cell for Energy and Nutrient Capture	**A low-cost wastewater treatment system comprised of an anaerobic digester** that generates organically rich acids to power a microbial fuel cell. The technology could reduce the burden of waterborne diseases while providing useful energy.	Centralised or decentralised? Beneficiation (energy generation and nutrient recovery)	Energy generation – acids for powering microbial fuel	Space Energy requirements O&M and other related cost
5. Design of Microorganisms with Semiconducting Membranes	**Artificial molecular wires (AMWs)** into a waste treatment system to break down organic contaminants in human waste and catalytically convert the microbial energy into electricity	Beneficiation : - Energy generation	Catalytical conversion	Space and costs Energy requirements
6. "Lego-Like" Sanitation System: Pit Latrines Made of Bio-compost	**Building blocks made from bio-composites** that will replace conventional brick/ cement constructions for pit latrines. Testing the	Beneficiation: Faecal sludge treatment through biodegradation	Beneficiation: - Development of bio-composites from FS	Handling and transportation Treatment of FS

	strength and their rate of biodegradation to determine their suitability for building latrines that will decompose once the pits are filled, allowing for the eventual reintroduction of the land for farming and other community uses.			Space, accessibility Health and environmental issues
7. A Low-Cost Decentralised Sanitary System	**A decentralised sanitation system** that uses a low-cost, waterless, vacuum system to collect excrement and kitchen waste. The combined waste could then be processed into organic fertiliser.	Water conservation Beneficiation (fertiliser production)	- Vacuum system - Waterless - Processing of combined waste	Space and access Vacuum system? (O&M & cost?) Required other services
8. Developing Fortified Excreta Pellets for Use in Agriculture	**Fortified fertiliser pellets** from treated human excreta for market sale, with a prolonged shelf life to withstand transportation over long distances.	Beneficiation: - Conversion of FS into pellets for easy handling and reuse - Environmental protection - Reduction of human waste	- Conversion of FS into pellet (for safe and easy transportation)	Access, space and costs Equipment
9. Ecological Sanitation	**Eco-san** experiments in alternative small-scale agro-forestry settings.	None	None	Space, FS handling and disposal
10. Prototype Micro-flush-Biofil Toilet Facilities	**A prototype toilet facility** that incorporates an innovative **aerobic digester** to decompose waste along with a **micro-flush valve** that uses minimal amounts of grey water.	Beneficiation: greywater reuse Water conservation	- Micro-flushing - Use of greywater	Space – GW collection Equipment, FS management
11. The Earth Auger Toilet: Innovation in Waterless Sanitation	**A pedal-operated, low-cost, easy-to-use, odourless, urine-diverting dry toilet**, in which faeces and urine disappear after each use, dry material is mixed in mechanically, and the end product becomes plant fertiliser.	Beneficiation - Urine - Faeces	- Pedal operation - Mechanical mixing	Conversion of excreta unclear
12. An Energy-Producing Waterless Toilet System	**A waterless toilet** that seals waste into a **portable cartridge** within biodegradable film for anaerobic digestion. The digester produces fuel and fertiliser, creating valuable resources and business opportunities.	Water conservation Beneficiation (fuel and fertiliser production)	- Cartridge (sealing) - Portability	Costs of collection and handling of cartridge Access, space & transport
13. Turning Latrines Into Fly Traps	Design **traps** that attract, capture, and kill flies in latrines.	Reduction of diarrheal diseases (human health protection)	Attraction and killing of flies	Not applicable to IS context unless VIP are used. May be useful for rural areas

14. Universal Slum Sanitation With 100% Safe Reuse of Nutrients	**A low-cost system to rapidly turn faeces into pathogen-free compost for use as fertiliser for farmers**. A viable financial market that will remove untreated sewage from urban areas and also provide farmers with recycled, safe, and natural soil improvements.	Beneficiation: treatment of FS for beneficial use	Rapid decomposition of FS and conversion into usable compost	Applicable but space, treatment mechanisms, handling, transport and conservation? Access to IS
15. Urban Sanitation Solutions for High-Use, Flooded, and Difficult-to- Serve Areas	**A new modular, knock-down toilet block system** that can be erected in high-density, difficult-to-serve communities, such as refugee camps. The system will feature urine-diverting toilet pans, as well as enlarged ventilation areas that could eliminate odours and dessicate faeces.	Beneficiation and waste minimisation	Ventilation as a method to combat odour and increase dessication Use of recycled billboard as a material (ceiling, wall and bladders to store FS)	Applicable to IS but required space, storage of FS, access to the site, transport and density should be considered
16. The Lotus Throne: A Self-Cleaning Solution to Sanitation	**Novel UV-resistant, super-water-repellent silica** as a coating for toilets, which could reduce the amount of water needed to clean the toilets after use while improving surface sanitation.	Water conservation	Smoothness of the toilet and water repellency	Applicable to IS as it can reduce significantly water use while reducing cleaning effort
17. Develop a simple auger die assembly that treats faecal waste	**A small-scale device in which an auger** forces faeces and other solid wastes through a die, a process that produces high temperatures and pressure that removes water and **destroys microorganisms**. The device could reduce odour, insects, and surface and ground water contamination.	Environmental protection	Forced aeration device – rapid dessication and die-off of pathogens	Applicable in case of use of dry sanitation systems
18. High-Efficiency Sanitary Toilet with Sewage Treatment .	A simple toilet with **integrated sewage treatment** that employs a hand crank to dessicate faeces and turn them into dry, odourless pellets that can be used for fertiliser or fuel. The air-tight system will also control odour and keep out flies and vermin	Beneficiation and environmental protection	Rapid palletisation of FS for easy handling and use	Applicable in IS but may requires space, treatment facility, handling and transport – access
19. Integrated Mobile Sanitation Solutions in Peri-urban Setting	**A consumer-driven line of latrines** that double as containment and transport systems for faecal waste. The latrines will be low cost, mass produced and easy to ship, enabling sanitation services and collection businesses to develop in suburban and rural communities.	Beneficiation and franchising opportunities	Double containment (reception and treatment)	Applicable to IS context but may require access, space and transportation

20. Safe Sludge	Disinfection of faecal sludge in latrines by converting the ammonia naturally found in urine and faeces into a powerful disinfectant with an alkaline additive that will raise the pH level.	Beneficiation: safe FS management	- Conversion of ammonia from urine /faeces into disinfectant - Rapid pathogens die-off	Not applicable to IS

Appendix B: Innovative sanitation proposals – emerging trends and components

Innovation proposal (BMGF)	Relevance		
	Drivers	Concept	Solution - component
Bio-solid treatment	Reduction of FS volume Reuse Zero waste generation	Beneficiation	Treatment
Easy and safe collection and disposal (pelletisation)	Health & Environ. protection Job creation	Health & environmental. protection	Treatment & disposal
Resource recovery and energy generation	Zero waste generation Energy & nutrient recovery	Beneficiation	Treatment and reuse
Low O&M cost	Cost effectiveness (O&M)	Cost-effectiveness	All components
Portability and mobility of the facility	Poor physical sites characteristics Cost recovery (through reuse)	Cost-effectiveness and reuse	Toilet & containment
Decentralised system	Space availability On—site treatment Cost of transport Health risk & environmental protection	On-site treatment and beneficiation	All components
Waterless and micro-flushing systems	Water conservation	Water conservation and low O&M	Toilet
Alternative building materials	Zero waste generation Reuse	Beneficiation	Reuse
Double containment (reception and treatment) and cartridge	Health risk & environ. Protection On-site treatment	Health & envir. protection – localised treatment	Containment
Rapid dessication/ dehydration of FS	Resource recovery Reuse Safety (health and envir. protection) Reduction of FS volume	Beneficiation – health & environmental protection & zero waste generation	Treatment
Smoothness of the toilet and water repellency	Low cost O&M Water conservation	Water conservation, O&M	Toilet
Pedal operation	Low O&M Robustness	Cost-effectiveness	Toilet
Mechanical mixing	Health risks and environ. protection	Health risk & envir. protection	Treatment
Wind driven systems	No energy requirement	Use of natural resources	Treatment
Processing of combined waste	Zero waste generation	Beneficiation	Treatment

Appendix C: Workshop pack – Development of the sanitation solutions and models

1. Sanitation problems identified in informal settlement

Several studies have identified various sanitation problems in informal settlements. These problems range from the simplest to the more complicated that requires interventions in order to sustain the lives of informal settlement dwellers. Looking closely at these problems, it can be viewed from two perspectives that include user and municipal. To each of these categories the view and understanding of the sanitation problems may be different in context but the similarities may also exist.

The key questions that need to be answered are:

- *What are the sanitation problem(s) being faced in informal settlement?*
- *What are the causal factors?*
- *What are the consequence(s) of the problem(s) on the settlements and its inhabitants?*

1.1 Sanitation problems from user perspectives

Problem	Causal factors	Consequences
High density	Rural exodus Migration High living costs Poverty	Lack of spaces Lack of access Open defecation Large number of users
Vandalism	Lack of job opportunities Political interference Sabotage Poverty	Lack of infrastructure Inadequate infrastructure Environmental pollution Health risk and diseases
Inappropriate technology	Negligence Lack of consideration	Breakdown Environmental pollution Health risks and diseases
Land status	Poverty Lack of job opportunities High living cost	Land invasion Lack of basic services Environmental and health risks
Lack of community participation	Political interference Intolerance Miscommunication Lack of community organisation	Negligence Vandalism Refusal and rejection Health risks and diseases Poor adherence to operational
Conflict of interest	Cultural differences Political interference Power struggle and alliances	Resistance to change Intransigence Inflexibility Rejection of technologies Sabotage and vandalism
Lack of ownership	Carelessness Political promises Poverty Lack of education	Vandalism Negligence Dysfunctional facilities Unhygienic sanitation practices
Security	Poverty Lack of job opportunities Political motivation and gain	Dysfunctional facilities Misuse Fear to use of the facility Unhygienic sanitation habits

1.2 Sanitation problems from municipal perspectives

The key question pursued is "what *is/are the sanitation problems faced by informal settlements?*" Additional questions include:

- *What are the causal factors?*
- *What are the consequences the sanitation problem identified?*

a) Findings from the literature

Problem	Causal factors	Consequences
Political interference	False promises Power struggle	Sabotage Vandalism Low acceptance Inadequate technologies
O&M costs	Lack of compliance with operational requirements Unsuitability of technologies Vandalism	Breakdown High cost Unsustainable service Abandonment
Poor management	Lack of understanding of the technology Bureaucracy Long reporting protocol	Breakdown Lack of O&M Crisis maintenance
Lack of communication	Miscommunication Political interference False promises	Vandalism Low acceptance of the sanitation Delay in service provision
Lack of budget	Inadequate planning Lack of prioritisation	Inadequate O&M Lack of facilities
Inappropriate design	Greediness of designers Lack of knowledge Inadequate selection Lack of alternative options Lack selection framework	Low acceptance Breakdown High O&M costs Lack of access
Lack of community involvement	Political interference Lack of communication Lack of consideration	Low acceptance Vandalism Misuse
Lack of sustainable partnership between user and provider	Miscommunication Political interference False promises	Vandalism Misuse Theft and sabotage
Lack of user awareness	Inadequate planning Miscommunication Lack of consideration	Misuse Vandalism Low acceptance
Cultural differences	Mind set Beliefs Affiliation (religion or political)	Resistance to change Sabotage Vandalism
Settlement patterns	Poverty Availability of space Close proximity to centre	Poor service provision Lack of access Potential hazards and risks

b) Additional sanitation problems faced by informal settlements

Problem	Causal factors	Consequences

2. Sanitation technologies options

Having identified these problems (from both user and municipal perspectives), the next stage is to look at the sanitation technology options that have been provided to informal settlement in order to deal with identified problems (as all). To this end, user are requested to identify and name the types of sanitation technology options provided to their settlements, outline briefly advantages and

disadvantages (based on their daily use and experience) and indicate whether if the option is suitable for the settlement conditions or if it respond adequately to various problem identified in the previous section.

The questions covering this section of the investigation include:

- *What is/are the types of sanitation technology options provided to the settlement?[1]*
- *What are the advantages and disadvantages of the provided option based on your personal experience from the daily use of the facility?[2]*
- *Is the provided sanitation option suitable for the conditions pertaining to the settlement?[3]*
- *Does the provided sanitation option respond to the identified sanitation problems?[4]*

This table should be completed by users, municipal officials and sanitation expert (member of the RGM)

Types of sanitation technologies[1]	Advantages[2]	Disadvantages[2]	Suitability to the settlements[3]	Response to the sanitation problem[4]

3. Drivers*

The identification of the sanitation problems opened a way to manufacturers and design engineers to come with various sanitation technologies ranging from the simplest to the more sophisticated one, individual and communal, dry and wet, etc.

The key question we should respond is that *"what are the drivers behind the development of the sanitation technologies intended for informal settlements?"*

The literature review and interviews with various sanitation vendors, manufacturers and designers have provided a number of drivers that are intentionally used for the development and design of different sanitation technologies. Some of these technologies have been implemented, being implemented and/or piloted in number of informal settlement; their use has been successful for some while others totally fail for various reasons. Despite failures or successes registered the development of new sanitation technologies still moving forward and are expecting several alternatives.

- ***Identification of drivers****

From the initial investigation, the identified drivers are related to the following:

(1) Health risks and Environmental protection
(2) Convenience
(3) Water conservation
(4) Elegance
(5) Low operation and Maintenance costs
(6) Upgradability and adaptability
(7) Overcome the impacts of climate change
(8) Resource recovery and reuse
(9) Rate of urbanisation

(10) Affordability and cost-effectiveness
(11) Accessibility and suitability to all user groups
(12) Effectiveness and suitability to local conditions
(13) Sustainability and reliability
(14) Scale of use and uptake

- *What are the additional drivers or needs you think can contribute to the development of the sanitation technologies intended to IS?*

(15) ...
(16) ...
(17) ...
(18) ...
(19) ...
(20) ...

*We are considering only drivers related to technical issues.

4. Innovation trends

The review of various sanitation technologies provided to informal settlement has provided an understanding of the types of sanitation technologies, their advantages and disadvantages, their application and O&M requirements. These sanitation technologies were further analysed in order to determine the innovation trends (referred as any feature that makes the technology different from other or a technology that present potential) with regard to the identified sanitation problems.

➢ Identified innovation trends

The review of various literatures and the analysis of various sanitation technologies identified suggest the following innovation trends:

- Zero waste generation
- Rapid dehydration of human faeces
- Bio-conversion of human faeces into protein
- Agricultural use/application of sanitation human excreta
- Bio-solid treatment and reuse
- On-site treatment (without chemical addition)
- Energy generation (from waste)
- Low water consumption sanitation
- ……..

➢ Innovation trends, their suitability and applicability in informal settlement context

In the light of these emerging trends, the key questions pursued are the following:

- ✓ *What are in your view the innovation trends emerging from the current drive on the development of the sanitation technologies targeting informal settlements?*

- ✓ *Do these innovation trends respond to the identified sanitation problems in informal settlements?*

- ✓ *To what extent the emerging innovation trends may be applicable in informal settlement context?*

Innovation trends	Response to the problem	Applicability

5. Prioritisation of drivers

Knowing the sanitation problems faced by informal settlements and having identified the drivers, this phase entitles prioritising drivers in relation to the sanitation problems in the context of informal settlements. The prioritisation may be based on opinions or perceptions but should emphasise on the real sanitation problems faced by informal settlements.

Since various drivers were identified, and used as motive for the development of the sanitation technologies, we believed that it should be prioritised (in the light of the sanitation problems occurring in informal settlements) in order to select only the most influential. Knowing the sanitation problems, drivers and emerging trends on the development of the sanitation technologies, we should now attempt to cluster these drivers in a given order of priority based on number of criteria.

Key questions that need to be answered are:

- ✓ *How identified drivers should be prioritised?*
- ✓ *Should we prioritise drivers from user and municipal perspectives?*
- ✓ *What are the selection criteria for prioritising drivers?*
- ✓ *What are the most influential drivers (according to their order of importance)?*

In response to this question, you are requested to provide a priority order to the identified drivers by allocating them a number ranging between 1 to the last number (depending on additional drivers identified). You may justify your order of priority selected.

Priority	Drivers	Justification
	Health risks & Environmental protection	
	Convenience Water conservation	
	Elegance	
	Low operation and Maintenance costs	
	Upgradability and adaptability	
	Overcome the impacts of climate change	
	Resource recovery and reuse	
	Rate of urbanisation	
	Affordability and cost-effectiveness	
	Accessibility and suitability to all user groups	
	Effectiveness and suitability to local conditions	
	Sustainability and reliability	
	Scale of use and uptake	
	……..	
	……..	

Assigning indicator(s) to identified drivers

What are the indicators that can be used to define or identify each driver outlined in this table?

	Drivers	**Indicators***					
1	Health risks & Environmental protection	Odour/smell					
2	Convenience	Accessibility	Location	Attractiveness	Comfort	?	?
3	Water conservation	Less water use	No water use	No leak	Reuse	?	?
4	Elegance	Comfort	Cleanness	External look	Attractiveness		
5	Low Operation & Maintenance costs	No breakdown	Cleanness	Functioning	?	?	?
6	Upgradability and adaptability	Extension	Connection	?	?	?	?
7	Overcome the impacts of climate change	Robustness	Cleanness	Resistance	?	?	?
8	Resource recovery & reuse	Treatability	Reuse	?	?	?	?
9	Rate of urbanisation	Accessibility	Robustness	Location	?	?	?
10	Affordability & cost-effectiveness	Accessibility	User ratio	Cleanness	Occurrence	?	?
11	Accessibility & suitability to all user groups	Location	Design	Usage	?	?	?
12	Effectiveness & suitability to local conditions	Robustness	Usage	Location	Handling	Design	
13	Sustainability & reliability	Robustness	Functioning	?	?	?	?
14	Scale of use & uptake	User ratio	Extension	Acceptance	?	?	?
15							

** Indicators refer to physical signs that can be used to define or identify a driver*

6. Development of the sanitation concept

Having prioritised drivers, this stage of the research seeks to develop the sanitation concept that can be used to develop or design technical sanitation solutions for informal settlements. Looking at the drivers presented (in order of priority in the previous section), we should choose one or two that can be used to develop the concept bearing in mind that the selected driver and emerging concept should focus towards solving the sanitation problems identified in informal settlements.

- ***Matching drivers to develop the concept***
  - ✓ Looking at IS sanitation problems, what drivers are suitable to assist in alleviating or solving the identified problems?

Matching drivers to develop the sanitation concept requires clustering identified drivers in a logical way (by selecting relevant drivers numbered) thinking about the sanitation problems occurring in informal settlements and the current sanitation status.

After careful consideration, the research team has found the following concepts:

- ✓ *Concept 1: Environmental protection – health risk – convenience – upgradability/adaptability to local conditions – sustainability/reliability;*
- ✓ *Concept 2: Convenience – Resource recovery and reuse – elegance – effectiveness and suitability to all user groups – affordability and cost-effectiveness;*
- ✓ *Concept 3: Convenience – effectiveness and suitability to local conditions – low operation and maintenance cost – affordability and cost-effectiveness – upgradability and adaptability;*
- ✓ *Concept 4: Convenience – Elegance – Effectiveness and suitability to local conditions – Subject to contain the rate or urbanisation – Resource recovery and reuse.*

- ***Any other option?***
  - ✓ *Concept 5:*
  - ✓ *Concept 6:*
  - ✓ *Concept 7*:

7. Technical sanitation solution(s)

Using the developed concept(s), we can design technical sanitation options by combining different elements of the concept in the light of the sanitation problems, taking into account drivers and considering emerging trends.

The key questions pursued are as follows:

- ✓ *What is the sanitation concept that suits the best to the condition pertaining to informal settlements?*
- ✓ *Is the selected concept meeting the intention of the selected driver(s)?*
- ✓ *What are the elements of the selected concept that are applicable to the settlement conditions?*

- ✓ *Looking at innovation trends, what are the technical options (in accordance with the concept) applicable to informal settlements?*
- ✓ *What are the key parameters that can be used to evaluate the developed sanitation technology options?*

- Development of the technical sanitation options

Technical sanitation options are developed by combining *the sanitation concept (6)* developed and innovation trends (4) emerging from the review of various sanitation technologies. The following table should be completed by filling relevant sections:

To each of the concept (in column 1) should be assigned relevant innovation trend(s) (column 2) and then determine the technical sanitation option (column 3) that emerging from the combination of columns 1 and 2.

Sanitation concept*	Innovation trends*	Emerging technical solution
Concept 1		
Concept 2		
Concept 3		
Concept 4		
Concept 5		

**Details of innovation trends and concept are outlined in section 4 and 6 above*

8. Technology assessment

From the section above (sanitation technology options) options are being developed based on the sanitation concept (previously developed under section 6). Having these technical sanitation options, we are required to select the most suitable(s) that can be further used to develop a model.

To select the suitable option(s) we need a selection matrix that provides criteria for the assessment. In this regard, the key questions pursued are as follows:

- *What are the key factors that should be considered to assess a technical sanitation option?*
- *What should be the scoring or weight of each the assessment criterion?*

Sanitation technology assessment – Decision matrix

Factor (weight)	Scoring or weight %
Functionality	?
Robustness	?
Accessibility	?
Affordability	?
Maintainability	?
Safety	?
Elegance	?
Construction	?
Durability	?
Reliability	?
Additional assessment criteria	?
……	?
……	?
……	?
……	?
……	?
Total	100%

9. Technical sanitation solution(s) model

Having selected the sanitation technology option(s), this stage of the research intends to develop a model that can be presented and discussed with both user and RGM. The model is a prototype miniature that shows all elements and components of the technical sanitation option(s) selected.

The model will be presented and discussed with the stakeholders during a workshop. The questions that should be answered are:

- *What are the key features of the model?*
- *Are these key features suitable and sustainable given the conditions and dynamic of IS?*
- *Are there any additional features that can be added?*

Sanitation technology options	Key features
Option 1	……
Option 2	……
Option 3	……
Option 4	……
Option 5	……
Option 6	……

Appendix D: Workshop findings

1. Sanitation problems identified in informal settlements

1.1 Business

Vendor	Designer	Manufacturer
Lack of maintenance	Misuse	Non-compliance with the operational requirements
Cost of repair and maintenance	Number of user	Large number of user
Negligence and sabotage	Lack of O&M	Sabotage and negligence
Favouritism	Insufficient number of facilities	Lack of adequate O&M
Inadequate technology choice	Non-compliance with design specification	Lack of awareness

1.2 Municipal officials

Engineer	Social worker /activist	Informal settlement work group
Solid waste	Lack of awareness/ education	Lack of awareness
Bad planning	Lack of responsibility	Vandalism and sabotage
Inappropriate technology	Lack of ownership	Misuse
Poor maintenance	Migration	Poverty
Inappropriate use	Poverty	
Lack of knowledge of technology	Political interference	
Settlement conditions		

1.3 Expert

Engineer	Social scientist	Researcher
Insufficient investment	Lack of education	Poor & inadequate maintenance
Response to breakdown	Lack of induction	Disrepair of breakdown
Lack of monitoring system	Lack of communication	Filthy toilet
Low maintenance level	Poor regulations	Contaminated facilities
Inadequate sanitation system	Bad contractors	Lack of local oversight
Location of the facility		Blockages
Number of facilities (in use)		
Cost of maintenance		
Planning and LOS policy		
Centralised/focus on disposal		

2. Sanitation technologies solutions

The sanitation technology options identified from the literature were validated by the workshop participants as those being provided to informal settlements dwellers. The group agreed that the implementation of each of these technologies is context-based and should respond to the conditions pertaining to each settlement.

In addition, the group suggested that the identified sanitation technologies should be grouped according to:

- ✓ The modes of use:
  - o individual
  - o communal
- ✓ The mode of operation:
  - o dry
  - o wet system (with or without conveyance)

3. Emerging trends from the assessment of innovative sanitation solutions

Emerging trends, their suitability and applicability in informal settlement context

In the light of these emerging trends, the key questions pursued are the following:

- ✓ *What are in your view the trends emerging from the innovative sanitation solutions targeting informal settlements?*
- ✓ *Do these trends respond to the identified sanitation problems in informal settlements?*
- ✓ *To what extent the emerging innovative sanitation solutions may be applicable in informal settlement context?*

Emerging trends	Response to the problem	Context of application
Bio-solid treatment & reuse[1]	Land availability, space, transport	Suitable for all IS context
Energy generation[1]	Zero waste, reuse and land availability	Suitable for all IS context
Low water consumption[1]	Increasing water demand and lack of access to water	Area where water is not available
Mobility[2]	Adapt to changing population and development	The unstable and temporary status of IS; density and expansion of settlements
Multiple purposes[2]	The facility can serve other purposes including recreational, laundry and domestic needs (not standalone)	Add value to local care and maintenance
Low water consumption[2]	Increasing water demand and water availability	Efficiency is appropriate to poverty context
Easy and safe collection and disposal[3]	Context suitable /infrastructure	Suitable for all IS context
Decentralised treatment[3]	Collection and disposal	Suitable for all IS context
Resource recovery[3]	Disposal	Suitable for all IS context
Income generation/ Cost recovery[3]	Responsibility	Suitable for all IS context
Managed communal systems[3]	Space constraint & responsibility	Dense settlements
Low water consumption[3]	Cost and infrastructure	Suitable for all IS context
Maintenance free system[3]	High cost of maintenance	Dense & medium settlements
Robustness[4]	Long lifespan and uneasy to dismantle	Dense and violence prone IS
Ease of O&M and access[4&5]	Easy to clean, access to main components of the system and repairs	Suitable for all IS context
Portability[4&5]	The system can be moved from one place to another without dismantling the entire infrastructure	Depend on the conditions of the settlements but may be suitable for all context
Replicability[4&5]	The system should be designed to fit all types of IS	Suitable for all IS context
Accessibility[6]	Close to user for safety reasons especially during off-peak and night times	Suitable for all IS context
Security and safety[6]	Fencing and provision of caretaker to ensure safety of vulnerable persons	Suitable for all IS context

[1]Social scientist, [2]Researcher, [3]Engineer, [4]Businesses (designer, manufacturer, vendor), [5]Municipal officials, [6]Social activist

4. Drivers

In addition to the drivers that were identified in the literature, the reference group members suggested the following:

Drivers	Relevance of drivers to the sanitation problem
Money market[1]	Irrelevant
Safety (for certain user groups)[2]	Relevant
Economic benefits[2]	Irrelevant
Local employment opportunities[2]	Relevant
Local decentralised[3]	Relevant
Extent of operation[3]	Relevant
Maintenance cost[3]	Relevant
Business[4&5]	Relevant
Technology choice[5]	Relevant
Improvement[6]	Relevant
Job creation[6]	Relevant

[1]Social scientist, [2]Researcher, [3]Engineer, [4]Businesses (designer, manufacturer, vendor), [5]Municipal officials, [6]Social activist

The engineer group pointed that sustainability, affordability and scale of use and update are not relevant drivers that can be considered when developing a sanitation technology concept or designing options. The group suggested that only drivers of technical connotation should be considered for the development of the sanitation technology concept. However, other drivers should be taken into account based on their impact on the general functioning of the technology.

It emerges from the discussion that drivers should be categorised as:

- ✓ Technical: referring to those drivers that influences the most the functioning of the sanitation technology;
- ✓ General: other drivers of least technical importance but with certain impact on the overall functioning of the technology.

5. Prioritisation of drivers

Knowing the sanitation problems, drivers and emerging trends on the development of the sanitation technologies, we should now attempt to cluster these drivers in a given order of priority based on number of criteria.

Key questions that need to be answered are:

- ✓ *How identified drivers should be prioritised?*
- ✓ *Should we prioritise drivers from user and municipal perspectives?*
- ✓ *What are the selection criteria for prioritising drivers?*
- ✓ *What are the most influential drivers (according to their order of importance)?*

Drivers were prioritised by each of the group as indicated below:

5.1 General prioritisation of drivers

a) Social scientist

Priority	Drivers	Justification
1	Effectiveness and suitability to local physical conditions	Appropriate for users
2	Accessibility and suitability to all user groups	User should access the facility at all time
3	Affordability and cost-effectiveness	The facility should be affordable for users
4	Sustainability and reliability	The facility should be maintainable and available
5	Low operation and Maintenance costs	The O&M should as lower as possible
6	Health risks & Environmental protection	The sanitation should protect the environment
7	Convenience and safety	The facility should be convenient for all users
8	Upgradability and adaptability	The sanitation should be upgradable and adaptable
9	Elegance	The facility should be presentable and usable
10	Resource recovery and reuse	Waste should be minimise and treated for reuse
11	Rate of urbanisation of unemployed population	The facility should consider the number of user to prevent regular breakdown
12	Money market & profit[1]	Cost recovery

b) Researcher

Priority	Drivers	Justification
1	Health risks & Environmental protection	Public health is core aim of sanitation
2	Accessibility and suitability to all user groups	Essential to achieve objectives of sanitation
3	Effectiveness and suitability to local physical conditions	Appropriate from user perspectives
4	Low operation and Maintenance costs	Build in assurance of affordability
5	Convenience and safety	Encourage use by all, essential to aim
6	Affordability and cost-effectiveness	Design
7	Rate of urbanisation of unemployed population and Job creation[6]	Design and plan – municipality
8	Sustainability (Economic benefits[2]) and reliability	Design and plan – municipality
9	Resource recovery and reuse	Design and plan – municipality
10	Overcome the impacts of climate change	Design and plan – municipality
11	Upgradability and adaptability	Design and plan – municipality
12	Water conservation	Design and plan – municipality
13	Scale of use and uptake	Based on evidence evaluation (municipality)

c) Engineer

- Group 1

Priority	Drivers	Justification
1	Health risks & Environmental protection	Focus of sanitation services
1	Accessibility and suitability to all user groups	Basis of operation, value
2	Water conservation	Reduce resources /infrastructure demand
3	Low operation and Maintenance costs	Municipal reserves limited, cost recovery not possible
4	Elegance & decentralisation of services	User acceptance; needs multipurpose
5	Upgradability and adaptability	Present option for improvement, flexibility
6	Resource recovery and reuse	Create opportunity and economic values

- Group 2

Priority	Drivers	Justification
1	Accessibility and suitability to all user groups	To prevent open defecation
2	Affordability and cost-effectiveness	To increase access to sanitation

3	Low operation and Maintenance costs	To minimise the cost
4	Water conservation	To prevent water loss
5	Elegance	The facility should attract user
6	Upgradability and adaptability	The facility can be adapted to local conditions
7	Effectiveness and suitability to local conditions	The facility shall respond to the settlement conditions
8	Sustainability and reliability	The facility to be available all times
9	Health risks & Environmental protection	Spillages and other pollution effects should not occur
9	Resource recovery and reuse	Waste to be considered as resource
10	Overcome the impacts of climate change	The facility should be adaptable to climate
11	Rate of urbanisation	
12	Scale of use and uptake	The sanitation should be upscaled to other areas
13	Convenience	User should be have comfort

- Group 3

Priority	Drivers	Justification
1	Convenience	User should feel comfortable
2	Health risks & Environmental protection	Human excreta shall not cause impacts
3	Effectiveness and suitability to local conditions	The sanitation should be effective to local conditions
4	Overcome the impacts of climate change	The facility should respond to difficult conditions
5	Water conservation	The sanitation should use less or no water
6	Sustainability and reliability	The sanitation should be sustainable in terms of cost
7	Accessibility and suitability to all user groups	Access should be guarantee at all time
8	Affordability and cost-effectiveness	Access should be guarantee for all users
9	Low operation and Maintenance costs	The cost of O&M to be minimal
10	Upgradability and adaptability	The facility should respond to local conditions
11	Scale of use and uptake	The facility should be used widely
12	Resource recovery and reuse	Waste shall be minimised
13	Rate of urbanisation	Number of user vs. facility to be considered
14	Elegance	The facility should be attractive and usable

d) Businesses (designer, manufacturer, vendor)

Priority	Drivers	Justification
1	Health risks & Environmental protection	To prevent sickness and waterborne diseases
2	Convenience	To prevent open defecation and pollution
3	Elegance	To attract users and prevent open defecation
4	Low operation and Maintenance costs	To minimise the cost and ensure reliability
5	Upgradability and adaptability	To prevent capital loss and replacement cost
6	Affordability and cost-effectiveness	To enhance access for all
7	Accessibility and suitability to all user groups	To enhance access for all
8	Effectiveness and suitability to local physical conditions	To respond to the settlements conditions
9	Sustainability and reliability	To ensure availability and access at all time
10	Economic benefits[2]	To produce benefits through cost recovery
11	Maintenance cost[3]	To ensure adequate functioning
12	Business[4&5]	To provide income through O&M

e) Municipal officials

- Group 1: Engineers

Priority	Drivers	Justification
1	Effectiveness and suitability to local physical conditions	To ensure access at all time
2	Health risks & Environmental protection	To prevent pollution and health risks
3	Scale of use and uptake	To be upscaled to other areas
4	Accessibility and suitability to all user groups	To enhance access for all users
5	Elegance	To attract users at all time
6	Rate of urbanisation	To consider number of user and enhance access
7	Extent of operation[3]	To ensure the reliability of the facility
8	Affordability and cost-effectiveness	To ensure access for all
9	Low operation and Maintenance costs	To ensure adequate functioning at all time
10	Convenience	To ensure access and dignity for all at all time
11	Resource recovery and reuse	To improve food security and reduce waster
12	Sustainability and reliability	To ensure adequate functioning
13	Overcome the impacts of climate change	To be adaptable to local conditions and ensure reliability
14	Upgradability and adaptability	To minimise the cost of construction
15	Water conservation	To reduce water at minimum

5.2 Selection and prioritisation of technical drivers

The participants were tasked to select only drivers that may impact on the operation and maintenance of the technology options. Technical driver in this context refers to drivers that influence the most on the functioning of the sanitation technology.

Following the discussion, the following emerge as technical drivers:

- ✓ Effectiveness and suitability to local physical conditions
- ✓ Operation and maintenance
- ✓ Sustainability (affordability, cost-effectiveness and economic benefits)
- ✓ Upgradability and adaptability
- ✓ Convenience (safety, elegance, reliability, accessibility and suitability to all user groups)
- ✓ Resource recovery and reuse
- ✓ Water conservation
- ✓ Decentralisation of services
- ✓ Technology choice

The priority given to these drivers as follows:

a) Technical group

Priority	Driver
1	Operation and maintenance
2	Effectiveness and suitability to local physical conditions
3	Sustainability (affordability, cost-effectiveness and economic benefits)
4	Convenience (safety, elegance, reliability, accessibility and suitability to all user groups)
5	Decentralisation of services
6	Resource recovery and reuse
7	Upgradability and adaptability
8	Water conservation

b) Social and business group

Priority	Driver
1	Convenience (safety, elegance, reliability, accessibility and suitability to all user groups)
2	Effectiveness and suitability to local physical conditions
3	Sustainability (affordability, cost-effectiveness and economic benefits)
4	Operation and maintenance
5	Upgradability and adaptability
6	Water conservation
7	Resource recovery and reuse
8	Decentralisation of services

Assigning indicator(s) to identified drivers

What are the indicators that can be used to define or identify each driver outlined in this table?

- ***Social scientist***

	Drivers	**Indicators***					
1	Health risks & Environmental protection	Odour/smell	No illness	No indication of pollution			
2	Convenience	Accessibility	Location	Attractiveness	Comfort	User satisfaction	Time of use
3	Water conservation	Less water use	No water use	No leak	Reuse		
4	Elegance	Comfort	Cleanness	External look	Attractiveness	User satisfaction	Condition of the facility
5	Low Operation & Maintenance costs	No breakdown	Cleanness	Functioning	Period / time of use		
6	Upgradability and adaptability	Extension	Connection				
7	Overcome the impacts of climate change	Robustness	Cleanness	Resistance	Water use		
8	Resource recovery & reuse	Treatability	Reuse				
9	Rate of urbanisation	Accessibility	Robustness	Location			
10	Affordability & cost-effectiveness	Accessibility	User ratio	Cleanness	Occurrence	O&M	
11	Accessibility & suitability to all user groups	Location	Design	Usage			
12	Effectiveness & suitability to local conditions	Robustness	Usage	Location	Handling	Design	User perception
13	Sustainability & reliability	Robustness	Functioning	O&M	User perception		
14	Scale of use & uptake	User ratio	Extension	Acceptance			

** Indicators refer to physical signs that can be used to define or identify a driver*

a) Researcher

	Drivers	**Indicators***					
1	Health risks & Environmental protection	Odour/smell	h/h water not contaminated	Clean drainage and standpipe	No grey/black stormwater	Reduce flies & fly breeding	Safe access for children
2	Convenience	Accessibility	Location	Attractiveness	Comfort	Personal safety for all users	Hand washing facilitation
3	Water conservation	Less water use	No water use	No leak	Reuse	Reduced waste	
4	Elegance	Comfort	Cleanness	External look	Attractiveness	Easy to keep clean	Appropriate to local context
5	Low Operation & Maintenance costs	No breakdown	Cleanness	Functioning	Local daily oversight	Local simple repairs	Ready access to parts
6	Upgradability and adaptability	Extension	Connection	Affordability for users	Range of choice available	Appropriate to local context	
7	Overcome the impacts of climate change	Robustness	Cleanness	Resistance	Reduced use of potable water	Reuse of on-site greywater	
8	Resource recovery & reuse	Treatability	Reuse	On-site separation	On-site reuse	Cost-effective	
9	Rate of urbanisation	Accessibility	Robustness	Location	Mobile system, top structure	Adaptable to changing population	Open to local employment
10	Affordability & cost-effectiveness	Accessibility	User ratio	Cleanness	Occurrence	Affordability for users	Range of choice available
11	Accessibility & suitability to all user groups	Location	Design	Usage	Safe access to children	Safe use by small children	Personal safety of girls/women
12	Effectiveness & suitability to local conditions	Robustness	Usage	Location	Handling	Design	Safe access to children
13	Sustainability & reliability	Robustness	Functioning	Easy to maintain	Cost-effective to repair	Easy to keep clean	
14	Scale of use & uptake	User ratio	Extension	Acceptance	No open defecation	Open to local employment	Appropriate to local context

b) Engineer

	Drivers	**Indicators***					
1	Health risks & Environmental protection	Odour/smell	Collection effective	Treatment/disposal effective	Cleanness		
2	Convenience	Accessibility	Location	Attractiveness	Comfort	Spacious	
3	Water conservation	Less water use	No water use	No leak	Reuse	No or low flush	Rainwater harvesting
4	Elegance	Comfort	Cleanness	External look	Attractiveness	Multiple use	
5	Low Operation & Maintenance costs	No breakdown	Cleanness	Functioning	Effluent + effective treatment	Availability of parts	
6	Upgradability and adaptability	Extension	Connection	Removal/relocation	Modular	Multiple use	Soil conditions
7	Overcome the impacts of climate change	Robustness	Cleanness	Resistance			
8	Resource recovery & reuse	Treatability	Reuse	Market established	Technology systems established & available		
9	Rate of urbanisation	Accessibility	Robustness	Location			
10	Affordability & cost-effectiveness	Accessibility	User ratio	Cleanness	Occurrence	Franchised, standardised	Local opportunities, modular
11	Accessibility & suitability to all user groups	Location	Design	Usage			
12	Effectiveness & suitability to local conditions	Robustness	Usage	Location	Handling	Design	
13	Sustainability & reliability	Robustness	Functioning				
14	Scale of use & uptake	User ratio	Extension	Acceptance			

***Notes**: drivers 7, 9, 12, 13 and 14 were not considered as driver by the engineer group.*

c) *Business* (designer, manufacturer, vendor)

	Drivers	**Indicators***				
1	Health risks & Environmental protection	Odour/smell	Cleanness	No spillage		
2	Convenience	Accessibility	Location	Attractiveness	Comfort	Robustness
3	Water conservation	Less water use	No water use	No leak	Reuse	
4	Elegance	Comfort	Cleanness	External look	Attractiveness	
5	Low Operation & Maintenance costs	No breakdown	Cleanness	Functioning	Availability	Established
6	Upgradability and adaptability	Extension	Connection			
7	Overcome the impacts of climate change	Robustness	Cleanness	Resistance		
8	Resource recovery & reuse	Treatability	Reuse	Transportability	Safe handling	
9	Rate of urbanisation	Accessibility	Robustness	Location		
10	Affordability & cost-effectiveness	Accessibility	User ratio	Cleanness	Occurrence	
11	Accessibility & suitability to all user groups	Location	Design	Usage		
12	Effectiveness & suitability to local conditions	Robustness	Usage	Location	Handling	Design
13	Sustainability & reliability	Robustness	Functioning			
14	Scale of use & uptake	User ratio	Extension	Acceptance		

d) Municipal officials

	Drivers	**Indicators***					
1	Health risks & Environmental protection	Odour/smell	Spillage of greywater	Breeding of flies, mosquito	Presence of rodents	Visible waste	
2	Convenience	Accessibility	Location	Attractiveness	Comfort	Odour /smell	cleanness
3	Water conservation	Less water use	No water use	No leak	Reuse of greywater		
4	Elegance	Comfort	Cleanness	External look	Attractiveness	Security /safety	
5	Low Operation & Maintenance costs	No breakdown	Cleanness	Functioning	Local repairs	Availability of parts locally	High maintainability
6	Upgradability and adaptability	Extension	Connection	Movability	Suitability to local physical conditions		
7	Overcome the impacts of climate change	Robustness	Cleanness	Resistance			
8	Resource recovery & reuse	Treatability	Reuse	Handling	Storage	Safe use	
9	Rate of urbanisation	Accessibility	Robustness	Location			
10	Affordability & cost-effectiveness	Accessibility	User ratio	Cleanness	Occurrence	Availability locally	
11	Accessibility & suitability to all user groups	Location	Design	Usage	Extent of use	Ease of access	
12	Effectiveness & suitability to local conditions	Robustness	Usage	Location	Handling	Design	
13	Sustainability & reliability	Robustness	Functioning	Extent of O&M	Payback investment		
14	Scale of use & uptake	User ratio	Extension	Acceptance			

6. Development of the sanitation concept

➢ Matching drivers to develop the concept

The sanitation concepts developed below are based on the:

- ✓ Prioritised drivers:
- ✓ Innovation trends:

Matching the prioritised drivers to develop the sanitation concept requires clustering these drivers in a logical way (according to their relevance – considering the sanitation problems in IS) and the suitability/adequacy of the innovation trend in this particular context.

The development of these concepts was driven by the following factors:

- Context (referred as key problem(s) that defines better IS
- The way the sanitation options will be presented
- The innovation trend that fits better in the context

Bearing this in mind, the following concepts emerged from each group:

6.1 General sanitation concept

a) Social scientist

Concept	Prioritised drivers	Emerging trends
1	*Effectiveness and suitability to local physical conditions – accessibility to all user groups – Affordability and cost-effectiveness – Sustainability and reliability – Low O&M – Health risks and environmental protection.*	Bio-solid treatment & reuse
2	*Effectiveness and suitability to local physical conditions – accessibility to all user groups – Affordability and cost – effectiveness – Health risks and environmental protection – Sustainability and reliability – Low O&M.*	Low water consumption

b) Researcher

Concept	Prioritised drivers	Emerging trends
1	*Health risks – Effectiveness and suitability to all user groups – environmental protection – resource recovery and reuse.*	Mobility
		Multiple purposes
2	*Health risk and environmental protection – accessibility and suitability for all user groups – low operation and maintenance – convenience and safety.*	Low water consumption

c) Engineer

Concept	Prioritised drivers	Emerging trends
1	*Convenience – Health risk and environmental protection – effectiveness –Water conservation – Low operation and maintenance*	Low water consumption & income generation /cost recovery
2	*Affordability and cost-effectiveness – Health and environmental protection – Convenience – Sustainability and reliability – Elegance.*	Easy and safe collection and disposal & Low O&M cost
3	*Health risk and environmental protection – accessibility – multiple use – water conservation – cost-effectiveness – low O&M costs –*	Decentralised treatment + multipurpose & resource

	decentralisation of service – Resource recovery	recovery & Managed communal systems

d) Business

Concept	Prioritised drivers	Emerging trends
1	*Health risks & Environmental protection – Convenience – Water conservation – Elegance – Low Operation & Maintenance costs – Upgradability and adaptability.*	Ease of O&M and access
2	*Health risks & Environmental protection – Convenience – Elegance – Low operation and Maintenance costs – Upgradability and adaptability – Affordability and cost-effectiveness*	Portability

e) Municipal officials

- *Engineers*

Concept	Prioritised drivers	Emerging trends
1	*Health and environmental risk – Convenience – Water conservation – Elegance – Low O&M – Upgradability and adaptability*.	Robustness & Ease of O&M and access
2	*Effectiveness and suitability to local physical conditions – Health risks & Environmental protection – Scale of use and uptake – Accessibility and suitability to all user groups – Elegance.*	Replicability & Portability

- *Informal settlement working group*

Concept	Prioritised drivers	Emerging trends
1	*Health risks & Environmental protection – Water conservation – Effectiveness and suitability to local conditions – Sustainability and reliability – Accessibility and suitability to all user groups*.	Robustness & Ease of O&M and access
2	*Health risk and environmental protection – Convenience – Water conservation – Elegance – Low O&M – Upgradability and adaptability.*	Replicability & Portability
3	*Health risk and Environmental protection – Water conservation – Effectiveness and suitability to local physical conditions – Sustainability and reliability – Accessibility and suitability to all user groups – User friendly.*	Security & safety, Accessibility[6]

- *Social activists*

Concept	Prioritised drivers	Emerging trends
1	*Health risks & Environmental protection – Convenience – Elegance – Low operation and Maintenance costs – Upgradability and adaptability*.	Security and safety

6.2 Technical sanitation concept

These concepts were developed using only the prioritised technical drivers while considering other general drivers such as health and environmental protection, accessibility to name few.

The concepts emerging are:

a) Social scientist

Concept	Prioritised drivers	Emerging trends
1	*Convenience – Effectiveness and suitability to local physical conditions – Sustainability and reliability – O&M – Upgradability and adaptability*.	Bio-solid treatment & reuse Low water consumption

b) Researcher

Concept	Prioritised drivers	Emerging trends
1	*Effectiveness and suitability to local physical conditions –resource recovery and reuse – operation and maintenance – Convenience – Upgradability and affordability*	Mobility Low water consumption Rapid dehydration Zero waste generation

c) Engineer

Concept	Prioritised drivers	Emerging trends
1	*Convenience – effectiveness and suitability to local physical conditions –Water conservation – Operation and maintenance – Decentralisation of services – Resources recovery and reuse – Upgradability and adaptability Water conservation*	Low water consumption & income generation /cost recovery Zero waste generation
2	*Operation and maintenance – Convenience – Sustainability – Decentralisation of services – Resources recovery and reuse – Water conservation – Upgradability and adaptability*	Easy and safe collection and disposal & Low O&M cost Bio-solid treatment & reuse
3	*Decentralisation of services – Operation and maintenance – Sustainability – Effectiveness and suitability to local physical conditions – Convenience – Water conservation – Resource recovery*	Decentralised treatment + multipurpose & resource recovery & Managed communal systems On-site treatment

d) Business

Concept	Prioritised drivers	Emerging trends
1	*Convenience – Effectiveness and suitability to local physical conditions – Sustainability – Operation & Maintenance costs – Upgradability and adaptability.*	Ease of O&M and access
2	*Convenience – Operation and Maintenance costs – Upgradability and adaptability – Sustainability – Effectiveness and suitability to local physical conditions*	Portability and mobility of the system

e) Municipal officials

- *Engineers*

Concept	Prioritised drivers	Emerging trends
1	*Operation and maintenance – Convenience – Sustainability – Decentralisation of services – Resources recovery and reuse – Water conservation – Upgradability and adaptability*	Robustness & Ease of O&M and access
2	*Effectiveness and suitability to local physical conditions – Sustainability – Operation and maintenance – Convenience – Upgradability and adaptability.*	Replicability & Portability

- *Informal settlement working group*

Concept	Prioritised drivers	Emerging trends
1	*Water conservation – Effectiveness and suitability to local physical conditions – Sustainability – Convenience*	Robustness & Ease of O&M and access
2	*Convenience – Water conservation – Low O&M – Upgradability and adaptability.*	Replicability & Portability
3	*Effectiveness and suitability to local physical conditions – Sustainability and reliability – Convenience – O&M*	Security & safety, Accessibility Rapid dehydration

➢ *Social activists*

Concept	Prioritised drivers	Emerging trends
1	*Convenience – Effectiveness and suitability to local physical conditions – Operation and Maintenance costs – Upgradability and adaptability*.	Security and safety On-site treatment

7. Technical sanitation solution(s)

Development of the technical sanitation options

Technical sanitation options are developed by combining *the sanitation concept (6)* developed and innovation trends (4) emerging from the review of various sanitation technologies. The following table should be completed by filling relevant sections:

To each of the concept (in column 1) should be assigned relevant innovation trend(s) (column 2) and then determine the technical sanitation option (column 3) that emerging from the combination of columns 1 and 2.

a) Social scientist

Concept	Emerging trends	Prioritised drivers	Emerging options	Elements of the options
1	Bio-solid treatment & reuse Low water consumption	*Convenience – Effectiveness and suitability to local physical conditions – Sustainability and reliability – O&M – Upgradability and adaptability*.	Waterborne Communal sanitation	- Containment - Conveyance - Collection - Treatment - Transport - Reuse
			Dry sanitation	- Containment - Collection - Storage/treatment - Transport - Reuse

b) Researcher

Concept	Emerging trends	Prioritised drivers	Emerging options	Elements of the options
1	Mobility Rapid dehydration Zero waste generation	*Effectiveness and suitability to local physical conditions – resource recovery and reuse – operation and maintenance – Convenience – Upgradability and affordability*	Dry Mobile Communal sanitation (with potential greywater collection and reuse)	- Containment - Collection/storage - Treatment (on-site) - Transport - Reuse
	Low water consumption		Pour flush sanitation (community ablution centre)	- Collection - Conveyance - Treatment - Reuse

c) Engineers

Concept	Emerging trends	Prioritised drivers	Emerging options	Elements of the options
1	Low water consumption /cost recovery, energy generation and Zero waste generation	*Convenience – effectiveness and suitability to local physical conditions – Water conservation – Operation and maintenance – Decentralisation of services – Resources recovery and reuse – Upgradability and adaptability Water conservation*	Managed communal systems Decentralised system	- Containment - Collection - Conveyance - Treatment (on-site) - Transport - Reuse
2	Easy and safe collection and disposal & Low O&M cost Bio-solid treatment & reuse	*Operation and maintenance – Convenience – Sustainability – Decentralisation of services – Resources recovery and reuse – Water conservation – Upgradability and adaptability*	Dry sanitation system	- Collection - Conveyance - Separation/Treatment - Reuse
3	Decentralised treatment + multipurpose & resource recovery & Managed communal systems On-site treatment	*Decentralisation of services – Operation and maintenance – Sustainability – Effectiveness and suitability to local physical conditions – Convenience – Water conservation – Resource recovery*	Communal (low flush or dry system)	- Containment - Collection - Conveyance - Treatment (on-site) - Transport - Reuse

d) Business

Concept	Emerging trends	Prioritised drivers	Emerging options	Elements of the options
1	Rapid dehydration Localised O&M	*Convenience – Effectiveness and suitability to local physical conditions – Sustainability – Operation & Maintenance costs – Upgradability and adaptability.*	Individual or communal dry sanitation (solid – liquid separation)	- Containment - Collection - Treatment (on-site) - Transport - Reuse
2	Less or no water use – portability & mobile system	*Convenience – Operation and Maintenance costs – Upgradability and adaptability – Sustainability – Effectiveness and suitability to local physical conditions*	Individual or communal dry sanitation	- Containment - Collection/Conveyance - Separation/Treatment - Reuse

e) Municipal officials

- *Engineers*

Concept	Emerging trends	Prioritised drivers	Emerging options	Elements of the options
1	*Rapid dehydration of human faeces and Bio-solid treatment*	*Operation and maintenance – Convenience – Sustainability – Decentralisation of services – Resources recovery and reuse – Water conservation – Upgradability and adaptability*	communal dry sanitation (solid – liquid separation)	- Containment - Collection/storage - Separation/Treatment (on-site) - Transport - Reuse
2	On-site localised treatment and resource recovery	*Effectiveness and suitability to local physical conditions – Sustainability – Operation and maintenance – Convenience – Upgradability and adaptability.*	communal low flush sanitation	- Containment - Collection - Conveyance - Treatment (on-site) - Reuse

- *Informal settlement working group*

Concept	Emerging trends	Prioritised drivers	Emerging options	Elements of the options
1	*On-site treatment Low water consumption*	*Water conservation – Effectiveness and suitability to local physical conditions – Sustainability – Convenience*	communal low flush sanitation	- Containment - Collection - Conveyance - Treatment (on-site) - Reuse
2	Bio-solid treatment and reuse	*Convenience – Water conservation – Low O&M – Upgradability and adaptability.*	communal dry sanitation (solid – liquid separation)	- Containment - Collection/storage - Separation/Treatment (on-site) - Transport - Reuse

- *Social activists*

Concept	Emerging trends	Prioritised drivers	Emerging options	Elements of the options
1	*On-site treatment Low water consumption Upgradability*	*Convenience – Effectiveness and suitability to local physical conditions – Operation and Maintenance costs – Upgradability and adaptability*.	communal low flush sanitation	- Containment - Collection - Conveyance - Treatment (on-site) - Reuse

8. Technology assessment framework

From the section above (sanitation technology options) options are being developed based on the sanitation concept (previously developed under section 6). Having these technical sanitation options, we are required to select the most suitable(s) that can be further used to develop a model.

8.1 Technology assessment criteria

To select the suitable option(s) we need a selection matrix that provides criteria for the assessment. In this regard, the key questions pursued are as follows:

- *What are the key factors that should be considered to assess a technical sanitation option?*

Factor	**Justification**
Functionality	The technical sanitation solution should be functional and reliable all time, ready for use regardless of the conditions
Robustness	Due to the nature of IS and social problems, the technical sanitation solution should designed to respond to vandalism, misuse, abuse, etc. in particular manner that user should always have access
Accessibility	The location and design should be made to provide equal access for all user groups
Affordability	The technology should be available in the market locally and affordable in terms of the cost, O&M
Maintainability	The technology should be easy to maintain; and the maintenance should not necessary requires qualified labour
Safety	The technology should be designed in such a way that vulnerable users are protected
Elegance	The technical sanitation solution should be attractive in order to stimulate users, while discouraging open defecation
Construction	The technical solution (where applicable) should be easy to build and dismantle, materials used should be available locally and at competitive price.
Durability	The technical sanitation solution should have an acceptable lifespan function to its capital cost
Reliability	The technical sanitation solution should be functional all time and trusted by users
User acceptance	The technical sanitation solution should be accepted by user – the acceptance is believed to enhance adequate use while discouraging vandalism, theft, etc.
Health risk & environmental protection	The technical sanitation solution should be designed considering the aim of the sanitation as starting point

- *What should be the scoring or weight of each the assessment criterion?*

8.2 Sanitation technology assessment – Decision matrix

- ✓ Technology assessment needs to be re-ordered to align with drivers/design elements
- ✓ Clarification of assessment categories (different perspectives indicators – user/service providers)
- ✓ Other engineering group suggests the following:

Factor and weight	Factor and weight
- Affordability (20%) - Health risks and environmental protection (15%) - Accessibility (15%) - Functionality (10%) - Safety (10%)	- Accessibility (20%) - Safety (15%) - Functionality (10%) - Ease of construction (10%) - Reliability (10%)

- Durability and robustness (10%) - Elegance (10%) - Reliability (10%)	- Durability (10%) - Affordability (8%) - Robustness (10%) - Maintainability (5%) - Elegance (2%)
Total: 100	Total: 100

a) Social scientist

Factor (weight)	Ranking	Weight %	Reason for scoring
Functionality	2	12	To attract user and provide comfort
Robustness	10	3	To prevent vandalism and misuse
Accessibility	3	12	To ensure access for all, enhance good sanitation
Affordability	6	9	To ensure access for all
Maintainability	4	12	To ensure reliability
Safety	5	12	To ensure access and confidence of users
Elegance	11	2	To enhance access
Construction	9	8	To improve access and enhance the service
Durability	8	9	To prevent breakdown
Reliability	7	9	To ensure access at all time
User acceptance	1	12	To create confidence that enhances use
Total		100%	

b) Researcher

Factor (weight)	Ranking	Weight %	Reason for scoring
Functionality	1	20	To improve access
Robustness	7	5	To prevent vandalism and misuse, theft
Accessibility	2	20	To improve access for all user's groups
Affordability	8	5	Increase access to sanitation for all
Maintainability	3	15	Easily repaired, availability of parts
Safety	4	10	Use by vulnerable group (women, children, disabled)
Elegance	X	X	Fit with the environment, surface, cleansing, hand wash
Construction	10	5	Local employment, skills development inbuilt
Durability	9	5	To prevent vandalism, theft and misuse
Reliability	5	10	Enhance access and confidence of users
Local employment opportunities	6	5	Reduce vandalism and increase responsibility
Total		100%	

c) Engineer

Factor (weight)	Ranking	Weight %	Reason for scoring
Functionality	5	11	Improve access and safety
Robustness	3	18	To respond to theft, high number of user, etc.
Accessibility	6	9	Reduce open defecation and unhygienic practices
Affordability	7	8	Increase access to sanitation for all
Maintainability	2	15	Enhance the functioning
Safety	8	7	Provide dignity and confidence
Elegance	9	5	Enhance access and better use
Construction	1	15	Increase access to sanitation for all
Durability	x	0	Same as robustness
Reliability	4	12	Enhance access and create confidence
Total		100%	

d) Business

Factor (weight)	Ranking	Weight %	Reason for scoring
Functionality	7	5	Accessibility and attractiveness
Robustness	5	7	Prevention of vandalism and theft
Accessibility	8	5	Prevention of open defecation
Affordability	2	20	Ensuring access for all
Maintainability	1	35	Ensuring reliability and functioning
Safety	6	6	Improve access and reliability
Elegance	4	10	Improve access
Construction	3	12	Minimise the cost
Durability	X	X	n/a
Reliability	X	X	n/a
Total		100%	

e) Municipal officials

- Engineers

Factor (weight)	Ranking	Weight %	Reason for scoring
Functionality	1	20	Increase access
Robustness	5	15	Prevent breakdown
Accessibility	7	10	Prevent unhygienic sanitation behaviour
Affordability	8	5	Ensure access for all
Maintainability	6	5	Ensure access and improve functioning
Safety	2	15	Enhance access for all user groups
Elegance	10	5	Enhance access and reduce open defecation
Construction	9	5	Enhance access
Durability	3	10	Enhance access
Reliability	4	10	Enhance access
Total		100%	

- Informal settlement working group

Factor (weight)	Ranking	Weight %	Reason for scoring
Functionality	4	12	Increase access
Robustness	3	15	Prevent breakdown
Accessibility	5	10	Prevent unhygienic sanitation behaviour
Affordability	6	7	Ensure access for all
Maintainability	1	25	Improve the functioning of the infrastructure
Safety	7	6	Improve access for user groups
Elegance	8	5	Improve access for all user groups
Construction	2	20	Enhance access and service delivery
Durability	X	X	n/a
Reliability	X	X	n/a
Total		100%	

- Social worker

Factor (weight)	Ranking	Weight %	Reason for scoring
Health risks & Envir.	1	20	Prevent sanitation related diseases
Functionality	2	15	To ensure access and reliability
Robustness	3	10	Prevent vandalism and theft
Accessibility	10	4	Ensure access for user groups
Affordability	8	6	Enhance access for all
Maintainability	6	7	Improve the functioning
Safety	7	6	Enhance access for all and improve dignity
Elegance	11	4	Enhance access
Construction	9	5	Increase the access and delivery

Durability	5	9	Increase the lifespan of the facility
Reliability	4	14	Enhance access
Total		100%	

9. Technical sanitation solution(s) model

Having selected the sanitation technology option(s), this stage of the research intends to develop a model that can be presented and discussed with both user and RGM. The model is a prototype miniature that shows all elements and components of the technical sanitation option(s) selected.

The model will be presented and discussed with the stakeholders during a workshop. The questions that should be answered are:

- *What are the key features of the model?*
- *Are these key features suitable and sustainable given the conditions and dynamic of IS?*
- *Are there any additional features that can be added?*

Sanitation technology options	Key features
Option 1: (no technology provided)[1]	Toilet facility, disposal, reuse/treatment and conveyance[1]
Option 2: Rapid dehydration[2]	Containment, conveyance and reuse[2]
Option 3: Multipurpose facility	Toilet facility, containment[2]
Option 4: Low water consumption[2]	Toilet facility, disposal and conveyance[2]
Option 5: Managed communal systems[3]	No comments
Option 6: Decentralised system Communal (low flush or dry system)[3]	No comments
Option 7: Rapid dehydration[4]	Toilet facility, Containment, treatment, reuse (decentralised)[4]
Option 8: Low water use toilet[4]	Toilet facility, containment, conveyance, treatment, transport and reuse[4]
Option 9: Dry sanitation system (UDT)[5]	Toilet facility, containment, treatment and reuse
Option 10: Chemical toilet[5]	Toilet facility, containment, disposal
Option 11: Biogas digester[5]	Toilet facility, containment, conveyance, treatment, reuse and disposal
Option 12: On-site waterborne, decentralised system[5]	Toilet facility, containment, conveyance, on-site treatment, disposal

[1]Social scientist, [2]Researcher, [3]Engineer, [4]Businesses (designer, manufacturer, vendor), [5]Municipal officials, [6]Social activist.

Appendix E: Workshop documentation – Sanitation models presentation

1. Purpose of the workshop

The provision of the sanitation to informal settlement is a challenging exercise view the number of problems these settlements are offering. The challenging environments compounded by the physical site characteristics are making the application of several sanitation solutions impossible.

This research was undertaken to develop a sanitation concept with the view to develop technical sanitation solutions for informal settlements. Having developed and tested these concepts, three technical sanitation solutions emerged as models for informal settlements. The design specifications of each of these sanitation solutions were outlined and models being built for further discussion.

The purpose of this workshop is to discuss the developed models in order to get the views of interested parties (designers, manufacturers, users and service providers) with regard to the design, application and use, operation and maintenance and monitoring and evaluation.

To achieve this, an interaction between interested parties during which the views, opinions and taught of each individual involved will be heard. Further, discussion and feedback will be requested from each individual.

Workshop: presentation and discussion of the developed sanitation models

Date	Time	Place	Meeting	
19/10	11.00-12.30	Masiphumelele (site A)	Community	NGO & Activists
22/10	13.30-15.00	Pook se Bos	Community	Municipal officials
23/10	11.45-12.30	Masiphumelele (site B)	Community	Municipal officials
24/10	12.30-14.30	Enkanini	Community leader	Councillor
27/10	11.00-12.30	City of Cape Town	Engineers	Designer
29/10	13.00-14.20	Durban ICC	Sanitation expert	Researcher
06/11	9.30-12.30	Alexandra	Community	Councillor

Programme

Programme	Activities	Inputs	Outcomes
Session 1	Presentation of the project	Questions and answers	Feedback & suggestions
Session 2	Presentation of the model	Questions for clarity	Users and municipal views
	Explanation of the feature and functioning of models	Visualisation of the models	Questions, opinions & views
	Question for clarity	Recapitulation for clarity	Feedback & suggestions
Session 3	Open discussion	Questionnaire	Questions for clarity
	Presentation of the models	Open discussion	Opinions and views
	Presentation of the models	Debate regarding various opinions and views	Suggestions
Session 4	Closing remarks	Selection of the models	Discussion
	Final words	Adequacy of models	Suggestions

2. Methodology

In order to ensure the participation and interaction between interested parties, the following stages were adopted:

2.1 Presentation and Description of the models

The developed models will be presented in a specific order starting with the individual system, followed by the community managed system and ending with the communal mobile system. The models will be described in terms of:

a) Design and features
b) Operational requirements
c) Operation and Maintenance requirements
d) Monitoring and Evaluation criteria

2.2 Questions regarding the design and application of the model

Following the description and presentation of the models, participant will be requested to respond or comments of the following issues:

2.2.1 Design and features

- ✓ What is your opinion regarding the design of the sanitation solution in general?
- ✓ What other design elements would you like to be added? And where specifically?
- ✓ What is your opinion regarding the suggested features?
- ✓ What additional features would you like to see being added to the facility?
- ✓ What improvement can you suggest in terms of design and features?

2.2.2 Application and use

- ✓ What types of settlements do you think this technical solution is suitable?
- ✓ Is the use of the sanitation solution acceptable for all users groups?
- ✓ In what context this sanitation solution may be applicable?
- ✓ What can you suggest as improvement in terms of application and use of the sanitation solution?
- ✓ Any additional comments?

2.2.3 Location

- ✓ Where do you think the facility should be located and why?
- ✓ Does the location of the facility impacts on the use or operation?
- ✓ What other problems may emerge from the location of the facility?
- ✓ What can you suggest in terms of finding a suitable/adequate location for the facility?

2.3 Technical aspects of the model

2.3.1 Operation and maintenance

- ✓ In your view is this facility easy to operate and maintain?
- ✓ What additional O&M tasks should be in place to ensure long term functioning of the facility?
- ✓ Who do you think should take responsibilities for the O&M of the facility?
- ✓ Can you as users assist in the O&M of the facility?

2.3.2 Monitoring and evaluation

- ✓ In your opinion is this sanitation solution easy to monitor?

- ✓ Who do you think should be monitoring the sanitation facility?
- ✓ What are the M&E criteria that can be used in this process?
- ✓ Can you suggest any M&E protocol that can be applied to ensure the functioning of the facility?

2.4 Selection of the models

2.4.1 Assessment criteria

- ✓ If asked to assess the model suggested what criteria would you use?
- ✓ List the selected criteria according to their importance.

2.4.2 Selection criteria

- ✓ What model did you found suitable for IS conditions?
- ✓ How do you go about selecting the sanitation model?
- ✓ What other criteria can be used to select a sanitation model?
- ✓ Can formulate criteria that can be generally used to select a sanitation solution?
- ✓ What are the subset of each criterion suggested

2.4.3 Typical model(s) for informal settlements

- ✓ What model suits adequately the conditions of IS? And why?
- ✓ What can be added to make the (other models suitable?

3. Conclusions and Recommendations

- ✓ Concluding the workshop by summarising what has been done
- ✓ Write and document recommendations.

Appendix F: Workshop reports

Appendix F.1: Masiphumelele (site A)

- Number of participant: 26 (20 females and 6 males)
- Level of education (range): grade 2 to matric
- Age (range): 24 to 52 years
- Employment status: Jobless or casual workers
- Marital status: mixed (married and single parent)


Picturing above the model presentation at a case study site

1. Design and application of the model

1.1 Design and features

- ✓ The design in general was found to be good and acceptable in terms of features
- ✓ Additional features suggested:
  - Ramp for disabled persons
  - Dedicated toilet for children
  - Nightsoil disposal toilet

- ✓ The proposed features were adequate except for the elements suggested above that where not apparent in the drawing or models
- ✓ Improved suggested include:
  - The appointment of a permanent caretaker and security for communal system
  - The assistance in the O&M for individual sanitation
  - Distance walk from the home to the facility

1.2 Application and use

- ✓ All models were found to be suitable for any type of IS
- ✓ The technical solutions shown on the models:
  - Can be acceptable by all users group as it respond to their need.
  - However, the individual system may not be accepted as users have to take responsibility for the O&M.
  - Given that most users are jobless, the individual facility may not be accepted as it will cost in terms of household O&M if no assistance is provided by the municipality.

- ✓ The context of application:
  - The model 1 can be used in IS where spaces are available or where users can accept to re-block their shacks;
  - The models 2 &3 are applicable in all context
  - The model 2 should be applied where water is available
  - The model 3 can be applied only where there is no water availability (e.g. new IS)

- ✓ Suggestion for improvement in terms of application and use of the sanitation solution
  - User education
  - Consideration of the user status (income, level of education and needs)

1.3 Location

- ✓ Location of the facility
  - At the entrance of the IS for safety reasons
  - At the back of IS because of dignity and fear to be exposed
  - In the middle of IS to accommodate everyone and safety
  - In the middle of IS as it will provide access to all

- ✓ Impacts of the location of the use or operation of the sanitation
  - People may be reluctant if the sanitation is far from their shacks
  - If the facility is far from the house, people may use bucket and throw it everywhere
  - The location influences the use and the operation of the sanitation

- ✓ Other problems that may emerge from the location of the facility
  - If situated far, it can be vandalised
  - Safety
  - Fear for being abducted, raped, etc.

- ✓ Suggestion in terms of finding a suitable/adequate location for the sanitation
  - The location should be chosen in consultation with users
  - The right place suitable for all to access
  - The sanitation should be located close to the house (for individual systems)
  - The facility should be located in the middle of IS (to give access to all)
  - Facilities should be made available in each zone of the IS (more toilets)

2. Technical aspects of the model

2.1 Operation and Maintenance

- ✓ The provided models:
  - In general looks easy to operate and maintain if the caretaker is there
  - Individual systems may not work as people don't have knowledge about it
  - The O&M should be done by the municipality or qualified workers

- ✓ Additional O&M tasks you believe may be in place to ensure long terms functioning of the facility
  - Daily cleaning and sweeping
  - Removal of solids

- ✓ Responsibilities for the O&M of the facility
  - Municipality
  - Caretaker (appointed by municipality)
  - No household because of lack of money and knowledge

- ✓ Assistance in the O&M of the facility
  - Cannot assist as we don't have knowledge
  - Can assist if trained and paid

2.2 Monitoring and evaluation

- ✓ The suggested models look easy to monitor
- ✓ It can be monitored by both users, caretaker or other municipal officials

- ✓ M&E criteria
  - No spillage and leakage
  - No odour
  - No blockages

- ✓ M&E protocol that can be applied to ensure the functioning of the facility
  - Identify problem
  - Report to the municipality

3. Assessment and selection of the model

3.1 Assessment criteria

- ✓ Assessment criteria
  - Easy to use
  - No blockages
  - Always available for use (readiness)
  - Clean and neat
  - No pollution (spillage)

- ✓ Criteria according to their importance
  - Availability to use (ready)
  - No blockages
  - No smell
  - Cleanness
  - No pollution

3.2 Selection criteria

- ✓ Suitable model for IS conditions
  - Model 3: because it is safe, caretaker to do the job, separation between male and female, no waste of water
  - Model 2: because it provide a space for laundry, separation male and female, no waste of water and collection of greywater
  - Model 1: not suitable as it requires user to take full responsibility for the O&M, breakages and any other problems.

- ✓ The selection was made according to the merit, looking at the solution that responds better to the needs;

- ✓ Other criteria for selecting a sanitation model
  - Reliability
  - Low O&M
  - Accessibility
  - Easiness to manage
  - Security

- ✓ These criteria can be generally used to select a sanitation solution

3.3 Typical model

- ✓ Model 2:
  - Use less water (to flush)
  - Separation male and female
  - Provision of urinal, shower and laundry
  - Caretaker and security
  - Fencing

- ✓ Additional features to make the (other models suitable)
  - Geyser
  - Flushing system
  - Caretaker

Appendix F.2: Masiphumelele (site B)

A. Users

- Number of participants: 22 (16 females and 6 males)
- Level of education (range): no formal education to matric
- Age (range): 20 to 36 years
- Employment status: Jobless or casual workers
- Marital status: mixed (married, single and predominantly single parents)


Presentation of the models to the community

1. *Design and application of the model*

1.1 Design and features

- ✓ The design in general was found to be good and acceptable in terms of features as an attempt was made to address number of issues including:
  - Safety
  - Gender
  - Other activities such as laundry, low water consumption, dignity and privacy

- ✓ Additional features suggested:
  - Ramp for disabled persons
  - Dedicated toilet for children
  - Nightsoil disposal toilet
  - Geyser
  - Sliding doors and locks
  - Sit toilet (not squat)
  - Bucket for water collection (in the case of pour flush)
  - Special pedestal for kids and disabled persons

- ✓ The proposed features were adequate except for the elements suggested above that where not apparent in the drawing or models. If some of the suggestions made above are addressed, the models will be suitable for all contexts.
- ✓ Improvements suggested include:
  - Fencing of communal sanitation

- Inclusion of security
- Extension of operation time (e.g. 5.00 to 22.00)
- Training of local to operate and maintain their own facilities
- The communal facilities to be provided for limited number of users

1.2 Application and use

✓ All models were found to be suitable for any type of IS provided user education with regard to:
- The operation and use
- The maintenance requirements
- Compliance with operational requirements

✓ The technical solutions shown on the models:
- Can be acceptable by all users group as it respond to their needs.
- The individual system can be accepted only if municipality can maintain it (at household level and municipal level).
- Given that most users are jobless, the individual facility may not be accepted as it will cost in terms of household O&M if no assistance is provided by the municipality.

✓ The context of application:
- The model 1 cannot be used in IS as spaces are not available; and users may not be ready to accept relocation to create space for the facilities and collection system as well as O&M;
- The models 2 &3 are applicable in all contexts but should be implemented where space is available
- The model 2 should be applied where water is available for flushing and where space is provided for discharging greywater and containment of faecal matters
- The model 3 can be applied only where there is no water availability and where water is not being sparingly used;

✓ Suggestion for improvement in terms of application and use of the sanitation solution
- User should be made aware with regard to the use and operational requirements;
- Consideration should be made for elderly people and children in terms of use and accessibility

1.3 Location

✓ Location of the facility
- At the entrance of the IS for safety reasons as every should see what is happening
- In the middle of IS as a central point to accommodate everyone and safety

✓ Impacts of the location of the use or operation of the sanitation
- Locating the sanitation far from user may not be adequate and people will be lazy to use
- The location may lead people to use easy method such as bucket instead of the provided facility
- The location has huge impact on the use and operation of the sanitation.

- ✓ Other problems that may emerge from the location of the facility
  - Vandalism
  - Safety
  - Fear (during off-peak hours)
  - Misuse

- ✓ Suggestion in terms of finding a suitable/adequate location for the sanitation
  - The location should consider the IS conditions (water table, topography)
  - The compromise between users
  - Individual system should be not more than 5 m from the shack

2. Technical aspects of the model

2.1 Operation and Maintenance

- ✓ The provided models:
  - In general looks easy to operate and maintain if the caretaker is there
  - Individual systems may not work as people don't have knowledge about it
  - The O&M should be done by the municipality or qualified workers

- ✓ Additional O&M tasks you believe may be in place to ensure long terms functioning of the facility
  - Cleaning and sweeping daily
  - Removal of solids
  - Clearing blockages

- ✓ Responsibilities for the O&M of the facility
  - Municipality (for the communal sanitation)
  - Caretaker (appointed by municipality) for small O&M works such as cleaning
  - Household for individual sanitation

- ✓ Assistance in the O&M of the facility
  - Can assist if trained and paid
  - Can assist if supported with relevant materials and equipment (at both communal and individual sanitation)

2.2 Monitoring and evaluation

- ✓ The models look easy to monitor but should be demonstrated to users prior to their implementation

- ✓ It can be monitored:
  - User for individual sanitation (at the household level) and municipality afterward
  - Caretaker and municipal officials for communal sanitation

- ✓ M&E criteria
  - No spillage and leakage
  - No odour
  - No blockages

- No broken toilets, urinal or taps

✓ M&E protocol that can be applied to ensure the functioning of the facility
- Identify problem
- Report to the municipality (for individual sanitation)
- Report to caretaker for communal facility
- Caretaker to report to municipal officials

3. Assessment and selection of the model

3.1 Assessment criteria

✓ Assessment criteria
- Easy to use
- No blockages
- Reliability
- Cleanness
- No running faeces and greywater

✓ Criteria according to their importance
- Reliability
- No blockages
- No smell
- Cleanness
- No spillage of faeces and greywater

3.2 Selection criteria

✓ Suitable model for IS conditions
- Model 2: because it is a flush toilet, provides a space for laundry, separation male and female, no waste of water and collection of greywater
- Model 3: because it is waterless, safe to use, caretaker to do the job, separation between male and female, no waste of water and use of faecal sludge for food security
- Model 1: not suitable users are not prepared to take responsibilities given their current status (job and income level).

✓ The selection was made according to the potential offered by each model. The potential include
- Response to user needs and requirements
- Adaptation to the conditions
- User satisfaction level

✓ Other criteria for selecting a sanitation model
- Reliability
- Low O&M
- Accessibility
- Water use

✓ These criteria can be generally used to select a sanitation solution

3.3 Typical model

- ✓ Model 2:
  - Use less water (to flush)
  - Separation male and female
  - Provision of urinal, shower and laundry
  - Caretaker and security
  - Fencing

- ✓ Additional features to make the (other models suitable)
  - Geyser
  - Full flushing system
  - Handwash inside toilets
  - Public light at the facility

B. Municipal officials

1. Design and application of the model

1.1 Design and features

- The design and features attempted to respond to certain issues such as safety, gender and considered privacy and dignity. However, the design and proposed features did not consider other aspects such as children and disabled persons who may not be access the system.

✓ Additional features suggested:
- Ramp for disabled persons
- Dedicated toilet for children
- Nightsoil disposal toilet
- Geyser (solar or biogas powered)
- Sliding doors and locks
- Pedestal for normal and disabled person (squat and sit to be considered)
- Tap inside the toilet and bucket for easy water collection (in the case of pour flush)

✓ The proposed features as shown on the models are adequate; additional features suggested above should make these models workable and acceptable by both users and officials.

✓ Improvements suggested include:
- Provision for flexibility of design in order to customise to local contexts
- The inside height should not be less than 2m in order to provide natural aeration
- Burglar bar to be provided at all aeration opening
- Aeration opening to be made wider in order to generate the circulation of air

1.2 Application and use

✓ All models are adequately designed but their application and use must be subject to number of considerations including:
- The type of settlements (in terms of density)
- The physical characteristics of the settlement
- The behaviour and needs of users
- The context of the service delivery (temporary, permanent…)

✓ The technical solutions shown on the models:
- Can be acceptable by all users group provided user awareness.
- The individual system will be accepted by users but not by municipality as the cost of O&M may be high.
- Options 2 and 3 are suitable and readily acceptable by users provided continuous awareness and mobilisation.

✓ The context of application:
- The model 1: not feasible in dense IS due to lack of space, cost of O&M and willingness of users to participate in the O&M;

- The models 2 &3 are applicable in all contexts but should be implemented where space is available; the number of unit to be implemented may be an issue as municipality may not have sufficient budget to employ caretaker for each facility.

- The model 2 requires water and can be applied only where water is available for flushing. The collection of greywater may require adequate soil conditions if other infrastructure (such as stormwater or sewer) is not in the vicinity and where space is provided for discharging greywater and containment of faecal matters.

- The model 3 can be applied only where there is no water availability and where water is not being sparingly used; however, user acceptance of dry sanitation may be problematic. In addition, the access to the facility for collecting, disposal of faecal sludge and urine should be considered.

✓ Suggestion for improvement in terms of application and use of the sanitation solution
- The topography and soil conditions should be considered;
- The community behaviour should be considered
- Awareness programme should be in place to assist user understanding the use of the sanitation

1.3 Location

✓ Location of the facility
- At the selected point (at least 200 m apart from household)
- The location will be determined by GPS and should be the most central point as possible
- The location should be dictated by the topography and soil conditions

✓ Impacts of the location of the use or operation of the sanitation
- The location of the sanitation plays an important role on the operation and use of the facility. In the context of IS, if the facility is far from user, it may be sabotaged in terms of use, vandalised and misused where applicable.

✓ Other problems that may emerge from the location of the facility
- Vandalism
- Safety
- Fear (during off-peak hours)
- Misuse

✓ Suggestion in terms of finding a suitable/adequate location for the sanitation
- The location should consider the IS conditions (water table, topography)
- Individual system should be not more than 5 m from the shack depending on available space

2. Technical aspects of the model

2.1 Operation and Maintenance

✓ The provided models:
- In general looks easy to operate and maintain; individual systems can be easily maintained as the key O&M include cleaning, sweeping, unblocking pipes or fixing leaking taps.

- Communal systems are also found easy to operate and maintain provided assignment of responsibility to a dedicated person to undertake such work on daily basis
- The O&M for option 3 should be done by the municipality or qualified workers as the collection, transport and disposal of urine and faeces may be costly and problematic.

✓ Additional O&M tasks you believe may be in place to ensure long terms functioning of the facility
- Cleaning and sweeping daily
- Removal of solids
- Clearing blockages
- Collection, transport and disposal of urine and faeces (option 3 only)

✓ Responsibilities for the O&M of the facility
- Municipality (for the communal sanitation)
- Caretaker (appointed by municipality) for small O&M works such as cleaning
- Contractor for extensive O&M tasks (options 2 and 3)
- Household for individual sanitation

✓ Assistance in the O&M of the facility
- User can be used to assist in the O&M but this option may not be possible given the large number of jobless people and can create big expectation;

2.2 Monitoring and evaluation

✓ The models look easy to monitor as all features are exposed and visible to all

✓ It can be monitored:
- Individual sanitation can be monitored by the household with the assistance of municipal officials (on certain basis) but the day to day monitoring should be under the user responsibility
- Caretaker and municipal officials for communal sanitation

✓ M&E criteria
- Physical signs such as odour, blockages, breakage should be considered as M&E criteria as it provides an idea regarding the functioning of the sanitation system.

✓ M&E protocol that can be applied to ensure the functioning of the facility will depend on many factors including willingness by users to collaborate with municipality. It is preferred to have a call centre within the settlement and the municipal office that deals with reported problems. It can be suggested that all problem identified should be:

- Reported directly to the municipality (for individual sanitation)
- Reported to the caretaker for communal facility
- Caretaker to report to municipal officials

3. Assessment and selection of the model

3.1 Assessment criteria

✓ Assessment criteria

- Usability (extent of use)
- Accommodation of users of various background
- Reliability
- Cleanness
- Environmental protection (no signs of spillage of black / greywater or illegal disposal, smell)

✓ Criteria according to their importance
- Usability
- Reliability
- Cleanness
- Environmental protection
- Accommodating all user groups

3.2 Selection criteria

✓ Suitable model for informal settlement conditions: the selection of the model will depend on the potential of the sanitation solution to solving sanitation problems in each context. In general, looking at informal settlement it can be suggested the following:
- Model 2: because it is a flush toilet, provides a space for laundry, separation male and female, no waste of water and collection of greywater and use of human waste to generate energy that can be used
- Model 3: because it is waterless, safe to use, caretaker to do the job, separation between male and female, no waste of water and use of faecal sludge for food security – but the collection and disposal or reuse of faecal sludge and urine may not found favour amongst users.
- Model 1: can be feasible but the conditions do not permit its implementation especially in dense IS; lack of knowledge and understanding of the operational requirements as well as the lack of responsibility are the conditions disfavouring this option.

✓ The selection was made according to the possibilities and capacity offered by each model in responding to the sanitation problems in informal settlements. These responses include
- Response to user needs and requirements
- Adaptation to the local conditions (topography, water table, etc.)
- User satisfaction level

✓ Other criteria for selecting a sanitation model
- Reliability
- Low O&M
- Accessibility
- Water use
- Environmental protection
- Reuse (excreta, energy generation, etc.)
- Handling and disposal of human excreta

- ✓ These criteria can be generally used to select a sanitation solution regardless of the technology, its use and operational requirements.

3.3 Typical model

- ✓ Model 2:
  - Use less water (to flush)
  - Separation male and female
  - Provision of urinal, shower and laundry
  - Caretaker and security
  - Fencing
  - Potential for reusing human excreta on site to generate energy that can be reused

- ✓ Additional features to make the (other models suitable)
  - Solar powered geyser
  - Solar panel for lightening at night
  - Transparent roof (to conserve electricity during day time)
  - Handwash inside toilets
  - Standby extension (if the facility should be upgraded in the future)

Appendix F.3: Pook se Bos

A. Users

- Number of participants: 43 (38 females and 5 males)
- Level of education (range): no formal education to matric
- Age (range): 23 to 62 years
- Employment status: Jobless or casual workers
- Marital status: mixed (married, single and predominantly single parents)


Presentation of the model in Pook se Bos informal settlement

1. Design and application of the model

1.1 Design and features

✓ The design and features suggested were found to be adequate for all 3 models (especially the model 2).

✓ Additional features suggested:
- Ramp for disabled persons
- Dedicated toilet for children
- Geyser
- Sliding doors for disabled and children toilet
- Sitting pan and Special pedestal for kids and disabled persons
- Flushing mechanisms not bucket for water collection (in the case of pour flush)

✓ The proposed features were adequate but if some issues such as disabled and children can be addressed in the design, the 3 models may work well in the context of their informal settlements.

✓ Improvements suggested include:
- Inclusion of security
- Extension of operation
- All day operation (24h00)
- The communal facilities to be provided for limited number of users
- The user ratio should be pre-defined and controlled by the caretaker

1.2 Application and use

- ✓ Models 2 and 3 were found to be suitable for any type of IS and model 1 was not responding to the local conditions. Model 1 may be feasible only when the settlement is not yet dense.

- ✓ The technical solutions shown on the models:
  - Can be acceptable by all users group as it respond to their needs.
  - The individual system cannot be accepted as users may not be ready to be relocated and leaving their spaces for the toilet and pipes, etc.
  - The communal sanitation systems are acceptable on condition that a caretaker is employed to fix problems daily.

- ✓ The context of application:
  - The model 1 cannot be used in IS as spaces are not available; and users may not be ready to accept relocation to create space for the facilities and collection system as well as O&M;
  - The models 2 &3 are applicable in all contexts but should be implemented where space is available
  - The model 2 should be applied where water is available for flushing and where space is provided for discharging greywater and containment of faecal matters
  - The model 3 can be applied only where there is no water availability and where water is not being sparingly used;

- ✓ Suggestion for improvement in terms of application and use of the sanitation solution
  - Consultation with user when design models and listen to their views and needs
  - The design should consider the physical conditions of the settlements

1.3 Location

- ✓ Location of the facility
  - In the middle of IS as a central point to accommodate everyone and safety
- ✓ Impacts of the location of the use or operation of the sanitation
  - The location has huge impact on the use and operation of the sanitation as users may be lazy to walk longer distances to use the toilet and vandalism may be another problem if the sanitation system is isolated from the user interface.
- ✓ Other problems that may emerge from the location of the facility
  - Lesser use of the system
  - Safety
  - Misuse
- ✓ Suggestion in terms of finding a suitable/adequate location for the sanitation
  - The compromise between users and municipality

2. Technical aspects of the model

2.1 Operation and Maintenance

- ✓ The provided models:
  - In general looks easy to operate and maintain if the caretaker is there
  - The O&M for communal sanitation should be done by the municipality or qualified workers

- Dry sanitation should be operated by specialised skilled workers
- Individual systems will not be easy to maintain because of lack of knowledge and money
- The collection, treatment (septic tank), digester, reedbed, etc. should be operated and maintained by the municipality.

✓ Additional O&M tasks you believe may be in place to ensure long terms functioning of the facility
- Cleaning and sweeping daily
- Removal of solids
- Clearing blockages
- Drying faeces (for dry sanitation)

✓ Responsibilities for the O&M of the facility
- Municipality (for the communal sanitation)
- Caretaker (paid by municipality) for small O&M works such as cleaning
- Household for individual sanitation (but only at the property level)

✓ Assistance in the O&M of the facility
- Can assist if trained and paid
- Can't assist because of lack of capacity

2.2 Monitoring and evaluation

✓ The models look easy to monitor as everything can be seen. All features are visible and if anything occurs, it can be easily seen and reported. However, users should be taught about the operation of the sanitation solution to be implemented in their settlement.

✓ It can be monitored:
- User for individual sanitation (at the household level) and municipality afterward
- Caretaker and municipal officials for communal sanitation; user can also assist if the caretaker is not around.

✓ M&E criteria
- No odour
- No blockages
- No broken toilets, urinal or taps
- No visible leaks or spillage
- No flies and rodent

✓ M&E protocol that can be applied to ensure the functioning of the facility
- Installation of a community public phone (connected to the municipal office)
- Identify problem and report to the call centre (if the caretaker cannot solve it)
- Report to caretaker and then to the municipality for communal facility
- Report to the municipality (for individual sanitation)

3. Assessment and selection of the model

3.1 Assessment criteria

✓ Assessment criteria

- Elegance and convenience
- Attractiveness and easy to use by all social group
- Reliability
- Cleanness
- No running faeces and greywater

✓ Criteria according to their importance
- The order of importance should be the one suggested above

3.2 Selection criteria

✓ Suitable model for IS conditions
- Model 2: because it is a flush toilet, provides a space for laundry, separation male and female, no waste of water and collection of greywater, and everything is operated and maintained by the municipality;
- Model 3: because it is waterless, safe to use, caretaker to do the job, separation between male and female, no waste of water and use of faecal sludge for food security
- Model 1: not suitable users are not prepared to take responsibilities given their current status (job and income level).

✓ The selection was made according to the potential offered by each model. The potential include
- Response to user needs and requirements
- User satisfaction level
- Safety and elegance
- Convenience (and accommodating nature)
- The way the model respond to the sanitation problems

✓ Other criteria for selecting a sanitation model
- Extent of O&M
- Accessibility
- Water use
- Robustness

✓ These criteria can be generally used to select a sanitation solution

3.3 Typical model

✓ Model 2:
- Flush toilet (despite being low flush)
- Use less water (to flush)
- Separation male and female
- Provision of urinal, shower and laundry
- Caretaker and security
- Fencing
- Accommodating for all user groups

✓ Additional features to make the (other models suitable)
- Full flushing system

- Provision of sanitary towel bin inside toilets
- Public light at the facility

B. Municipal officials

1. Design and application of the model

1.1 Design and features

- The design and features are relevant and fit well to the local context of any IS. However, the design and features should be made flexible in such a way that it can be customised to the local context.

✓ Additional features suggested: additional features proposed below are general; it is suggested that additional features where applicable should be added by considering the local conditions of the settlements and users behaviour. Some of the proposed features are:

- Ramp for disabled persons
- Dedicated toilet for children and disabled persons
- Nightsoil disposal toilet
- Communal taps for water collection (in the case of pour flush)

✓ The proposed features as shown on the models are adequate in general but should be made specific to each context.

✓ Improvements suggested include:

- Provision for flexibility of design in order to customise to local contexts
- Aeration opening to be made wider in order to generate the circulation of air
- The design should rely less on electricity (e.g. ventilation)

1.2 Application and use

✓ All models are adequately designed, features are adequate but their application must be subject to number of considerations including:

- The type of settlements (in terms of density)
- The physical characteristics of the settlement
- The behaviour and needs of users

✓ The technical solutions shown on the models:

- Can be acceptable by all users group provided user awareness.
- The individual system can be accepted by users but not by municipality as the cost of O&M may be high.
- Options 2 and 3 are suitable and may not be accepted by users as they want their own facilities.

✓ The context of application:

- The model 1: not feasible in dense IS due to lack of space, cost of O&M and willingness of users to participate in the O&M;
- The models 2 &3 are applicable in all contexts but should be implemented where space is available; the number of unit to be implemented may be an issue as municipality may not have sufficient budget to employ caretaker for each facility.

- The model 2 requires water and can be applied only where water is available for flushing. The collection of greywater may require adequate soil conditions if other infrastructure (such as stormwater or sewer) is not in the vicinity; and where space is provided for discharging greywater and containment of faecal matters.

- The model 3 can be applied only where there is no water availability and where water is not being sparingly used; however, user acceptance of dry sanitation may be problematic. In addition, the access to the facility for collecting, disposal of faecal sludge and urine should be considered.

✓ Suggestion for improvement in terms of application and use of the sanitation solution
- The topography and soil conditions should be considered;
- The community behaviour should be considered
- Awareness programme should be in place to assist user understanding the use of the sanitation

1.3 Location

✓ The location of the facility should be dictated by the local conditions; and where applicable it can be determined by mean of GIS bearing the 200 m diameter policy. Individual systems should be located as closer as possible to the user shack and the service sewer should be situated at about 2 m from the toilet.

✓ Impacts of the location of the use or operation of the sanitation
- The location of the sanitation plays an important role on the operation and use of the facility. In the context of IS, if the facility is far from user, it may be sabotaged in terms of use, vandalised and misused where applicable.

✓ Other problems that may emerge from the location of the facility
- Vandalism
- Safety
- Misuse
- Theft of parts

✓ Suggestion in terms of finding a suitable/adequate location for the sanitation
- The location should consider the IS conditions (water table, topography)
- Individual system should be far from the shack depending on available space

2. Technical aspects of the model

2.1 Operation and Maintenance

✓ The provided models:
- The models look easy to operate as every feature is apparent and visible. However, the O&M tasks should be pre-defined in order to avoid expectations.
- The O&M of communal systems is adequate as long the caretaker can be available to undertake soft tasks and the municipality to do the rest. It should be noted that the operation and maintenance of the septic tank and digester may require skilled persons; in this context (of IS) it may be problematic given the large number of users.

- The O&M for option 3 should be done by the municipality or qualified workers as the collection, transport and disposal of urine and faeces may be costly and problematic.

✓ Additional O&M tasks you believe may be in place to ensure long terms functioning of the facility
- Daily cleaning and sweeping (individual and communal systems)
- Removal of solids
- Clearing blockages
- Collection, transport and disposal of urine and faeces (option 3 only)

✓ Responsibilities for the O&M of the facility
- Municipality (for the communal sanitation)
- Caretaker (appointed by municipality) for small O&M works such as cleaning
- Contractor for extensive O&M tasks (options 2 and 3)
- Household for individual sanitation (at the household level) and the municipality for the central collection points.

✓ Assistance in the O&M of the facility
- In the context of IS, it is hard to have users participating in the O&M voluntarily; relying on users in this case may be utopic.

2.2 Monitoring and evaluation

✓ The models look easy to monitor as all features are apparent and visible to all;
✓ The monitoring should be done on daily basis to ensure adequate functioning.

✓ It can be monitored:
- Individual sanitation can be monitored by the household with the assistance of municipal officials (on certain basis) but the day to day monitoring should be under the user responsibility
- User, caretaker and municipal officials for communal sanitation

✓ M&E criteria
- The physical signs such as odour, blockages, breakage should be considered as a basis for M&E.

✓ The simplest M&E protocol is to provide and install a 24 hour toll free call within the settlement. This toll free number can be directly linked to a central server situated at the municipal office:
- Problems are reported directly to the municipality (for individual sanitation)
- For communal facility, problems can be reported to the caretaker or directly to the municipality. It is preferable for users to report to the caretaker and this later report to the municipal officials.

3. Assessment and selection of the model

3.1 Assessment criteria

✓ Assessment criteria
- Accommodation of users of various background

- Cleanness and pleasance
- Reliability
- Environmental protection (no signs of spillage of black and greywater or illegal disposal, smell)

✓ Criteria according to their importance
- Cleanness
- Environmental protection
- Reliability
- Accommodating all user groups

3.2 Selection criteria

✓ Suitable model for informal settlement conditions: each model suggested can work provided adequate user education and accommodating conditions of the settlements. Generally speaking, the following models can be selected in order of priority:

- Model 2: because it is a flush toilet, provides a space for laundry, separation male and female, no waste of water and collection of greywater and use of human waste to generate energy that can be used;

- Model 3: because it is waterless, safe to use, caretaker to do the job, separation between male and female, no waste of water and use of faecal sludge for food security – but the collection and disposal or reuse of faecal sludge and urine may not found favour amongst users;

- Model 1: can be feasible but the conditions do not permit its implementation especially in dense informal settlement; lack of knowledge and understanding of the operational requirements as well as the lack of responsibility is disfavouring this option.

✓ The selection was the model was made according to the potential offered by the sanitation solutions in the context of informal settlement. These potential offered include:
- Reuse
- Generation of energy from waste
- Localised treatment
- Accommodating nature of the sanitation solutions
- Flexibility of the design
- Inclusion of features that respond better to the IS problems

✓ Other criteria for selecting a sanitation model
- Low O&M
- Accessibility
- Water use
- Environmental protection
- Handling and disposal of human excreta

✓ These criteria can be generally used to select a sanitation solution regardless of the technology, its use and operational requirements.

3.3 Typical model

- ✓ Model 2:
  - Use less water (to flush)
  - Separation male and female
  - Provision of urinal, shower and laundry
  - Potential for reusing human excreta on site to generate energy that can be reused
  - On-site treatment

- ✓ Additional features to make the (other models suitable)
  - Solar panel for lightening at night
  - Mechanisms to use generated gas
  - Transparent roof (to conserve electricity during day time)

Appendix F.4: Enkanini

A. Community leaders

Picturing above a site visit with community leaders

1. Design and application of the model

1.1 Design and features

- ✓ The design in general was found to be good and acceptable in terms of features as an attempt was made to address number of issues including:
  - Safety
  - Gender
  - Other activities such as laundry, low water consumption, dignity and privacy

- ✓ Additional features suggested:
  - Ramp for disabled persons
  - Dedicated toilet for children
  - Nightsoil disposal toilet
  - Geyser
  - Sliding doors and locks
  - Sit toilet (not squat)
  - Bucket for water collection (in the case of pour flush)
  - Special pedestal for kids and disabled persons

- ✓ The proposed features were adequate except for the elements suggested above that where not apparent in the drawing or models. If some of the suggestions made above are addressed, the models will be suitable for all contexts.

- ✓ Improvements suggested include:
  - Fencing of communal sanitation
  - Inclusion of security
  - Extension of operation time (e.g. 5.00 to 22.00)
  - Training of local to operate and maintain their own facilities

- The communal facilities to be provided for limited number of users

1.2 Application and use

- ✓ All models were found to be suitable for any type of informal settlement provided user education with regard to:
  - The operation and use
  - The maintenance requirements
  - Compliance with operational requirements

- ✓ The technical solutions shown on the models:
  - Can be acceptable by all users group as it respond to their needs.
  - The individual system can be accepted only if municipality can maintain it (at household level and municipal level).
  - Given that most users are jobless, the individual facility may not be accepted as it will cost in terms of household O&M if no assistance is provided by the municipality.

- ✓ The context of application:
  - The model 1 cannot be used in informal settlement as spaces are not available; and users may not be ready to accept relocation to create space for the facilities and collection system as well as O&M;
  - The models 2 &3 are applicable in all contexts but should be implemented where space is available
  - The model 2 should be applied where water is available for flushing and where space is provided for discharging greywater and containment of faecal matters
  - The model 3 can be applied only where there is no water availability and where water is not being sparingly used;

- ✓ Suggestion for improvement in terms of application and use of the sanitation solution
  - User should be made aware with regard to the use and operational requirements;
  - Consideration should be made for elderly people and children in terms of use and accessibility

1.3 Location

- ✓ Location of the facility
  - At the entrance of the informal settlement for safety reasons as every should see what is happening
  - In the middle of informal settlement as a central point to accommodate everyone and safety

- ✓ Impacts of the location of the use or operation of the sanitation
  - Locating the sanitation far from user may not be adequate and people will be lazy to use
  - The location may lead people to use easy method such as bucket instead of the provided facility
  - The location has huge impact on the use and operation of the sanitation.

- ✓ Other problems that may emerge from the location of the facility
  - Vandalism
  - Safety
  - Fear (during off-peak hours)
  - Misuse

- ✓ Suggestion in terms of finding a suitable/adequate location for the sanitation
  - The location should consider the informal settlement conditions (water table, topography)
  - The compromise between users
  - Individual system should be not more than 5 m from the shack

2. Technical aspects of the model

2.1 Operation and Maintenance

- ✓ The provided models:
  - In general looks easy to operate and maintain if the caretaker is there
  - Individual systems may not work as people don't have knowledge about it
  - The O&M should be done by the municipality or qualified workers

- ✓ Additional O&M tasks you believe may be in place to ensure long terms functioning of the facility
  - Cleaning and sweeping daily
  - Removal of solids
  - Clearing blockages

- ✓ Responsibilities for the O&M of the facility
  - Municipality (for the communal sanitation)
  - Caretaker (appointed by municipality) for small O&M works such as cleaning
  - Household for individual sanitation

- ✓ Assistance in the O&M of the facility
  - Can assist if trained and paid
  - Can assist if supported with relevant materials and equipment (at both communal and individual sanitation)

2.2 Monitoring and evaluation

- ✓ The models look easy to monitor but should be demonstrated to users prior to their implementation
- ✓ It can be monitored:
  - User for individual sanitation (at the household level) and municipality afterward
  - Caretaker and municipal officials for communal sanitation

- ✓ M&E criteria
  - No spillage and leakage
  - No odour
  - No blockages
  - No broken toilets, urinal or taps

- ✓ M&E protocol that can be applied to ensure the functioning of the facility
  - Identify problem
  - Report to the municipality (for individual sanitation)
  - Report to caretaker for communal facility
  - Caretaker to report to municipal officials

3. Assessment and selection of the model

3.1 Assessment criteria

- ✓ Assessment criteria
  - Easy to use
  - No blockages
  - Reliability
  - Cleanness
  - No running faeces and greywater

- ✓ Criteria according to their importance
  - Reliability
  - No blockages
  - No smell
  - Cleanness
  - No spillage of faeces and greywater

3.2 Selection criteria

- ✓ Suitable model for informal settlement conditions
  - Model 2: because it is a flush toilet, provides a space for laundry, separation male and female, no waste of water and collection of greywater
  - Model 3: because it is waterless, safe to use, caretaker to do the job, separation between male and female, no waste of water and use of faecal sludge for food security
  - Model 1: not suitable users are not prepared to take responsibilities given their current status (job and income level).
- ✓ The selection was made according to the potential offered by each model. The potential include
  - Response to user needs and requirements
  - Adaptation to the conditions
  - User satisfaction level

- ✓ Other criteria for selecting a sanitation model
  - Reliability
  - Low O&M
  - Accessibility
  - Water use

- ✓ These criteria can be generally used to select a sanitation solution

3.3 Typical model

- ✓ Model 2:

- Use less water (to flush)
- Separation male and female
- Provision of urinal, shower and laundry
- Caretaker and security
- Fencing

✓ Additional features to make the (other models suitable)
- Geyser
- Full flushing system
- Handwash inside toilets
- Public light at the facility

B. Municipal officials

Municipal officials were invited to attend different workshops organised during the course of the study. Given their roles in the sanitation delivery, their views and taught were found to be relevant in the context of this study.

Municipal officials during a workshop

1. Design and application of the model

1.1 Design and features

- The design and features are relevant as long an attempt was made to the safety, gender and considered privacy and dignity. However, the design and proposed features did not consider other aspects such as children and disabled persons who may not be access the system.

✓ Additional features suggested:
- Dedicated toilet for children
- Nightsoil disposal toilet
- Ramp for disabled persons

✓ The proposed features as shown on the models are relevant; additional features such as solid disposal and incinerator should be provided.

✓ Improvements suggested include:
- Provision for flexibility of design in order to customise to local contexts
- Sludge drying bed and solid disposal to be added

1.2 Application and use

✓ All models are adequately designed but their application and use must be subject to number of considerations including:
- The type of settlements (in terms of density)
- The physical characteristics of the settlement

✓ The technical solutions shown on the models:
- Can be acceptable by all users group provided user awareness.
- The individual system not feasible as the cost of O&M may be high.

- Options 2 and 3 are suitable for users provided continuous awareness and mobilisation.

✓ The context of application:
- The model 1: not feasible in dense IS due to lack of space, cost of O&M and willingness of users to participate in the O&M;
- The models 2 &3 are applicable in all contexts but should be implemented where space is available; the number of unit to be implemented may be an issue as municipality may not have sufficient budget to employ caretaker for each facility.

✓ Suggestion for improvement in terms of application and use of the sanitation solution
- The topography and soil conditions should be considered;
- Awareness programme should be in place to assist user understanding the use of the sanitation

1.3 Location

✓ Location of the facility
- The location should be dictated by the topography and soil conditions

✓ Impacts of the location of the use or operation of the sanitation
- The location of the sanitation plays an important role on the operation and use of the facility. In the context of informal settlement, if the facility is far from user, it may be sabotaged in terms of use, vandalised and misused where applicable.

✓ Other problems that may emerge from the location of the facility
- Vandalism
- Safety
- Misuse

✓ Suggestion in terms of finding a suitable/adequate location for the sanitation
- The location should consider the informal settlement conditions (water table, topography)
- Individual system should be not more than 3 m from the shack

2. Technical aspects of the model

2.1 Operation and Maintenance

✓ The provided models look easy to operate and maintain except for the individual system that may pose some challenges in terms on user responsibility. The O&M for options should be undertaken by skilled and trained operators

✓ Additional O&M tasks you believe may be in place to ensure long terms functioning of the facility
- Cleaning and sweeping daily
- Removal of solids
- Clearing blockages
- Collection, transport and disposal of urine and faeces (option 3 only)

- ✓ Responsibilities for the O&M of the facility
  - Municipality (for the communal sanitation)
  - Caretaker (appointed by municipality) for small O&M works such as cleaning
  - Contractor for extensive O&M tasks (options 2 and 3)
  - Household for individual sanitation

- ✓ Assistance in the O&M of the facility
  - User can be used to assist in the O&M but this option may not be possible given the large number of jobless people and can create big expectation;

2.2 Monitoring and evaluation

- ✓ The models look easy to monitor as all features are exposed and visible to all

- ✓ It can be monitored:
  - Individual sanitation can be monitored by the household with the assistance of municipal officials (on certain basis) but the day to day monitoring should be under the user responsibility
  - Caretaker and municipal officials for communal sanitation

- ✓ M&E criteria
  - Physical signs such as odour, blockages, breakage should be considered as M&E criteria as it provides an idea regarding the functioning of the sanitation system.
- ✓ M&E protocol that can be applied to ensure the functioning of the facility should be as follows:
  - Reporting to the municipality (for individual sanitation)
  - Caretaker to reporting to municipal officials

3. Assessment and selection of the model

3.1 Assessment criteria

- ✓ Assessment criteria
  - Environmental protection (no signs of spillage of black and greywater or illegal disposal, smell)
  - Accommodation of users of various background
  - Reliability
  - Cleanness
- ✓ Criteria according to their importance
  - Environmental protection
  - Reliability
  - Cleanness
  - Accommodating all user groups

3.2 Selection criteria

- ✓ Suitable model for informal settlement conditions: the selection of the model will depend on the potential of the sanitation solution to solving sanitation problems in each context. The main criteria are the cost (in general), environmental protection and sustainability.

- ✓ The selection was made according to the possibilities and capacity offered by each model in responding to the sanitation problems in informal settlement. These responses include
  - Response to user needs and requirements
  - Adaptation to the local conditions (topography, water table, etc.)
  - The cost of O&M

- ✓ Other criteria for selecting a sanitation model
  - Environmental protection
  - Comfort
  - Low O&M
  - Accessibility
  - Water use
  - Reuse (excreta, energy generation, etc.)
  - Handling and disposal of human excreta

- ✓ These criteria can be generally used to select a sanitation solution regardless of the technology, its use and operational requirements.

3.3 Typical model

- ✓ Model 2:
  - Use less water (to flush)
  - Separation male and female
  - Provision of urinal, shower and laundry
  - Caretaker and security
  - Fencing
  - Potential for reusing human excreta on site to generate energy that can be reused

- ✓ Additional features to make the (other models suitable)
  - Solar panel for lightening at night
  - Standby extension (if the facility should be upgraded in the future)

Appendix F.5: Engineers and Designers

A. Engineers

1. Design and application of the model

1.1 Design and features

- The design and features are relevant and fit well to the local context of any informal settlement. However, the design and features should be made flexible in such a way that it can be customised to the local context.

✓ Additional features suggested: additional features proposed below are general; it is suggested that additional features where applicable should be added by considering the local conditions of the settlements and users behaviour. Some of the proposed features are:

- Ramp for disabled persons
- Dedicated toilet for children and disabled persons
- Nightsoil disposal toilet
- Communal taps for water collection (in the case of pour flush)
- Elevated platform (for preventing flooding)

✓ The proposed features are adequate in general but should be made specific to each context.

✓ Improvements suggested include:

- Provision for flexibility of design in order to customise to local contexts
- Aeration opening to be made wider in order to generate the circulation of air
- Consideration of the local conditions
- The septic tank should be maintained watertight all time,
- The design of the septic tank should make provision for uncontrolled use.
- The biogas digester should be well constructed and monitored to prevent risks.

1.2 Application and use

✓ All models are adequately designed and respond to the sanitation problems; features are adequate but their application must be subject to number of considerations including:

- The type of settlements (in terms of density)
- The physical characteristics of the settlement
- The behaviour and needs of users

✓ The technical sanitation solutions presented is accepted by all user groups. The acceptance will mainly depend on the level of comfort and safety offered by each option. In view of the models, option 1 followed by 2 will be preferred than option 3.

✓ The context of application:

- The model 1: not feasible in dense IS due to lack of space, cost of O&M and willingness of users to participate in the O&M;
- The models 2 &3 are applicable in all contexts but should be implemented where space is available;

- The model 3 can be applied only where there is no water availability and where water is not being sparingly used; however, user acceptance of dry sanitation may be problematic. In addition, the access to the facility for collecting, disposal of faecal sludge and urine should be considered.

✓ Suggestion for improvement in terms of application and use of the sanitation solution
- The topography and soil conditions should be considered;
- The community behaviour should be considered
- Awareness programme should be in place to assist user understanding the use of the sanitation,
- Access to the facility should be made available,
- Odour control measures should be explored.

1.3 Location

✓ The location of the facility should be dictated by the local conditions; it preferable to have the facility (the toilet) closer to user as possible.

✓ Impacts of the location of the use or operation of the sanitation
- In the context of informal settlement, if the facility is far from user, it may be sabotaged in terms of use, vandalised and misused where applicable.

✓ Other problems that may emerge from the location of the facility
- Vandalism
- Safety
- Misuse
- Theft of parts

✓ Suggestion in terms of finding a suitable/adequate location for the sanitation
- The location should consider the informal settlement conditions (water table, topography)
- Individual system should be far from the shack depending on available space

2. Technical aspects of the model

2.1 Operation and Maintenance

✓ The provided models:
- The models look easy to operate as every feature is apparent and visible. However, the O&M tasks should be pre-defined in order to avoid wrong expectations.
- The O&M of the septic tank and biogas digester should be carefully planned to prevent breakdown;
- The O&M for option 3 should be done by the municipality or qualified workers as the collection, transport and disposal of urine and faeces may be costly and problematic.

✓ Additional O&M tasks you believe may be in place to ensure long terms functioning of the facility
- Daily cleaning and sweeping (individual and communal systems)
- Removal of solids
- Clearing blockages

- Collection, transport and disposal of urine and faeces (option 3 only)

✓ Responsibilities for the O&M of the facility
- Municipality (for the communal sanitation)
- Caretaker (appointed by municipality) for small O&M works such as cleaning
- Contractor for extensive O&M tasks (options 2 and 3)
- Household for individual sanitation (at the household level) and the municipality for the central collection points.

✓ Assistance in the O&M of the facility
- In the context of IS, it is hard to have users participating in the O&M voluntarily; relying on users in this case may be utopic.

2.2 Monitoring and evaluation

✓ The models look easy to monitor as all features are apparent and visible to all;
✓ The monitoring should be done on daily basis to ensure adequate functioning,
✓ Monitoring of the tightness and biogas digester is crucial and should be carefully planned.

✓ It can be monitored:
- Individual sanitation can be monitored by the household with the assistance of municipal officials (on certain basis) but the day to day monitoring should be under the user responsibility
- User, caretaker and municipal officials for communal sanitation and for the septic tank and digester

✓ M&E criteria
- The physical signs such as odour, blockages, breakage should be considered as a basis for M&E; gas leak, etc.

✓ The simplest M&E protocol is to provide and install a 24 hour toll free call within the settlement. This toll free number can be directly linked to a central server situated at the municipal office.

3. Assessment and selection of the model

3.1 Assessment criteria

✓ Assessment criteria
- Cleanness and pleasance
- Reliability
- Environmental protection (no signs of spillage of black and greywater or illegal disposal, smell)

✓ Criteria according to their importance
- Cleanness
- Environmental protection
- Reliability
- Accommodating all user groups

3.2 Selection criteria

- ✓ Suitable model for informal settlement conditions: generally speaking, the following models can be selected in order of priority:

  - Model 2: because it provides a space for laundry, separation male and female, no waste of water and collection of greywater and use of human waste to generate energy that can be used; it can accommodate large number of user and the O&M is localised.

  - Model 3: because it is waterless, safe to use, caretaker to do the job, separation between male and female, no waste of water and use of faecal sludge for food security – but the collection and disposal or reuse of faecal sludge and urine may not found favour amongst users;

  - Model 1: can be feasible but the conditions do not permit its implementation especially in dense informal settlement; lack of knowledge and understanding of the operational requirements as well as the lack of responsibility is disfavouring this option.

- ✓ The selection was the model was made according to the ability of the proposed model (in terms of design and features) to respond to the sanitation issues.
- ✓ Other criteria for selecting a sanitation model
  - Low O&M
  - Accessibility
  - Water use
  - Environmental protection
  - Handling and disposal of human excreta

- ✓ These criteria can be generally used to select a sanitation solution regardless of the technology, its use and operational requirements.

3.3 Typical model

- ✓ Model 2:
  - Use less water (to flush)
  - Separation male and female
  - Provision of urinal, shower and laundry
  - Potential for reusing human excreta on site to generate energy that can be reused
  - On-site treatment

- ✓ Additional features to make the (other models suitable)
  - Solar panel for lightening at night
  - Mechanisms to use generated gas
  - Transparent roof (to conserve electricity during day time)