Chapter 3

Regenerative sanitation framework

'contrary to popular opinion, innovation without some standardized conceptual framework is tantamount to chaos'

Stephen Bush

3.1 INTRODUCTION

Improving services and expanding access to safely managed sanitation facilities requires a radical shift from technocentric and toilet-focused conceptual frameworks to a more comprehensive, inclusive, holistic, integrated and standardized framework with elements of technology, institutions, cultural values, resource recovery and reuse, users' expectations and rules and regulations; all embedded in a systemic pattern. The restrictive nature of existing frameworks does not depict the complex-dynamic interactions that are inherent in sanitation systems because they primarily focus on particular problem areas of individual aspects of sanitation. For example, the *service ladder framework* focuses on provision and access to toilets without regard to facility functionality (Kvarnström *et al.*, 2011; Potter *et al.*, 2011), the *service chain framework* focuses on analysis of physical flow of faecal sludge and its management (Trémolet & Rama, 2012; USAID, 2016) and the *decision support framework* focuses on technology selection, etc. (Kalbermatten *et al.*, 1980, 1982; Zurbrügg & Tilley, 2007) (Section 1.5); all focusing on technology.

These frameworks leave a lot of lacuna, which create challenges for sanitation management because by providing solutions to a few aspects, other aspects (such as acceptability) are left unattended, so whatever achievement could have been recorded is nullified when placed within the whole sanitation system. A comprehensive and systemic sanitation framework, however, that accommodates synergistic operations of these other aspects and allows for interdisciplinary and transdisciplinary research and practice in policy, technology, sociocultural, economic and ecological considerations, will produce more effective and inclusive results. The regenerative sanitation (ReGenSan) conceptual framework aims to fill this gap

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and seeks to connect the different sanitation subsystems, dimensions and components and synergize their interactions toward a common goal (Cumming, 2011; Pickett *et al.*, 2007). It would serve as a foundation for other elaborate models as it would guide a systemic understanding of the sanitation system towards solution provision (Pollack, 2005). The overall aim of ReGenSan is to refocus the perspectives of researchers, professionals, practitioners, advocacy-agents, policymakers and solution-providers from attacking a problem to providing services and solutions; and then ultimately expand access and improve service by 2030.

3.2 DEVELOPING AN INTEGRATED HOLISTIC FRAMEWORK

An iterative mixed methods approach was adopted in developing this framework by combining technical, experimental and experiential practical knowledge as well as a literature review that included previous related theories, research and concepts that were used to represent similar problems (Brewerton & Millward, 2001; Bocken *et al.*, 2014; Campbell *et al.*, 2015; Martínez-Jurado & Moyano-Fuentes, 2014; Novak & Canas, 2008; Seuring & Muller, 2008). A four-step methodological 'input-processing-output-outcome' detailed approach with rigorous sequential steps of activities was used (Levy & Ellis, 2006; Mayring, 2003; Sethi & King, 1998). The holistic integrated system research approach from Pahl-Wostl *et al.* (2011) was also adopted, together with evidence from scientific literature to assess the ongoing discourse for paradigm shift from technocentric sanitation systems to integrated holistic sanitation systems. To assess the current state of development in this direction, a bibliometric analysis of publications was conducted using the SCOPUS database, and different combination of keywords were applied to define search terms. The resulting dataset, shown in Table 3.1, records the number of publications in peer-reviewed journals in the search space (Pahl-Wostl *et al.*, 2010).

Table 3.1 highlights the fact that research on sanitation focuses primarily on technology and the impact of sanitation on health, hygiene and water. Publications on sanitation-related science show serious emphasis on technology over integrated systems and governance, even given the increase in publications on integrated systems and governance in recent years. In the case of integrated sanitation systems, the publications grew from 14 in 2002 to over 44 in 2015; while sanitation management and governance grew from two publications in 2002 to 15 in 2016. There was also an increase in research that focused on resource recovery and reuse.

The data showed that not much research focused on retrofitting, rehabilitation and repairs of sanitation infrastructures, suggesting the need for a holistic, integrated and systemic sanitation conceptual framework that is not technocentric, but embraces dynamic complexities and contextual issues while delivering context-dependent integrated solutions. This framework seeks to capture the essential characteristics of sanitation systems, elements and structures enunciated by several authors in literature, which constitute the ReGenSan paradigm.

Despite the recognition of the importance of psycho-socio-cultural-economic-ecological issues (including governance, resource recovery and reuse) to providing sanitation services, there has really been no inclusive and comprehensive conceptual framework that captures these dynamic complexities and answers the following questions:

- (I) What are the essential elements needed to transit from rigid locked-in linear conventional (sewer and non-sewer) sanitation to more integrated, holistic and systemic approaches?
- (II) What are the ingredients necessary to understand the complex dynamics of sanitation infrastructure and management solutions?

Table 3.1 Development of Holistic Integrated Sanitation System Research (Cell Value Indicates Number of Papers Matching Each Search Term in Each Year).

	Year																
Search Term	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Total**
Governance AND sanitation	6	9	9	12	13	18	24	39	21	27	36	31	44	30	40	15	374
Sanitation AND social AND science	11	14	11	14	9	9	14	15	22	15	17	30	26	24	14	9	254
Sanitation AND Stakeholders	8	13	17	22	15	27	32	37	29	37	27	59	48	54	46	22	493
Sanitation AND behaviour AND change	7	16	19	13	13	25	24	28	27	30	39	47	44	46	41	11	430
Sanitation AND management AND governance	2	7	6	5	6	10	11	19	10	11	18	14	22	15	15	0	171
Sanitation AND integration	9	5	15	14	15	17	15	19	23	24	26	34	33	24	29	6	308
Sanitation AND integrated AND system	14	19	19	11	23	37	25	38	27	33	29	39	30	44	32	12	432
Sanitation AND management AND integration	3	4	6	9	11	9	9	12	12	11	12	13	16	11	14	2	154
Sanitation AND Integrated AND management AND governance	0	1	1	0	0	3	4	6	0	3	8	3	2	6	4	0	41
Sanitation AND resource AND recovery	3	8	11	7	7	12	9	15	8	14	9	21	12	17	20	14	187
Sanitation AND Reuse	8	8	30	25	17	26	22	45	39	28	17	25	30	39	44	14	417
Sanitation AND retrofitting	0	0	1	1	1	0	3	1	1	4	0	1	0	1	1	0	15
Sanitation AND rehabilitation	8	6	11	10	11	16	11	12	9	9	11	18	15	18	10	2	177
Sanitation AND repairs	2	6	6	8	11	8	8	4	7	4	11	7	8	16	7	7	120
Sanitation AND maintenance	24	24	38	36	32	47	40	70	37	46	56	49	53	59	34	18	663
Sanitation AND water	368	391	554	561	457	618	586	714	659	778	742	882	811	868	766	283	10,038
Sanitation AND health	426	453	520	572	517	601	547	622	680	739	706	824	823	824	605	201	9660
Sanitation AND hygiene	123	167	186	205	180	208	211	251	249	266	253	367	313	380	274	107	3740
Sanitation AND toilet	45	62	50	55	74	93	67	95	104	108	100	124	124	200	97	40	1536
Sanitation AND technology	54	69	99	100	75	106	96	117	115	147	109	158	137	161	135	57	1438
Sanitation AND technology AND management	21	34	37	42	33	49	43	41	49	53	47	53	61	62	45	23	693

Source: Scopus database.

(III) Which kinds of guidance are required to restore unimproved and dysfunctional sanitation systems and incorporate resource recovery and reuse as well as ensure continuous upgrading of existing facilities and providing opportunities for nouveau sanitation systems, especially for populations without access to any sanitation facilities?

(IV) What are the appropriate methodologies to incorporate existing proven approaches such as governance, sociocultural, technologies, social marketing and mobilization and financing mechanisms, at scale, to rethink sanitation practices?

(V) What kind of guidance and tools are required for policymakers and practitioners to implement integrated, holistic and systemic approaches in sanitation spheres?

The ReGenSan framework is primarily based on the potential of holistic and systemic integration as highlighted above. This framework is an interdisciplinary and transdisciplinary conceptual framework that supports an understanding of the complex-dynamic, systemic, integrated and holistic characteristics of sanitation. It is based on the ecological worldview and the 'place-context' and 'scale' focus where comprehensive sanitation solutions are provided within sani-sheds (see Chapter 4). ReGenSan defines 'place-based' as activities, programmes, projects, plans, designs, solutions and such like that are focused on particular singular or groups of localities geographically connected within specific regions and/or areas with similar ethnicities and/or cultures, while context-specific refers to regions, areas and other places that have similar features without necessarily being geographically linked (e.g. coastal areas, arid/water-scarce areas, densely populated, shared religions, high-end, industrial, rural/urban, etc). In addition, scale could be based on population of users/inhabitants, number of required units and area of specific development (e.g. factory/industry, large office area, estates, apartment buildings, airports, schools, healthcare facilities, military bases) as well as levels of pilot study.

This framework aims to induce improvement and mind-change in sanitation planning, technology innovations and implementation. It provides a functional and progressive approach to improving and expanding access to sanitation services at a 'scale' by achieving net benefits for the society (Kvarnström *et al.*, 2011; Potter *et al.*, 2011). The framework combines and integrates sanitation processes and technologies into a systemic whole that addresses the interconnectedness of socio-cultural-economic, environmental, technical and institutional aspects of sanitation management (Marshall & Farahbakhsh, 2013). The aim is to ensure that sanitation systems do not transfer ecological and public health burdens, but provide net benefits to the people and environment. The framework embraces diagnostic (Ostrom, 2005), prescriptive (Cookey *et al.*, 2016a) and normative (Pahl-Wostl, 2009) analytical approaches designed to deliver comprehensive integrated and adaptive sanitation solutions (sani-solutions). This framework is essentially built on the ReGenSan principles (Section 2.4, Chapter 2) and theory (Section 2.3, Chapter 2).

3.3 SYSTEM ELEMENTS OF REGENSAN FRAMEWORK

The ReGenSan system elements include the subsystems, dimensions, components, their relationships, attributes and interactions. Seiffert and Loch (2005) suggested that the most important property of systems is that they are made up of several parts that are not isolated but closely interlinked, forming a complex structure (Chang *et al.*, 2011; Charnley & Lemon, 2011). Therefore, subsystems are part of the whole system, but can still be regarded as individual systems; indicative of the 'system of systems' concept, which depicts the collection of a few dedicated systems or subsystems that pool their resources and capabilities together to connect a more complex metasystem offering more functionality and performance than simply the sum of the constituent systems (Maier, 1998). ReGenSan fits the complex dynamic 'system of the systems' where subsystems (socio-ecological, technology and resource systems) are linked with each other (Chang *et al.*, 2011). The social-ecological subsystem (SES) is made up of two dimensions, governance and psycho-socio-ecophilia (PSEP), with six components; the technology subsystem (TeS) comprises three dimensions: existing improved design technology (EIDT), restorative design technology (ReDT) and nouveau design technology (NoDT) with fourteen components; and the resource subsystem (ReS) is made up of three dimensions: design for recovery and reuse (DeRaR), sanitation service chain raw materials (SSC-RaMs) and sanitation-derived products (SDPs) with 16 components (Figure 3.1 and Table 3.2).

The ReGenSan framework is unique in that it is applicable to both developed and developing countries, and to all stages, processes and cycles of delivering sanitation solutions. The framework has the potential to critically evaluate, analyze and provide credible, adequate and appropriate sanitation solutions by adopting diagnostic, prescriptive and normative analytical approaches (Cookey *et al.*, 2016a; Ostrom, 2005; Pahl-Wostl, 2009). The 'diagnostic' provides detailed existing status reports for interventions that are geared towards either restorative, existing or nouveau solutions. The 'prescriptive' is built upon the diagnostic and strategically determines the appropriateness and adequacy of the applied interventions and at the same time promotes continuous improvement of the sanitation system. The 'normative' is associated with the governance and PSEP considerations that provide the optimum enabling and operating environment for the uptake of scalable solutions. Together, they provide better understanding of the interconnections of knowledge and interactions among the sanitation subsystems, dimensions and components. The framework's overarching objectives are presented in Box 3.1.

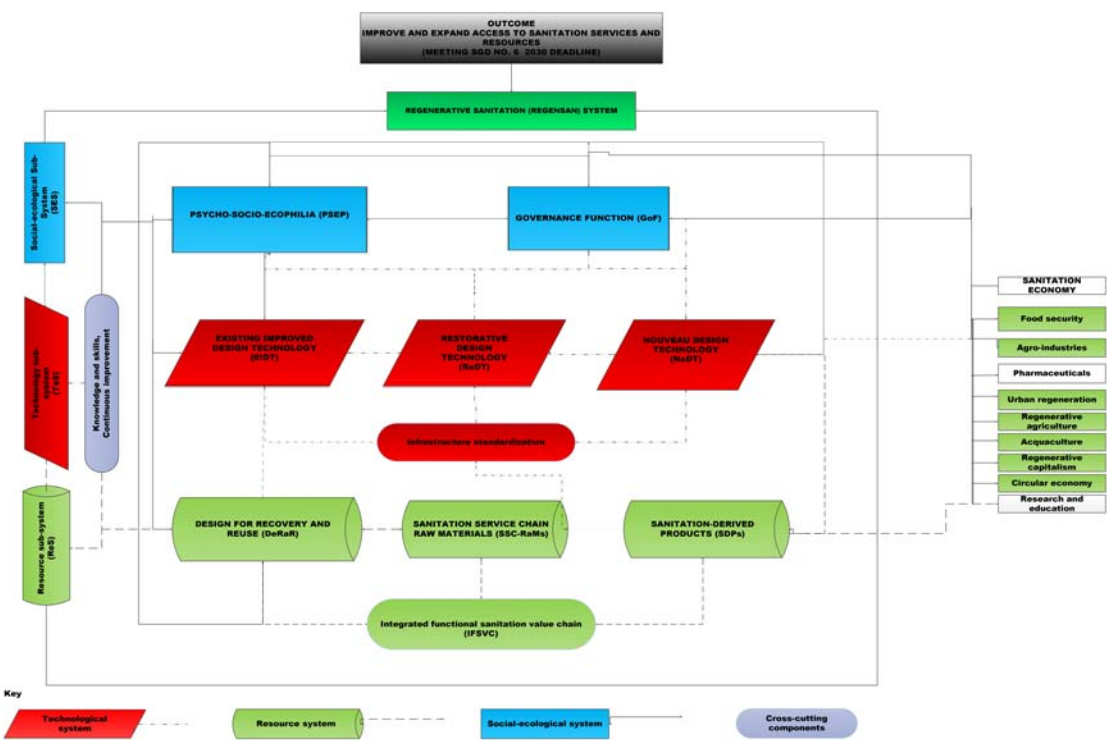

Figure 3.1 Conceptual framework of ReGenSan designed for the acceleration of sanitation coverage and service improvement.

Table 3.2 Summary of Regenerative Sanitation Subsystems, Dimensions and Components

Subsystems	Dimensions	Cross-Cutting Components	Components
Social-ecological system (SES)	**Psycho-socio-ecophilia (PSEP):** provides contextual and sociotechnical contributions for decision-making in sanitation infrastructure and management solutions as well as providing the needed socio-ecological-technology fit.	*(i) Continuous improvement*[†] *(CiM), (ii) knowledge and skills*[†] *(KaS), (iii) sanitation infrastructure standardization (SIS), (iv) integrated functional sanitation service chain (IFSVC)*	(*i*) *Psycho-social-cultural*: religion, norms, customs, availability, accessibility, acceptability, willingness to use, gender equity, inclusiveness, perceptions and attitude, health, hygiene and handwashing, preference, status, (*ii*) *Socio-economic:* educational level (formal and informal), income level (affordability, willingness to charge and willingness-to-pay), livelihood support (economic activities and occupational engagement), access to basic services (water supply, electricity, and healthcare), access to sanitation services and types (sewer, non-sewer, *shared and non-shared facilities*), geographical location (urban and rural), housing/dwelling types, household sizes and head of household, age, gender and race *(iii) Bio-geo-chemical:* nutrients and water (C (carbon), N, P, H_2O) cycling, ecosystem services and functions, fauna and flora
	Governance: provides an enabling environment, standards and regulations, funding mechanism and asset management procedures with the socio-ecological support for the uptake of functional and adaptable technologies and resource recovery fit for the 'place' and 'scale'.		*(iv) Institutions:* policies, legislation and regulations, informal institutions, international treaties and protocols *(v) Management:* sanitation management entities (SMEs), planning and implementation, asset management, clearly defined roles of actors, stakeholders' information and communication, regulatory compliance and enforcement, monitoring and evaluation *(vi) Sustainable financing:* Blending public and private funding sources, resource leveraging, cost recovery and lifecycle costing, supplementary income and social marketing and utilization of local/domestic private sector

Technological system (TeS)	**Existing improved design technology (EIDT):** focuses on continuous service improvement, expansion of access and coverage of the currently adjudged improved and safely managed sewer and non-sewer sanitation facilities estimated to be used by 5 billion people.	*(i) service chain functionality and serviceability, (ii) integrity, reliability, safety and quality, (iii) preventive and proactive maintenance, (iv) inspection and monitoring and (v) infrastructure standardization**
	Restorative design technology (ReDT): addresses the issues of upgrading and retrofitting of dysfunctional, aged, disused and unimproved, basic and limited sanitation facilities for both sewer and non-sewer to safely manage sanitation estimated to be used by 2.4 billion people.	*(vi) Rehabilitation, (vii) retrofitting and (viii) remediation and mitigation*
	Nouveau design technology (NoDT): focuses on the issues of emerging novel sanitation facilities solutions because of failure of current technologies to address the underlying challenges behind the lack of sanitation infrastructure and resources recovery as well as provide better alternative for new development area and the population exposed to open defecation estimated to be nearly 1 billion people.	*(ix) Design for service and products (DeSaP), (x) design for nature (DeN) and (xi) design for the base-of-the-pyramid (DeBoP).*

(*Continued*)

Table 3.2 Summary of Regenerative Sanitation Subsystems, Dimensions and Components (*Continued*).

Subsystems	Dimensions	Cross-Cutting Components	Components
Resource system (ReS)	**Design for recovery and reuse (DeRaR):** provides technological and infrastructural support for operationalization of ReS.		*(i) Recovery and reuse from existing facilities, (ii) alternative design for recovery and reuse, (iii) demand based-design and (iv) health and safety, (v) integrated functional sanitation value chain (IFSVC)**.
	Sanitation service chain raw materials (SSC-RaMs): provides the input materials for ReS.		*(vi) faeces, (vii) urine, (vii) flushwater, (ix) greywater, (x) anal cleansing water and other materials and (xi) sludge (faecal and sewage)*
	Sanitation-derived products (SDPs): provide recoverable and reusable products and sanitation systems.		*(xii) used water, (xiii) sanitation-derived fertilizers (SDFs) (xiv) bioenergy, (xv) soil conditioners and (xvi) other output materials, e.g. protein feed, building materials, trace elements*

*Components applicable to all dimensions of technology subsystem.
†Components applicable to all subsystems.

BOX 3.1 OBJECTIVE OF ReGenSan FRAMEWORK

(I) Generate transdisciplinary system understanding for service improvement and access expansion;
(II) Develop and implement sani-shed specific methods, models, technological and resource recovery and reuse solutions as well as evolve contextual-dependent governance structures and strategies for 'place'- and 'scale'-based sanitation service delivery;
(III) Integrate science-policy-technology-practice research into sanitation space through a cyclical learning process; and
(IV) Indicate the potential for a sanitation economy that interacts with the circular economy.

ReGenSan identifies and integrates three subsystems and cross-cutting subsystems' components, seven dimensions and 26 components (Table 3.2). These subsystems and dimensions are described below (for more details see Chapters 4 to 6).

3.3.1 Social-ecological subsystem (SES)

SES seeks to provide an understanding of the multifaceted/multilevel interactions and intersections between ecology and society in the management of sanitation in sani-sheds. It acknowledges that the divide between ecosystem, human system and technological system is largely arbitrary; and the success of any sanitation intervention depends on the symbiotic-synergistic understanding of the SES and their linkages to other subsystems (Repella, 2014). The subsystem seeks to provide better understanding of the interactive effects of psycho-social, cultural, economic, geographical and ecological issues that influence the whole spectrum of sanitation science, governance, practice and technology guided by knowledge and skills (Hinkel *et al.*, 2014; Ostrom, 2009; Ostrom & Cox, 2010; Partelow, 2016; van Vliet *et al.*, 2011; Whittington *et al.*, 1993). SES consists of two dimensions: (psycho-socio-ecophilia and governance) and seven components (Figure 3.1 and Table 3.2).

3.3.1.1 Psycho-socio-ecophilia (PSEP)

PSEP provides contextual and behavioural perspectives to introduce psycho-socio-ecological-technical variables into assessment and decision-making for sanitation solutions. It emphasizes the importance of 'place' and 'scale' and focuses on providing sanitation solutions within 'sani-sheds', which ensures that sanitation systems connect with the peculiar characteristics of the locality (Kellert *et al.*, 2008; Mang & Reed, 2012a, b; Whittington *et al.*, 1993) to sustain the essential functions and processes of the ecosystem (Lyle, 1984, 1994; Van der Ryn & Cowan, 2007). Ambitious sustainability goals can only be fulfilled by co-design of sanitation technology with potential users in the 'system of the place' (Tobias *et al.*, 2017). ReGenSan argues that sanitation systems should be designed to suit 'place' because the diversity of social and ethnic groups existing in any locality greatly influences appropriate designs, accessibility, acceptability, affordability, construction and use of such systems (Domènech & Saurí, 2010; Hegger *et al.*, 2007; Larsen *et al.*, 2010; McConville *et al.*, 2014; Raven, 2007; Whittington *et al.*, 1993). PSEP could potentially become a strong driving force for the needed transition (Spaargaren *et al.*, 2007) in planning, operations, maintenance and cost recovery, where stakeholders are empowered to make choices about what kind of sanitation systems they wish to use and how it will be managed (See Box 3.2, Ferguson *et al.*, 2003).

3.3.1.2 Governance

Governance enhances the effectiveness and efficiency of sanitation operational responsibilities (i.e. the day-to-day functionality of the services delivered) and institutional arrangements (i.e. the formal and informal institutional contexts that help or hinder the successful delivery of day-to-day activities) (Joshi *et al.*, 2015; Kooiman, 2003; Maurer *et al.*, 2012; Ross *et al.*, 2014; Schertenleib, 2005; Starkl *et al.*, 2013). It encompasses arrangements for ownership, management and operations, institutional and regulatory frameworks (including setting and meeting requirements of standards, resource recovery, emission standards, pricing guidelines, funding mechanisms, cost recovery etc. (Galli *et al.*, 2014; Kooiman, 2003; Lüthi *et al.*, 2011a, b; Maurer *et al.*, 2012; Rodic, 2015; Ross *et al.*, 2014; Schertenleib, 2005; Starkl *et al.*, 2013; Tilley *et al.*, 2014a, b). It could also support and indicate technology selection and uptake as well as financial mechanisms for sanitation solutions (Figure 3.1 and Table 3.2).

3.3.2 Technological subsystem (TeS)

TeS is the configurations of infrastructures and services combined to treat by-products of human digestion from the point of generation to the final point of reuse or disposal. It includes an extensive range of possible combinations of technical and sociotechnical components driven by sanitation infrastructural standardization to deliver the most appropriate and best applicable solutions (Maurer *et al.*, 2012; Ramoa *et al.*, 2015; Tilley *et al.*, 2014a, b; Zurbrügg & Tilley, 2009). The ReGenSan TeS encompasses the entire sanitation service of '*users' interface-drop/or flush-store-treat-recover-utilize*'. The sociotechnical components are the economic, social, cultural and institutional contexts made up of multidimensional technological characteristics (place, scale and process), management and governance, financial arrangements and organizational set-up as well as active involvement of the end users (Altaf, 2011; Grübler, 1998; Oosterveer & Spaargaren, 2010; Starkl *et al.*, 2015). There are three dimensions to TeS: Existing Improved Design Technology (EIDT), Restorative Design Technology (ReDT) and Nouveau Design Technology (NoDT), and 12 components (Figure 3.1 and Table 3.2).

3.3.2.1 Existing Improved Design Technology (EIDT)

EIDT focuses on continuous improvement of the currently adjudged improved sanitation (safely managed, basic and limited services) facilities estimated to be used by 5 billion people (JMP, 2015; WHO/UNICEF, 2017) as well as ensuring an effective and efficient service chain management for the estimated 2.7 billion people using on-site sanitation worldwide (Nakagiri *et al.*, 2016; Strande *et al.*, 2014). The cardinal rule of EIDT is to ensure long-term sustainability of sanitation services and avoid the risk of 'slippage' – a term coined in India to refer to the slipping back of a community from 'fully covered with improved services' to 'partially or non-covered' (Lockwood & Smits, 2011; Rosenqvist *et al.*, 2016, UN-Water & WHO, 2012; Verhagen & Carrasco, 2013). This is achieved through standard operations and maintenance and enhanced advancement on the sanitation service ladder (Exley *et al.*, 2014; Ghosh & Elvira, 2011; Nakagiri *et al.*, 2016; Strande *et al.*, 2014). It aims to address the ageing problems of sewer infrastructures that do not deliver standard and quality effluent and sludge treatment (Baum *et al.*, 2013; Hutton *et al.*, 2007; Nansubuga *et al.*, 2016; Nhapi *et al.*, 2006; Starkl *et al.*, 2013, World Bank, 2003) as well as issues of actual use, cleanliness, quality of latrines/toilets, handwashing, hygiene promotion, toilet waste management (e.g. used tissue, menstrual pads, baby diapers, etc) behavioural change, facilities' integrity, quality control and assurance (Exley *et al.*, 2014; Gine *et al.*, 2011) (Figure 3.1 and Table 3.2).

3.3.2.2 Restorative design technology (ReDT)

ReDT seeks to retrofit unimproved and dysfunctional sanitation systems as well as support mitigation and remediation of polluted/degraded sites damaged by existing sanitation practices (Jenkin & Pedersen, 2009; Mang & Reed, 2012a, b). This strategy is necessary in view of the large population (2.4 billion) with inadequate and dysfunctional sanitation infrastructures (JMP, 2015). The pressing goal is to better understand the reasons for continued system failure and how they could be avoided in the future (Starkl *et al.*, 2013). Restorative designs arise due to structural inadequacies, material degradation and poor construction and workmanship, as well as ageing facilities and lack of operation and maintenance (Brepolsa *et al.*, 2008; Brikke, 2000; Cookey *et al.*, 2016a), which increase exposure to pathogens present in unconfined or poorly disposed human excreta (Boschi-Pinto *et al.*, 2006; Cairncross & Feachem, 1993; Ekane *et al.*, 2014). ReDT will ensure sustainability of sanitation systems to deliver services at an appropriate level of hygiene, quality, quantity, convenience, comfort, continuity, efficiency and reliability; and the institutionalization of complete coverage of operations, maintenance, administration and replacement strategies (Brikke, 2000). ReDT advocates for retrofitting and upgrading of existing wastewater treatment systems to meet stringent treatment requirements, increasing hydraulic and/or organic loading capacity, improving poor performance due to improper plant designs and/or operations, elongating expiry lifespan of ageing treatment plants and changing effluent limitations and wastewater treatment trends (Bozkurt *et al.*, 2015; Brepolsa *et al.*, 2008; El-Sheikh, 2011; USEPA, 1974). ReDT also aims to address the challenges of on-site systems, especially the unimproved systems that are poorly designed, constructed, operated and maintained (Giné-Garriga *et al.*, 2017; JMP, 2008, 2012, 2015; Mjoli, 2012; Pham & Kuyama, 2013) as well as improved systems that do not deliver, especially where local contexts were ignored (Starkl *et al.*, 2013) (Figure 3.1 and Table 3.2).

3.3.2.3 Nouveau design technology (NoDT)

NoDT addresses a spectrum of emerging technological and novel solutions based on the core principles of regenerative sanitation. It seeks to develop sanitation technologies that integrate eco-efficiency with ecologically based approaches that mimic nature to deliver improved functional systems peculiar to local contexts. The strategic role of NoDT is to contribute to the development of innovative solutions for the 700 million people who missed the MDG new development areas, as well as the 892 million people who have no facilities at all and are exposed to open defecation (JMP, 2015; WHO/UNICEF, 2017). Depending on the possibilities of the opportunity in the 'place', NoDT is to provide solutions at a scale in sani-sheds, taking into account the PSEP to deliver optimum services (Spaargaren *et al.*, 2006). Thus, within an SES, there might be different technologies in operation with each responding to local conditions, but playing its part in the larger whole (Lyle, 1994) (Figure 3.1 and Table 3.2). NoDT systems set an extensive range of possible combinations of SES and ReS to deliver sanitation technological infrastructural solutions for the provision of adequate products and services.

3.3.3 Resource subsystem (ReS)

ReS is concerned with 'closing the loop' by turning the linear resource management schemes of sanitation systems into a cyclical one that feeds the sanitation economy to eventually support the circular economy. Thus, ReS focuses on how to recover and reuse valuable resources of by-products of human digestion in order to ensure that sanitation systems minimize depletion of natural resources and environmental degradation. Recovering and reusing the valuable resources present in excreta, urine and wastewater contributes to resource efficiency and improved food security (Andersson *et al.*, 2016a, b). Closing these loops require synergies between technological, social, environmental and institutional systems and sound financing mechanisms, thus, making resource management systems major components of the overall sanitation system. There are three dimensions: design for recovery and reuse (DeRaR), sanitation service chain raw materials (SSC-RaMs) and sanitation-derived products (SDPs), with 16 components (Figure 3.1 and Table 3.2).

3.3.3.1 Design for recovery and reuse (DeRaR)

DeRaR facilitates a shift from 'design-for-disposal' to 'design-for-recovery' to ensure that SSC-RaMs are provided in the right quality and quantity for the needed transformational processes to SDPs. This approach effectively shifts the goal of sanitation from solely 'safe disposal' and/or 'safely managed' facilities to maximizing the extent to which embodied resources are safely captured for recovery and reuse as well as to deliver public and environmental health benefits. It has the potential to contribute productively to local economies and livelihoods (Murray & Buckley, 2009) and is characterized by the process of 'sanitise and recycle', based on preventing pollution through nutrient recovery for food production in the local communities (Haq & Cambridge, 2012) and producing water, nutrients, organic matter, energy and other valuable minerals from human waste and wastewater (Bahri, 1999; Jenkins & Sugden, 2006; Kujawa-Roeleveld & Zeeman, 2006; Lazarova *et al.*, 2001; Lens *et al.*, 2001; Maurer *et al.*, 2012; Simha *et al.*, 2017; Wielemaker *et al.*, 2016; Zeeman, 2012). DeRaR approaches are not technocentric or toilet-focused, but centre on resources and their management (Andersson *et al.*, 2016a, b) and have the capacity to act across the whole spectrum of the sanitation system (Brands, 2014; Esrey, 2002; Larsen *et al.*, 2013; Lens *et al.*, 2001; SuSanA, 2008) (Figure 3.1 and Table 3.2).

3.3.3.2 Sanitation service chain raw materials (SSC-RaMs)

SSC-RaMs provide the raw materials for the biophysical-chemical transformation to SDPs through DeRaR. These input materials such as faeces, urine, flushwater, greywater, cleansing water, sludge (faecal and sewage) and other materials. These materials require integrated and holistic management approaches to ensure that adequate resources are recovered and to maintain public health and environmental protection.

3.3.3.3 Sanitation-derived products (SDPs)

SDPs ensure that the transformed materials are delivered to target potential direct and indirect users and customers for utilization. For example, SDPs such as used water and struvite can contribute to improving agricultural productivity and soil quality (Andersson *et al.*, 2016a, b; Brands, 2014; Esrey, 2002; Larsen *et al.*, 2013; Lens *et al.*, 2001; SuSanA, 2008). Thus, a viable business model could emerge from used materials recovered from sanitation systems, which in turn helps ensure sustainable provision of safely managed sanitation facilities (Murray & Ray, 2010) (Figure 3.1 and Table 3.2).

3.3.4 Cross-cutting components

The ReGenSan framework has four major cross-cutting components, namely: continuous improvement (CiM), knowledge and skills (KaS), sanitation infrastructure standardization (SIS) and integrated functional sanitation value chain (IFSVC). These transversing features cut across the whole system and are vital and applicable to all the subsystems, dimensions and other components. They are essential for a successful implementation of ReGenSan solutions, practices, innovations and interventions. They serve as decussating (cross-cutting) parts that keep the wheels of the system well-oiled to guarantee unhindered progress and sustained maintenance. First, they interact and blend together in appropriate portions to form a brew that provides subsystems' dimensions and components with essential ingredients to operate and function as they should; and then they interact with actors in the subsystem along the

IFSVC to create a sanitation informion system that supports the entire system process as well as the robustness of the sanitation economy within and across sani-sheds. Thus, they enable a ReGenSan system to contribute to food security, agro-industries, agriculture, construction etc. (Figure 3.2).

In broad terms, knowledge of the processes involved in core sanitation is key to ensuring sustainability and effective comprehension of the intricate and complex dynamics that often play out in practice. One major challenge in the field of sanitation is that decisions are generally made on available information (e.g. number of toilets), but information is not knowledge. Knowledge is the logical assessment of information that produces concepts and direction for design, development, fabrication, installation, treatment, recovery, distribution, monitoring and evaluation etc. Subsequently, products and services are created for sanitation and support. When acquired and accumulated knowledge is put to practice, appropriate skills are developed to provide products and render services. Without adequate and required skills, ReGenSan will be stopped in its tracks because (contrary to past opinion) sanitation is a skilled occupational field. Most sanitation workers (particularly in the informal sector of developing countries) are unskilled and untrained and so are exposed to occupational hazards as well as putting public health at risk (Košturiak & Frolík, 2006). Therefore, KaS is essential in all subsystems, dimensions and components.

In addition, standards are key to ensure replicability, reliability and functionality across the subsystems. They also support continuous improvement (CiM), where KaS is required to perform and maintain acceptable quality output. These cross-cutting components form the backdrop for the structure of the ReGenSan framework and guarantee the sustainability of improved, enhanced and upgraded sanitation provisions in the system. Consequently, standardization interacts with all dimensions and components to ensure that sanitation facilities, technology and practices are regularized to create required uniformity, scalability and replicability that eventually leads to affordability, which encourages return on investment (see Section 5.3). In addition, sanitation infrastructural standardization (SIS) is an essential foundation for CiM because without standards there can be no strategic improvement and progressive processes for effective and efficient implementation of EIDT, ReDT, NoDT, DeRaR, SDPs, IFSVC and Governance (MÍkva *et al.*, 2016). Integrating SIS and CiM ensures that sanitation systems operate at a reduced failure, abandonment and operational dysfunctional rate while also maintaining and rehabilitating aged infrastructure/facilities to reduce negative effects on public health and environment (Košturiak & Frolík, 2006). The IFSVC of ReS (see Section 6.3) is designed to drive the economic viability, livelihood support and supply chain within and across sani-sheds to boost the sanitation economy; and also interacts with other dimensions and components to ensure holistic and systemic integration between sanitation enterprises' operational functions such as primary productions, transformation, marketing and final sale with key actors/operators such as designers, producers, integrators, processors, traders, suppliers and distributors to deliver value-added SDPs to users and/or customers (Chapter 6). For details of CiM and KaS see the next two sections.

3.3.4.1 Continuous improvement (CiM)

ReGenSan proposes a CiM that will ensure sustained progressive strategies, practices and processes (Kiran, 2016; Yang *et al.*, 2016). This defines key performance indicators (KPIs) that would be used to measure the performance of sanitation solutions (Kiran, 2016) and provides opportunistic learning from past performance that could lead to future improvements. CiM operates with standards and certifications to guarantee performance quality, replicability, reliability, functionality, serviceability, acceptability, accessibility and contextuality. It will provide innovative measures for reducing abandonment, dysfunctionality and failures of existing sewered and non-sewered sanitation by increasing the information flow and decreasing the costs of poor-quality infrastructure (Robescu *et al.*, 2016; Silivestru *et al.*, 2014). KaS will deliver innovative management using best applicable and most appropriate techniques, tools and practice to ensure that the quality of products and services meet users/customers' requirements and long-term objectives. CiM will depend on effective record-keeping that builds up a sanitation information system database that is used to pursue environmental quality, technological specification and resource recovery among other things on a persistent loop in order to correct errors, problems and gaps as they occur or are exposed. This cross-cutting component is based on the ReGenSan principles of ApT (2.4.1), NToB (2.4.5), FPG (2.4.3) and RoDT (2.4.10) and is designed to incrementally improve sanitation products/services and access/delivery so as to meet set goals and targets (Anand *et al.*, 2009; Peng *et al.*, 2008; Yang *et al.*, 2016). ReGenSan proposes that CiM could support effective and efficient products and service and delivery (Robescu *et al.*, 2016) if:

(I) CiM is seen as a primary tool for positive change that will improve sanitation infrastructure technology;
(II) Sanitation services and products are designed and provided from users/customers' perspectives;
(III) System and subsystem processes are assessed externally and collaboratively to identify the issues for improvement;
(IV) Processes in the sanitation system are continuously improved (this will require constantly providing KaS to empower people to tackle problems as soon as they arise to prevent escalation; as early improvements will lead to proactive activities that produce positive effects later);
(V) Provide KaS training (for CiM) to equip operators, service providers, users/customers, regulators, auditors etc. with requisite understanding and capacity; and
(VI) Standards and key performance indicators (KPIs) are developed to direct CiM.

CiM strengthens SIS by KaS to support sanitation facility integrity, reliability and improved performance. This is dependent on knowledge, skills, competencies and significant information, which make it possible to visualize total quality sanitation management striving towards expanding access and improving service of safely managed and resource recovery facilities in the sani-sheds (Deighton, 2016).

3.3.4.2 Knowledge and skills (KaS)

Knowledge is acquired through the comprehension of information gained through learning that creates and enhances the skills, and the proven ability to apply acquired knowledge and skills (KaS) to technological management of solutions in sanitation is indispensable to successful and effective ReGenSan implementation (Grün *et al.*, 2009; Quendler *et al.*, 2013). Over the years, KaS for regenerative transformations in society has been in short supply, which has led to serious shortfall in the human resource requirement for disciplines related to regenerative development (Bagwell, 2007). In addition, there already exist skills gaps in traditional/conventional sanitation practice, which impacts the ability to deliver set goals and targets for the sector (Bos, 2006), especially in the services sectors that lack holistic perspective on skill development (IWA, 2014a). Countries such as Indonesia and the Netherlands among others are faced with systemic issues such as staff attrition, erosion of experience, the reluctance of new graduates to join the sanitation sector (WWAP, 2016) and (particularly in OECD) an ageing workforce (Wehn & Alaerts, 2013). The gruelling tasks of sanitation workers in the informal sectors of most developing countries are often carried out without requisite KaS to ensure occupational health and safety (OHS), public health and environmental protection. This negates the progress of the sanitation movement and it is imperative that ReGenSan target KaS upgrading and dissemination to guarantee effective programmes.

This challenge requires the design of adequate training tools and innovative learning approaches to enhance the competencies of staff as well as strengthen institutional capacity to deliver effective and efficient services (WWAP, 2016). Lower- and middle-income countries failed to ensure that the corresponding human resource base needed to design, construct, operate and maintain services was available and adequate for longer-term efforts in the pursuit of agreed goals and targets (IWA, 2014b). This could be related to:

(I) Lack of financial resources for hiring and retaining staff (salaries and benefits), especially in the public sector;
(II) Difficulty of attracting skilled workers to live and work in rural areas;
(III) Mismatch between courses offered and job requirements;
(IV) Inadequate funding for educational institutions;
(V) High cost of tuition;
(VI) Absence of continuous training systems in many countries;
(VII) Lack of government policies that create enabling environments;
(VIII) Image problems and stigma associated with the sanitation sector.

Optimum services satisfactory to users/customers will require new ways of working and new sets of skills for sector practitioners (Bagwell, 2007). Sanitation workers should have the requisite understanding of and ability in KaS in order to comprehend, operate and implement ReGenSan requirements, as it will take creative and systemic planning and designs to weave diverse factors (human and natural) together into one coherent whole. And then, within the whole, creative, functional, operational and logical skills are crucial for effective service delivery (Lyle, 1994). Subsequently, this could be achieved by:

(I) Creating enabling policy environments for collaborative frameworks between education, employers (public, private, NGOs), trade unions and employees in the sector;
(II) Developing incentives to attract and retain staff;
(III) Strengthening technical and vocational training; and
(IV) Giving attention to human resources capacity development in rural areas

A transition to sanitation 4.0, as proposed by the ReGenSan framework (see Sections 1.4.4 and 1.4.5) will entail critical support for KaS that provides the ability to expand access to safely managed facilities, devices and services as well as enhance resource capturing with environmental/natural resource protection. Accordingly, ReGenSan advocates that sanitation practitioners' generic and technical KaS (at high and low levels) be sufficient for effective and satisfactory ReGenSan practice that could deliver the required changes the sector craves (McGrath & Powell, 2016). Adequate and appropriate education and training are necessary so as to equip sanitation practitioners, workforce and the society with the core values, competences and KaS for the future of sanitation. ReGenSan draws from several disciplines such as environment, medicine, nutrition, agronomics, geography, engineering, architecture, citizenship, sociology, psychology, fishery/aquaculture, urban and rural development, political science, history, law, anthropology, economics and business; and so cannot be pursued in isolated disciplines (Annan-Diab & Molinari, 2017; Defries *et al.*, 2012). It therefore implies a revision of sanitation teaching and research contents to respond to global and local challenges. The idea is to promote teaching methods that generate KaS for interdisciplinary and systemic thinking, integrated planning, cooperative/collaborative decision-making and understanding the inherent complexities in the sanitation system, within sani-sheds. In other words, targeted and practical capacity-building for adequate and appropriate KaS across IFSVC (Quendler *et al.*, 2013). KaS that simultaneously cuts across through the subsystems (SES, TeS and ReS) and relevant external forces (sanitation economy, agriculture etc) will facilitate real-time problem-solving as it engenders better comprehension of each part to create solutions that tap in to different disciplines thereby blurring boundaries in the delivery of sustainable sanitation solutions. In essence, scientists (physical, medical, biological and social); engineers (sanitary, environmental, chemical, biological, mechanical, electrical/electronics etc), humanities professionals (philosophers, anthropologists, historians etc), builders (architecture, urban regeneration, rural development, planners, landscapers etc), finance and economics professionals and others should work together from local to global scales to combine knowledge, tools and approaches to develop ReGenSan infrastructural technological and management sanitation solutions (Annan-Diab & Molinari, 2017; Defries *et al.*, 2012).

3.4 SUBSYSTEMS' SYNERGISTIC INTERACTIONS

Figure 3.1 highlights the interactions, interrelationships and interdependencies of the three subsystems, seven dimensions and 27 components of ReGenSan for research, policy-making, planning, design, development and management of sanitation systems that are in harmony with the physical environment, human systems and the surrounding natural systems. The framework depicts a holistic and system thinking design for the integration of technological, ecological, economic, psycho-social and political systems for sanitation management.

The SES is the foundation of the ReGenSan system, in which the governance dimension provides the rules, guidelines and enabling environment for practice and service delivery based on the system of the 'place' and 'scale' (PSEP dimension). Governance and PSEP work in tandem to prescribe design and develop technologies for the 'place' and 'scale' and also influence resource recovery and reuse by determining appropriate approaches for adoption. The objective is to improve service delivery and expand access by meeting the goals and targets of SDG no. 6 by the year 2030. The overall outcome could support a sanitation economy where resources from sanitation support the circular economy through a symbiotic synergistic relationship between the subsystems, dimensions and other external actors via continuous feedback mechanisms. The governance and PSEP dimensions provide needed support to each other with governance directing behaviours and incorporateing peculiar features, norms, customs and practices, while PSEP assists governance processes and mechanisms with information, knowledge, skill, support and acceptability among other things. There is a positive and negative feedback loop between the two dimensions of SES. Previously, the inadequate considerations for PSEP and lack of synergy between all dimensions negatively impacted the successful implementation of sanitation intervention programmes, as illustrated in the National Sanitation Bucket Replacement programme in South Africa presented in Box 3.2.

BOX 3.2 SOUTH AFRICA'S NATIONAL SANITATION BUCKET REPLACEMENT PROGRAMME

The South African National Sanitation Bucket Replacement was a near classic case of RoDT aimed at replacing and upgrading an estimated 252–254 bucket toilets located across seven provinces. The bucket sanitation systems were unhygienic and expensive to maintain and violated the dignity of users and those responsible for collection and disposal (Mjoli, 2012). The national programme started in 2005 and by the end of 2008 more than 91% of the target number of bucket toilets had been replaced by waterborne sanitation systems and upgraded Ventilated Improved Pit (VIP) toilets (DWAF, 2008a). The programme, however, faced challenges that could be attributed to a disregard of the PSEP dimension because some municipalities' bulk sewers and wastewater treatment capacities were inadequate and in some areas the available water supply could not support the new waterborne sanitation systems (Mjoli, 2012). Also, in areas where upgraded VIP toilets were implemented, emptying trucks could hardly access the more than 60,000 VIPs due to the nature of the houses, especially in the informal settlements; and many resource recovery and reuse strategies also impacted negatively (Murray & Buckley, 2009 – Figure 3.2).

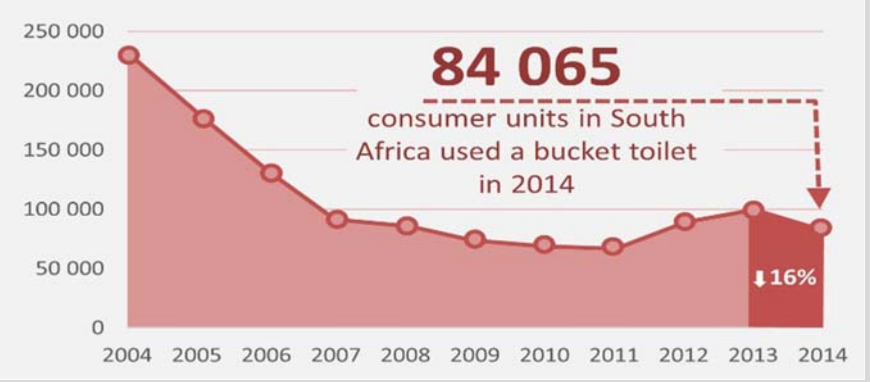

Figure 3.2 Use of bucket toilets in South Africa. (*Source*: Stats SA, 2015).

In addition, the governance dimension provides adequate guidance, standards, design criteria and asset management strategies for the technology dimensions of EIDT, RoDT and NoDT and resource system dimensions: design for recovery and reuse (DeRaR), sanitation service chain raw materials (SSC-RaMs) and sanitation-derived products (SDPs). Subsequently, the technology dimensions are adequately connected through negative feedback mechanisms, especially in situations where the three technology dimensions are required in a 'place' and 'scale' for appropriate sanitation solutions/interventions. The understanding of these complex dynamic interactions and their maximization could result in innovative sanitation solutions with output minimization and resource utilization, as in the case of the Asian I-nstitute of Technology's (AIT) solar septic tank, which increased recovery of biogas and inactivation of pathogens in the effluents (Koottatep *et al.*, 2014, 2015, 2016; Pussayanavin *et al.*, 2015) as presented in Box 3.3.

BOX 3.3 ASIAN INSTITUTE OF TECHNOLOGY (AIT) SOLAR SEPTIC TANK

The unique feature of this on-site sewage treatment system is that it draws energy directly from the sun, which makes it suitable for places with abundant sunlight and inadequate electricity supply. In addition, the increased temperature of the influent inside the septic tank rapidly and effectively destroys pathogens and reduces sludge formation while increasing biogas production. This biogas can then be used for domestic purposes, while the effluent, further purified by constructed wetland, can be used for irrigation, aquaculture and horticulture as well as redirected to the sanitation system as flush water (Koottatep *et al.*, 2015, 2016, Pussayanavin *et al.*, 2015 – Figure 3.3, Table 3.3).

Figure 3.3 Field testing of the solar septic tank at the Asian Institute of Technology, Thailand (*Source*: AIT 2015).

Table 3.3 Comparative Performance of Laboratory-Scale Solar Septic Tanks and Conventional Septic Tanks (Koottatep *et al.*, 2015, 2016; Pussayanavin *et al.*, 2015).

Parameters	**Solar Septic Tank (40–50°C)**	**Conventional Septic Tank (30°C)**
Sludge accumulation (m^3/year)	0.5	1
TVS accumulation in sludge (g/g TVS input)	0.26	0.50
CH_4 production (L/d)	1.5	0.9
CH_4 production (L/g TVS input)	0.027	0.01
E.coli in effluents (MPN/mL)	1.6×10^3 12.3 (50°C)	4.6×10^3

The TeS dimensions can also independently provide the needed inputs for each dimension in the ReS and the ReS in turn could provide necessary feedbacks into the technology design system. For example, EIDT delivers SSC-RaMs (e.g. urine) required by the fit-for-purpose infrastructure of DeRaR, then DeRaR in turn delivers the SSC-RaMs in the right quality and quantity to transform them to SDPs and deliver products and services to the customers in the IFSVC (e.g. struvite to farmers), which could then be used in food production and subsequently returned by users (through toilets – EIDT) as urine. South Africa showcases an example where well-intentioned sanitation resource-recovery and reuse-intervention projects produce low return on investment due to weak synergy and poor understanding of the SES, TeS and ReS (Box 3.4).

BOX 3.4 POOR SES AND TECHNOLOGY SUBSYSTEMS SYNERGY EXPERIENCE, SOUTH AFRICA

A recovery and reuse strategy in the Mnini district of the eThekwini Municipality, South Africa, which involved treating wastewater via a pond system that was then used for irrigation of a 2-ha. banana and mango farm, was stalled at 75% completion in spite of its technical viability. The system was never commissioned because it did not comply with ReGenSan's PSEP and governance even though it fitted with the ReDT component of replacement. Particularly, lack of prior permissions from local traditional leaders for land use, no prior permission from local households to install irrigation systems and utilize land for agriculture, as well as no approval from relevant government agencies, shot down the scheme before it could begin (Murray & Buckley, 2009).

Consequently, the entire process could have a cyclical feedback that creates beneficial outcomes between ReGenSan interactions and other aspects of the society. For example, recovered products and materials for reuse will serve agriculture, aquaculture, horticulture and other circular economy industries within and outside the sanitation economy, and in the same way such agro-industries will also feed ReGenSan through value chain services and products.

3.5 DELIVERING INTEGRATED SANITATION SOLUTIONS

ReGenSan does not seek to replace existing frameworks, but integrates all aspects of sanitation holistically and systematically to interact with related issues (e.g. water, health, hygiene, gender etc.) and creates a comprehensive scheme for the best approach and solution in particular contexts. The ReGenSan framework shows for the first time how socio-ecological, resource recovery and technology considerations can be inter-synergistically linked in a systemic whole to deliver comprehensive integrated sani-solutions. ReGenSan brings four innovative perspectives into the sanitation sphere (Box 3.5).

BOX 3.5 ReGenSan FRAMEWORK INNOVATION

(I) Offers a comprehensive, holistic, integrated and systemic outlook for sanitation technological and management solutions rather than a singular focus,
(II) Embraces the dynamic complexities and contextual peculiarities of 'place and scale' in delivering sanitation solutions,
(III) Introduces the concept of sani-sheds in sanitation management, and
(IV) Applies the regenerative concept to the field of sanitation for the first time

The intention is to improve management, planning and technological innovations to help guide the activities of practitioners, policymakers and academics working in the sanitation space. ReGenSan framework advocates for comprehensive integration of all the components of the sanitation systems to ensure the capacity of sustained service delivery as well as improve participatory processes that enhance users' ownership. The diversity that often exists in social and ethnic groups of any locality greatly influences the design, access, acceptability, affordability, construction and use of sanitation systems. Therefore, this framework will strengthen understanding of the unique dynamics and potential of a location to influence types and processes of technologies and determine systems' capacity to improve their own performance.

This ReGenSan framework has the potential to induce improvement and mind-change in sanitation system-thinking, management, planning and technology innovations without compromising ecosystem sustainability. It is also broad enough to accommodate other pre-existing frameworks and perspectives, as it provides functional and progressive approaches towards improving and expanding access to sanitation services at a 'scale'. The framework also advocates comprehensive, explorative, experimental and descriptive assessments using qualitative and quantitative datasets for better understanding of sanitation subsystems, dimensions and components. ReGenSan shall serve as a guide for funding/donor and intervention agencies by helping them to identify where and when to fund and support for more effective and practical outcomes. It could also help to strengthen global planning and implementation towards expanding access and improving service delivery of sanitation solutions. At the same time, it could really serve as a pathway or portal for innovative designs and development of sanitation technologies and social solutions.

The major constraint on the application of the ReGenSan framework is the disregard for the use of conceptual frameworks in most sanitation research. This trend is changing as framework perspectives and paradigm research in the sanitation space increase. The perception of sanitation only through the lens of toilets as isolated structures for defecation with products and by-products only considered as waste and nuisances that contaminate, pollute and degrade the ecological system must change. *Sanitation should rather be seen as a catalyst for systemic community regeneration and transformation*.

3.6 EXERCISES

(I) Give examples of NoDT, RoDT and EIDT and show possible complex-dynamic interactions between the three technology dimensions using a system diagram applicable to your home town.

(II) Describe the following ReGenSan subsystems: (a) SES, (b) TeS and (c) ReS and their application to help your country meet the SDG no. 6 by the year 2030.

(III) Explore the relationship between the ReGenSan principles and the framework.

(IV) Briefly describe the interactions between the cross-cutting components and the subsystems shown in Figure 3.1 and Table 3.2.

(V) Using scenario development, create sani-solutions for the following options based on the ReGenSan framework: (a) upgrading of urban slum areas' bucket sanitation systems, (b) community transformation from open defecation and (c) provision of sanitation to new development areas in coastal, valley and arid regions.

(VI) Using the ReGenSan framework, propose sanitation solutions at a scale of 5,000 population in high-, middle- and low-income urban areas.

3.7 RECOMMENDATIONS FOR FUTURE RESEARCH

Future research could look at the following:

(I) Explore PSEP pre-considerations that could lead to practical, effective and acceptable technological solutions.

(II) Using the ReGenSan framework, design sani-solution to match a 'place' and 'scale'.
(III) Using the ReGenSan framework, design sani-solution for retrofitting dysfunctional and failing infrastructure and facilities to fit a particular place and scale.
(IV) Using the ReGenSan framework, design sani-solutions to replace dysfunctional and failing infrastructure and facilities with NDT that fit with a chosen location and particular scale type.
(V) Using the ReGenSan framework, explore options for a governance and institutional framework that fits a particular chosen place towards improving sanitation solutions and service delivery.
(VI) Using the ReGenSan framework, explore options to incorporate ReGenSan into the design and plans for new cities, areas, estates and apartments, which include reducing transfer of burden at final disposal (i.e. resource recovery/reuse and treatment within point of generation) as much as possible.
(VII) Explore the need and potential for capacity development and training for relevant government officials and regulators in sanitation management.

REFERENCES

AIT (Asian Institute of Technology) (2015). Innovative DEWAT technologies. Reinventing the Toilet – Progress Report 3, submitted to Bill & Melinda Gates Foundation.

Altaf S. W. (2011). So Much Aid, So Little Development: Stories from Pakistan. Johns Hopkins University Press, Baltimore, USA.

Anand G., Ward P., Tatikonda M. and Schilling D. (2009). Dynamic capabilities through continuous improvement infrastructure. *Journal of Operations Management*, **27**(6), 444–461.

Andersson K., Dickin S. and Rosemarin A. (2016a). Towards 'sustainable' sanitation: challenges and opportunities in urban areas. *Sustainability*, **8**, 1289.

Andersson K., Rosemarin A., Lamizana B., Kvarnström E., McConville J., Seidu R., Dickin S. and Trimmer C. (2016b). Sanitation, Wastewater Management and Sustainability: From Waste Disposal to Resource Recovery. UNEP/GPA/SEI, Stockholm, Sweden, Sanitation,_wastewater_management_and_sustainability_From_waste_disposal_to_resource_recovery-2016sanitation_wastewater_management_and_sustainabilit.pdf?sequence=2&isAllowed=y (accessed 15 March 2018).

Annan-Diab F. and Molinari C. (2017). Inter-disciplinarity: practical approach to advancing education for sustainability and for the Sustainable Development Goals. *The International Journal of Management Education*, **15**, 73–83, http://dx.doi.org/10.1016/j.ijme.2017.03.006

Bagwell S. (2007). Skills needs for regeneration professionals. *Journal of Urban Regeneration and Renewal*, **1–2**, 191–204.

Bahri A. (1999). Agricultural reuse of wastewater and global water management. *Water Science and Technology*, **40**(4), 339–346.

Baum R., Luh J. and Bartram J. (2013). Sanitation: a global estimate of sewerage connections without treatment and the resulting impact on MDG progress. *Advances in Environmental Science and Technology*, **47**(4), 1994–2000, doi: 10.1021/es304284f

Bocken N. M. P., Short S. W., Rana P. and Evans S. (2014). A literature and practice review to develop sustainable business model archetypes. *Journal of Cleaner Production*, **65**, 42–56.

Bos A. (2006). Capacity Building in the Water and Sanitation Sector at times of the MDGs. Discussion paper prepared for the Round Table Meeting organised by WaterLinks and PSO, January 2006. UNESCO-IHE, December 2005–January 2006. http://www.bibalex.org/Search4Dev/files/314800/145385.pdf (accessed 15 July 2018).

Boschi-Pinto C., Lanata C. F., Mendoza W. and Habte D. (2006). Diarrheal diseases. Disease and mortality in Sub-Saharan Africa. In: Disease and Mortality in Sub-Saharan Africa, D. T. Jamison, R. G. Feachem, M. W. Makgoba, E. R. Bos, F. K. Baingana, K. J. Hofman and K. O. Rogo (eds), 2nd edn, World Bank, Washington D.C., USA, http://www.ncbi.nlm.nih.gov/books/NBK2302/

Bozkurt H., Gernaey K. and Sin G. (2015). Computer-Aided Framework for Synthesis, Design and Retrofit of Wastewater Treatment Plants. Danmarks Tekniske Universitet (DTU), Kgs. Lyngby. http://orbit.dtu.dk/files/110810194/Hande_Bozkurt_CAP15_08_01_1_.pdf (accessed 30 April 2017).

Brands E. (2014). Prospects and challenges for sustainable sanitation in developed nations: a critical review. *Environmental Reviews*, **22**, 1–18, doi: 10.1139/er-2013-0082

Brepolsa C. H., Dorgeloh E., Frechen F. B., Fuchs W., Haider S., Joss A., de Korte K., Ruiken C. H., Schier W., van der Roest H., Wett M. and Wozniak T. H. (2008). Upgrading and retrofitting of municipal wastewater treatment plants by means of membrane bioreactor (MBR) technology. *Desalination*, **231**, 20–26.

Brewerton P. and Millward L. (2001). Organisational Research Methods. Sage, London, UK.

Brikke F. (2000). Operation and Maintenance of Rural Water Supply and Sanitation Systems: A Training Package for Managers And planners. World Health Organization Geneva, Switzerland, http://apps.who.int/iris/bitstream/10665/66716/1/WHO_SDE_WSH_00.2_p1-124.pdf (accessed 30 April 2017).

Cairncross S. and Feachem R. G. (1993). Environmental Health Engineering in the Tropics: An Introductory Text. 2nd edn. Wiley, Chichester, UK, http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0471938858.html

Campbell O. M. R., Benova L., Gon G., Afsana K. and Cumming O. (2015). Getting the basic rights – the role of water, sanitation and hygiene in maternal and reproductive health: a conceptual framework. *Tropical Medicine and International Health*, **20**(3), 252–267, doi: 10.1111/tmi.12439

Chang N.-B., Pires A. and Martinho G. (2011). Empowering systems analysis for solid waste management: challenges, trends, and perspectives. *Critical Reviews in Environmental Science and Technology*, **41**(16), 1449–1530, https://doi.org/10.1080/10643381003608326

Charnley F. and Lemon M. (2011). Exploring the process of whole system design. *Design Studies*, **32**, 156–179. doi: 10.1016/j.destud.2010.08.002

Cookey P. E., Darnsawasdi R. and Ratanachai C. (2016a). A conceptual framework for assessment of governance performance of Lake Basins: towards transformation to adaptive and integrative governance. *Hydrology*, **3**(1), 12, doi: 10.3390/hydrology3010012

Cumming G. S. (2011). Spatial Resilience in Social-Ecological Systems. Springer, Dordrecht, Heidelberg, London, New York, doi:10.1007/978-94-007-0307-0

DeFries R. S., Ellis E. C., Chapin F. S., III, Matson P. A., Turner B. L., II, Agrawal A. et al. (2012). Planetary opportunities: a social contract for global change science to contribute to a sustainable future. *BioScience*, **62** (6), 603e606, http://dx.doi.org/10.1525/bio.2012.62.6.11

Deighton M. G. (2016). Facility Integrity Management: Effective Principles and Practices for the Oil, Gas and Petrochemical Industries. Gulf Professional Publishing, Elsevier, Amsterdam, the Netherlands, eBook ISBN: 9780128018323.

Domènech L. and Saurí D. (2010). Socio-technical transitions in water scarcity contexts: public acceptance of greywater reuse technologies in the Metropolitan Area of Barcelona. *Resources Conservation and Recycling*, **55**, 53–62.

DWAF (Department of Water Affairs and Forestry) (2008a). the National Sanitation Bucket Replacement Programme – Lessons Learnt. http://www.ewisa.co.za/misc/WIN_SA_Facts/WIN%20SA/TheNSRPLessonLearnt.pdf (accessed 12 July 2017).

Ekane N., Nykvist B., Kjellén M., Noel S. and Weitz N. (2014). Multi-level sanitation governance: understanding and overcoming the challenges in the sanitation sector in Sub-Saharan Africa. Working paper no. 2014–4. Stockholm Environment Institute. https://www.sei-international.org/mediamanager/documents/Publications/Water-sanitation/sei-workingpaper-ekane-multi-level-sanitation.pdf (accessed 8 May 2017).

El-Sheikh M. A. (2011). Optimization and upgrading wastewater treatment plants. *Journal of Engineering Sciences, Assiut University*, **39**(4), 697–713. http://www.aun.edu.eg/journal_files/82_J_8366.pdf (accessed 30 April 2017).

Esrey S. A. (2002). Philosophical, ecological and technical challenges for expanding ecological sanitation into urban areas. *Water Science and Technology*, **45**(8), 225–228, PMID:12019825.

Exley J. L. R., Liseka B., Cumming O. and Ensink J. H. J. (2014). The sanitation ladder, what constitutes an improved form of sanitation? *Environmental Science & Technology*, **49**, 1086–1094, doi: 10.1021/es503945x

Ferguson G., Dakers A. and Gunn I. (2003). Sustainable Wastewater Management A Handbook for Smaller Communities. Ministry for the Environment, Wellington, New Zealand, http://www.mfe.govt.nz/sites/default/files/summary_0.pdf (accessed 11 May 2017).

Galli G., Nothomb C. and Baetings E. (2014). Towards systemic change in urban sanitation. (IRC Working Paper) The Hague: IRC.

Ghosh B. S. and Elvira M. (2011). Africa's Water and Sanitation Infrastructure: Access, Affordability, and Alternatives. Directions in Development; Infrastructure. World Bank, Washington D.C., USA, http://documents.worldbank.org/curated/en/712211468202191672/Africas-water-and-sanitation-infrastructure-access-affordability-and-alternatives (accessed 24 June 2017).

Gine R., Jimenez A. and Perez-Foguet A. (2011). The Future of Water, Sanitation and Hygiene: Innovation, Adaptation and Engagement in a Changing World – A Closer Look at the Sanitation Ladder: Issues of Monitoring the Sector. Water, Engineering and Development Centre International Conference. 35th WEDC International Conference: The Future of Water, Sanitation and Hygiene in Low-Income Countries: Innovation, Adaptation and Engagement in a Changing World, Loughborough, UK. http://hdl.handle.net/2117/14199 (accessed 15 March 2018).

Giné-Garriga R., Flores-Baquero O., de Palencia A. J. and Pérez-Foguet A. (2017). Monitoring sanitation and hygiene in the 2030 Agenda for Sustainable Development: a review through the lens of human rights. *Science of the Total Environment*, **580**, 1108–1119.

Grübler A. (1998). Technology and Global Change. Cambridge University Press, Cambridge, UK.

Grün G., Tritscher-Archan S. and Weiß S. (2009). Guidelines for the Description of Learning Outcomes. http://ibw4.mservices.at/zoom/pdf/wp2/Guidelines_EN_final_2.pdf (accessed 3 June 2013).

Haq G. and Cambridge H. (2012). Exploiting the co-benefits of ecological sanitation. *Current Opinion in Environmental Sustainability*, **4**(4), 431–435.

Hegger D. L. T., van Vliet J. and van Vliet B. J. M. (2007). Niche management and its contribution to regime change: the case of innovation in sanitation. *Technology Analysis and Strategic Management*, **19**, 729–746.

Hinkel J., Bots P. W. G. and Schluter M. (2014). Enhancing the Ostrom social–ecological system framework through formalization. *Ecology and Society*, **19**(3), 51, 1–19, doi: 10.5751/ES-06475-190351

Hutton G., Haller L. and Bartram J. (2007). Economic and Health Effects of Increasing Coverage of Low Cost Household Drinking-Water Supply and Sanitation Interventions to Countries Off-Track to Meet MDG Target 10. World Health Organization, Geneva, Switzerland, http://www.irc.nl/ page/38443 (accessed 15 March 2018).

IWA (2014a). An Avoidable Crisis: WASH Human Resource Capacity Gaps in 15 Developing Countries. IWA Publishing, London, http://www.iwa-network.org/downloads/1422745887-an-avoidable-crisis-wash-gaps.pdf (accessed 15 March 2018).

IWA (2014b). YWP Conference: Key Message from IWA International Young Water Professional Conference hosted in Taipei December 2014.

Jenkin S. and Pedersen Z. M. (2009). Rethinking Our Built Environments: Towards a Sustainable Future. Ministry for the Environment, Manatu Mo Te Taiao, Wellington, New Zealand, https://www.researchgate.net/publication/261476724_Rethinking_our_built_environments_Towards_a_sustainable_future (accessed 10 February 2018).

Jenkins M. and Sugden S. (2006). 'Rethinking sanitation: lessons and innovation for sustainability and success in the new millennium'. in Human Development Report 2006, United Nations Development Programme, New York, p. 37.

Joint Monitoring Programme (JMP) (2015). Progress on Sanitation and Drinking Water: 2015 Update and MDG Assessment Geneva/New York.

Joshi D. K., Hughes B. B. and Sisk T. D. (2015). Improving governance for the post-2015 sustainable development goals: scenario forecasting the next 50 years. *World Development*, **70**, 286–302, 2015 0305-750X, http://dx.doi.org/10.1016/j.worlddev.2015.01.013 (accessed 15 March 2018).

Kalbermatten J. M., Julius D. S., Mara D. D. and Gunnerson C. G. (1980). Appropriate Technology for Water Supply and Sanitation A Planner's Guide. The International Bank for Reconstruction and Development/the World Bank. https://www.ircwash.org/sites/default/files/201-80AP-19010.pdf (accessed 27 May 2017).

Kalbermatten J. M., Julius D. S. and Gunnerson C. G. (1982). Appropriate sanitation alternatives: a technical and economic appraisal. World Bank studies in Water Supply and Sanitation; no. 1. World Bank, Washington D.C., USA. http://documents.worldbank.org/curated/en/637021468740368977/Appropriate-sanitation-alternatives-a-technical-and-economic-appraisal (accessed 27 May 2017).

Kellert S. R., Heerwagen J. and Mador M. (2008). Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life. John Wiley & Son Inc, New York, USA.

Kiran D. R. (2016). Total Quality Management. Butterworth-Heinemann-Elsevier, Oxford, UK.

Kooiman J. (2003). Governing as Governance. Sage Publications, London, UK.

Koottatep T., Phuphisith S., Pussayanavin T., Panuvatvanich A. and Polprasert C. (2014). Modeling of pathogen inactivation in thermal septic tanks. *Journal of Water Sanitation and Hygiene for Development*, **4**(1), 81–88.

Koottatep T., Chapagain S. K., Watanatanachart J. and Polprasert C. (2015). Application of nano-silver coated granular activated carbon for inactivation of septic tank effluent. *Journal of Water Sanitation and Hygiene for Development*, **5**(4), 632–637.

Koottatep T., Chapagain S. K., Polprasert C., Panuvatvanich A. and Ahn K.-H. (2016). Sanitation situations in selected Southeast Asian countries and application of innovative technologies. *Environ Dev Sustain*, doi: 10.1007/s10668-016-9892-6

Košturiak J. and Frolík Z. (2006). Lean and Innovative Company. Alfa Publishing, s. r. o., Prague, Czech Republic.

Kujawa-Roeleveld K. and Zeeman G. (2006). Anaerobic treatment in decentralized and source-separation-based sanitation concepts. *Reviews in Environmental Science and Bio/Technology*, **5**, 115–139.

Kvarnström E., McConville J., Bracken P., Johansson M. and Fogde M. (2011). The Sanitation Ladder – a Need for a Revamp? *Journal of Water Sanitation and Hygiene for Development*, **1**(1), 3–12.

Larsen T. A. and Gujer W. (2013). Implementation of source separation and decentralization in cities. In: Source Separation and Decentralization for Wastewater Management, T. A. Larsen, K. Udert and J. Lienert (eds), IWA Publishing, London, UK, pp. 135–150.

Larsen T. A., Maurer M., Eggen R. I. L., Pronk W. and Lienert J. (2010). Decision support in urban water management based on generic scenarios: the example of NoMix technology. *Journal of Environmental Management*, **91**, 2676–2687.

Larsen T. A., Udert K. and Lienert J. (2013). Source Separation and Decentralization for Wastewater Management. IWA Publishing, London, UK.

Lazarova V., Levine B., Sack J., Cirelli G., Jeffrey P., Muntau H., Salgot M. and Brissaud F. (2001). Role of water reuse for enhancing integrated water management in Europe and Mediterranean countries. *Water Science and Technology*, **43**(10), 25–33.

Lens P., Zeeman G. and Lettinga G. (2001). Decentralized Sanitation and Reuse: Concepts, Systems and Implementation. IWA Publishing, London, UK.

Levy Y. and Ellis T. J. (2006). A systems approach to conduct an effective literature review in support of information systems research. *Informing Science: The International Journal of an Emerging Transdiscipline*, **9**, 181–212.

Lockwood H. and Smits S. (2011). Supporting Rural Water Supply: Moving Towards a Service Delivery Approach. Practical Action Publishing Ltd, Warwickshire, UK.

Lüthi C., Morel A., Tilley E. and Ulrich L. (2011a). Community-Led Urban Environmental Sanitation Planning (CLUES); Swiss Federal Institute of Aquatic Science and Technology (EAWAG) Dübendorf, Switzerland. http://www.susana.org/_resources/documents/default/2-1300-cluesguid.pdf (accessed 14 May 2017).

Lüthi C., Panesar A., Schütze T., Norström A., McConville J., Parkinson J., Saywell D. and Ingle R. (2011b). Sustainable Sanitation in Cities: A Framework for Action. Papiroz Publishing House, Netherlands.

Lyle J. T. (1984). Designing Human Ecosystems. John Wiley & Sons, Hoboken, USA.

Lyle J. T. (1994). Regenerative Design for Sustainable Development. John Wiley & Sons, Hoboken, USA.

Maier M. W. (1998). Architecting principles for systems-of-systems. *Bioprocess and Biosystems Engineering*, **1**, 267–284.

Mang P. and Reed B. (2012a). Designing from place: a regenerative framework and methodology. *Building Research & Information*, **40**(1), 23–38.

Mang P. and Reed B. (2012b). Regenerative Development and Design. Regenesis Group and Story of Place, Encyclo. Sustainability Science & Technology.

Marshall R. E. and Farahbakhsh K. (2013). Systems approaches to integrated solid waste management in developing countries. *Waste Management*, **33**, 988–1003, http://dx.doi.org/10.1016/j.wasman.2012.12.023 (accessed 15 March 2018).

Martínez-Jurado P. J. and Moyano-Fuentes J. (2014). Lean management, supply chain management and sustainability: a literature review. *Journal of Cleaner Production*, **85**, 134–150.

Maurer M., Bufardi A., Tilley E., Zurbrügg C. and Truffer B. (2012). A compatibility-based procedure designed to generate potential sanitation system alternatives. *Journal of Environmental Management*, **104**, 51–61.

Mayring P. (2003). Qualitative Inhaltanalyse – Grundlagen und Techniken. (Qualitative Content Analysis), 8th edn. Beltz Verlag, Weinheim, Germany.

McConville J., Kunzle R., Messmer U., Udert K. M. and Larsen T. A. (2014). Decision support for redesigning wastewater treatment technologies. *Environmental Science & Technology*, **48**(20), 12238–12246.

McGrath S. and Powell L. (2016). Skills for sustainable development: transforming vocational education and training beyond 2015. *International Journal of Educational Development*, **50**, 12–19, http://dx.doi.org/10.1016/j.ijedudev.2016.05.006

Mjoli N. P. (2012). Evaluation of Sanitation Upgrading Programmes – The Case of the Bucket Eradication Programme. Report to the Water Research Commission. WRC Report no. 2016/1/12.

MÍkva M., Prajová V., Yakimovich B., Korshunov A. and Tyurin I. (2016). Standardization – One of the Tools of Continuous Improvement. International Conference on Manufacturing Engineering and Materials, ICMEM 2016, Nový Smokovec, Slovakia, 6–10 June 2016, Procedia Engineering 149, pp. 329–332. https://ac.els-cdn.com/S1877705816311845/1-s2.0-S1877705816311845-main.pdf?_tid=aa028662-9f87-4594-9932-77b079fe27db&acdnat=1531597772_5e793fff7675c6f2103c88d09db8b0bc (accessed 15 July 2018).

Murray A. and Buckley C. (2009). Designing reuse-oriented sanitation infrastructure: the design for service planning approach. In: Wastewater Irrigation and Health Assessing and Mitigating Risk in Low-income Countries, P. Drechsel, C. A. Scott, R.-S. Liqa, M. Redwood and A. Bahri (eds), Earthscan, London, UK, pp. 303–318.

Murray A. and Ray I. (2010). Commentary: back-end users: the unrecognized stakeholders in demand-driven sanitation. *Journal of Planning Education and Research*, **30**(1), 94–102.

Nakagiri A., Niwagaba C. B., Nyenje P. M., Kulabako R. N., Tumuhairwe J. B. and Kansiime F. (2016). Are pit latrines in urban areas of SubSaharan Africa performing? A review of usage, filling, insects and odour nuisances. *BMC Public Health*, **16**, 120, doi: 10.1186/s12889-016-2772-z

Nansubuga I., Banadda N., Verstraete W. and Rabaey K. (2016). A review of sustainable sanitation systems in Africa. *Reviews in Environmental Science and Bio/Technology*, **15**, 465, doi: 10.1007/s11157-016-9400-3

Nhapi I., Siebel M. A. and Gijzen H. J. (2006). A proposal for managing wastewater in Harare, Zimbabwe. *Water and Environment Journal*, **20**, 101–108.

Novak J. and Canas A. (2008). The Theory Underlying Concept Maps and How to Construct and Use Them. Florida Institute for Human and Machine Cognition. http://cmap.ihmc.us/Publications/ResearchPapers/TheoryUnderlyingConceptMaps.pdf

Oosterveer P. and Spaargaren G. (2010). Meeting social challenges in developing sustainable environmental infrastructures in East African Cities. In: Social Perspectives on the Sanitation Challenge, B. van Vliet (ed.), Springer Science+Business Media B.V., Dordrecht, Netherlands. doi: 10.1007/978-90-481-3721-3_2

Ostrom E. (2005). Understanding Institutional Diversity. Princeton University Press, Princeton, USA.

Ostrom E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science 24*, **325** (5939), 419–422. https://doi.org/10.1126/science.1172133

Ostrom E. and Cox M. (2010). Moving beyond panaceas: a multi-tiered diagnostic approach for social-ecological analysis. *Environmental Conservation*, **37**, 451–463, doi: 10.1017/S0376892910000834

Pahl-Wostl C. (2009). A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change*, **19**(3), 354–365, doi: 10.1016/j.gloenvcha.2009.06.001

Pahl-Wostl C., Holtz G., Kastens B. and Knieper C. (2010). Analyzing complex water governance regimes: the management and transition framework. *Environmental Science & Policy*, **13**, 571–581.

Pahl-Wostl C., Jeffrey P., Isendahl N. and Brugnach M. (2011). Maturing the new water management paradigm: progressing from aspiration to practice. *Water Resources Management*, **25**, 837–856, doi: 10.1007/s11269-010-9729-2

Partelow S. (2016). Coevolving Ostrom's social–ecological systems (SES) framework and sustainability science: four key co-benefits. *Sustainability Science*, **11**, 399–410, doi: 10.1007/s11625-015-0351-3

Peng D. X., Schroeder R. G. and Shah R. (2008). Linking routines to operations capabilities: a new perspective. *Journal of Operations Management*, **26**(6), 730–748.

Pham N. B. and Kuyama T. (2013). Decentralized domestic wastewater management in Asia – challenges and opportunities. Policy Brief – Series 1, Water Environment Partnership in Asia (WEPA), Institute for Global Environmental Strategies (IGES). http://www.wepa-db.net/pdf/1403policy_brief/WEPA_PB1_2013.pdf (accessed 30 April 2017).

Pickett S. T. A., Jones C. and Kolasa J. (2007). Ecological Understanding: The Nature of Theory and the Theory of Nature. Academic Press, New York, USA.

Pollack H. N. (2005). Uncertain Science … Uncertain World, 1st edn. Cambridge University Press, Cambridge, UK.

Potter A., Klutse A., Snehalatha M., Batchelor C., Uandela A., Naafs A., Fonseca C. and Moriarty P. (2011). Assessing sanitation service levels. IRC International Water and Sanitation Centre, Working Paper 3, 2nd edn. https://www.ircwash.org/sites/default/files/Potter-2011-Assessing.pdf (accessed 18 May 2017).

Pussayanavin T., Koottatep T., Eamrat R. and Polprasert C. (2015). Enhanced sludge reduction in septic tanks by increasing temperature. *Journal of Environment Science and Health, Part A*, **50**(1), 81–89.

Quendler E., Van der Luit J., Monteteone M., Aguado P., Pfeiffenscheider M., Wagner K., Valente F. and Cunha-Queda C. (2013). Employers' needs on competences, knowledge and skills for sustainable development as a reference framework for higher education in life sciences. *Procedia – Social and Behavioral Sciences*, **106**, 1063–1085, https://doi.org/10.1016/j.sbspro.2013.12.121 (last accessed 05/04/2018).

Ramoa A., Matos J. and Luthi C. (2015). System-Based Decision Trees for the Selection of Sanitation Technologies. 38th WEDC International Conference, Loughborough University, UK. http://wedc.lboro.ac.uk/resources/conference/38/Ramoa-2250.pdf (accessed 26 June 2017).

Raven R. (2007). Co-evolution of waste and electricity regimes: multi-regime dynamics in the Netherlands (1969–2003). *Energy Policy*, **35**, 2197–2208.

Repella A. (2014). Framework Perspectives for Water: a small sample of the range of frameworks for addressing questions about water. Water Diplomacy Network Blog. http://blog.waterdiplomacy.org/2014/01/framework-perspectives-for-water/ (accessed 6 June 2017).

Robescu L. D., Silivestru C., Presura A., Pana A. and Mihai R. (2016). Application of Continuous Improvement Strategy for reducing environmental impact of a wastewater treatment plant. *Water Utility Journal*, **14**, 29–40, https://www.ewra.net/wuj/issue_14.htm (accessed 14 July 2018).

Rodic L. (2015). Waste governance. In: Global Waste Outlook, D. C. Wilson (ed.), ISWA/UNEP, Nairobi, Kenya, http://www.unep.org/ietc/Portals/136/Publications/Waste%20Management/GWMO%20report/GWMO%20full%20report.pdf (accessed 12 September 2016).

Rosenqvist T., Mitchell C. and Willetts J. (2016). A short history of how we think and talk about sanitation services and why it matters. *Journal of Water, Sanitation and Hygiene for Development*, **06.2**, doi: 10.2166/washdev.2016.118

Ross K., Abeysuriya K., Mikhailovich N. and Mitchell C. (2014). Governance for decentralised sanitation: Global Practice Scan. A working document. Prepared by the Institute for Sustainable Futures, UTS as part of the Australian Development Research Award Scheme (ADRAS). http://communitysanitationgovernance.info/wp-content/uploads/2016/06/20140125-ADRAS-GDS-Global-Practice-Scan-a.pdf (accessed 14 October 2017).

Schertenleib R. (2005). From conventional to advanced environmental sanitation. *Water Science and Technology*, **51** (10), 7–14.

Seiffert M. E. B. and Loch C. (2005). Systemic thinking in environmental management: support for sustainable development. *Journal of Cleaner Production*, **13**, 1197–1202. doi: 10.1016/j.jclepro.2004.07.004

Sethi V. and King W. R. (1998). Organizational Transformation thought Business Process Reengineering. Prentice Hall, Upper Saddle River, USA.

Seuring S. and Muller M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production*, **16**, 1699–1710.

Silivestru C., Ifrim D., Gugu A. M. and Mihalache R. (2014). Define Manual, MIS ETC 2177.

Simha P., Lalander C., Vinnerås B. and Ganesapillai M. (2017). Farmer attitudes and perceptions to the reuse of fertiliser products from resource-oriented sanitation systems – The case of Vellore, South India. *Science of the Total Environment*, **581–582**, 885–896, https://doi.org/10.1016/j.scitotenv.2017.01.044

Spaargaren G., Mommaas H., Van Den Burg S., Maas L., Drissen E. and Dagevos H. (2007). More sustainable lifestyles and consumption patterns: a theoretical perspective for the analysis of transition processes within consumption domains. Contrast Research Report, TMP project. Wageningen: Environmental Policy Group, Wageningen University; Telos: Tilburg University; RIVM; LEI, Wageningen, Netherlands.

Spaargaren G., Oosterveer P., Van Buuren J. and Mol A. P. J. (2006). Mixed Modernities: Towards Viable Urban Environmental Infrastructure Development in East Africa. Wageningen University, Wageningen, Netherlands.

Starkl M., Brunner N. and Stenstrom T. (2013). Why do water and sanitation systems for the poor still fail? Policy analysis in economically advanced developing countries. *Advances in Environmental Science and Technology*, **47**(12), 6102–6110, doi: 10.1021/es3048416

Starkl M., Brunner N., Feil M. and Hauser A. (2015). Ensuring sustainability of non-networked sanitation technologies: an approach to standardization. *Advances in Environmental Science and Technology*, **49**, 6411–6418, doi: 10.1021/acs.est.5b00887

Stats SA (Statistic South Africa) (2015). Bucket toilets: an update. http://www.statssa.gov.za/wp-content/uploads/2015/09/BucketToilet_Slider.jpg (accessed 22 June 2018).

L. Strande, M. Ronteltap and D. Brdjanovic (2014). Faecal Sludge Management: Systems Approach for Implementation and Operation. IWA Publishing, London, UK.

SuSanA (ed.) (2008). Towards More Sustainable Sanitation Solutions. (Version 1). Sustainable Sanitation Alliance (SuSanA), Eschborn. https://www.susana.org/_resources/documents/default/3-267-7-1452594644.pdf (accessed 21 June 2017).

Tilley E., Strande L., Luthi C., Mosler H., Udert K. M., Gebauer H. and Hering J. G. (2014a). Looking beyond technology: an integrated approach to water, sanitation and hygiene in low income countries. *Advances in Environmental Science and Technology*, **48**(17), 9965–9970, doi: 10.1021/es501645d

Tilley E., Ulrich L., Luthi C., Reymond P. H. and Zurbrugg C. (2014b). Compendium of Sanitation Systems and Technologies, 2nd rev. edn. Swiss Federal Institute of Aquatic Science and Technology (EAWAG), Dübendorf, Switzerland.

Tobias R., O'Keefe M., Künzle R., Gebauer H., Gründl H., Morgenroth E., Pronk W. and Larsen T. A. (2017). Early testing of new sanitation technology for urban slums: the case of the Blue Diversion Toilet. *Science of the Total Environment*, **576**, 264–272.

Trémolet S. and Rama M. (2012). Tracking National Financial Flows into Sanitation, Hygiene and Drinking Water. World Health Organization.

UN-Water and WHO (2012). GLAAS 2012 Report. UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water. The Challenge of Extending and Sustaining Services. WHO, Geneva, Switzerland.

USAID (2016). Global Sanitation Service Chain Technology Manual: An analysis of sanitation technology innovations. http://www.path.org/publications/files/PATH_dt_ssd_tech_manual.pdf (accessed 20 June 2017).

USEPA (1974). Process design manual for upgrading existing wastewater treatment plants. U.S. Environmental Protection Agency, Technology Transfer. http://www.un.org/waterforlifedecade/pdf/glaas_report_2012_eng.pdf (accessed 28 June 2017).

Van der Ryn S. and Cowan S. (2007). Ecological Design, 10th anniversary edn. Island Press, Washington D.C., USA.

van Vliet B. J. M., Spaargaren G. and Oosterveer P. (2011). Sanitation under challenge: contributions from the social sciences. *Water Policy*, **13**, 797–809.

Verhagen J. and Carrasco M. (2013). Full-Chain Sanitation Services that Last: Non-Sewered Sanitation Services. IRC International Water and Sanitation Centre, Netherlands, https://www.ircwash.org/sites/default/files/201306_sanitation_framework_final.pdf (accessed 17 June 2017).

Wehn U. and Alaerts G. (2013). Leadership in knowledge and capacity development in the water sector: a status review. *Water Policy*, **15**, 1–14.

Whittington D., Lauria D. and Choe K. (1993). Household sanitation in Kumasi, Ghana: a description of current practices, attitudes, and perceptions. *World Development*, **21**(5), 733–748. https://doi.org/10.1016/0305-750X(93)90030-D (accessed 15 March 2018).

WHO/UNICEF (2017). Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines. World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), Geneva, Licence: CC BY-NC-SA 3.0 IGO.

Wielemaker R. C., Weijma J. and Zeeman G. (2016). Harvest to harvest: recovering nutrients with New Sanitation systems for reuse in Urban Agriculture. *Resources, Conservation and Recycling*, **128**, 426–437, http://dx.doi.org/10.1016/j.resconrec.2016.09.015 (accessed 15 March 2018).

World Bank (2003). Appraisal report: Tanzania-Dar-es Salaam water supply and sanitation project. World Bank, Washington D.C., USA, http://documents.worldbank.org/curated/en/2003/04/2301336/tanzania-dar-es-salaam-water-supplysanitation-project (accessed 15 March 2018).

WWAP (United Nations World Water Assessment Programme) (2016). The United Nations World Water Development Report 2016: Water and Jobs. UNESCO, Paris, http://unesdoc.unesco.org/images/0024/002439/243938e.pdf (accessed 16 July 2018).

Yang Y., Lee P. K. C. and Cheng T. C. E. (2016). Continuous improvement competence, employee creativity, and new service development performance: a frontline employee perspective. *International Journal of Production Economics*, **171**, 275–288, http://dx.doi.org/10.1016/j.ijpe.2015.08.006 (accessed 15 March 2018).

Zeeman G. (2012). New Sanitation: Bridging Cities and Agriculture. Wageningen University, Wageningen, Netherlands.

Zurbrügg C. and Tilley E. (2007). Evaluation of Existing Low Cost Conventional as Well as Innovative Sanitation System and Technologies – NETSSAF Deliverable D22&23. Swiss Federal Institute of Aquatic Science and Technology (EAWAG), Dübendorf, Switzerland.

Zurbrügg C. and Tilley E. (2009). A system perspective in sanitation – Human waste from cradle to grave and reincarnation. *Desalination*, **248**, 410–417.