BIO-CENTERS: ECOLOGICAL SANITATION AND RENEWABLE ENERGY HARVESTING IN INFORMAL SETTLMENTS

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1 ABSTRACT

Lack of adequate sanitation affects approximately one-sixth of the global population, causing major environmental and public health problems (UNDESA, 2013). Many of those affected live in informal settlements where traditional sanitation systems are not feasible (Shouten & Mathenge, 2010). This case study investigates a new type of structure, called a "bio-center," developed by Umande Trust, which provides ecological sanitation (Umande, 2013). Situated as a hybrid between a productive landscape and an architectural topology, bio-centers provide a paradigmatic example of ways in which landscape architecture can redefine the problematics it addresses and the criteria under which solutions are judged, thereby allowing the discipline to increase its contribution to the monumental challenges facing informal settlements. A variety of case study methods were utilized including site visits, site analysis, interviews, and archival material analysis (Francis, 2001). This case study provides a unique example of an ecological sanitation model that embodies an integrated view of social-ecological systems and offers crucial lessons for sustainable infrastructure design. This research finds that by layering multiple community-service and income-generating functions into a shared facility, bio-centers become anchor-buildings or nodes within communities, with the potential to facilitate positive social and ecological change. The bio-center model addresses the most acute problems informal settlements face, and the benefits land squarely amid the overlapping economic, social, ecological, and energy challenges present in such settlements.

1.1 Keywords

Ecological Sanitation, Informal Urbanism, Ecological Economics

2 INTRODUCTION

The major demographic story of the twentieth century was the increasing urbanization of an ever-increasing human population. Between 1900 and 2000, the population grew from 1.65 billion to over 6 billion (United Nations Population Division, 1999). With much of the growth happening in impoverished, unplanned, haphazardly built informal settlements that lack running water and other elements of basic civic infrastructure. Currently around 2.5 billion people live without access to adequate sanitation facilities (UNDESA, 2013). In Kenya, about 80% of hospital attendance is from preventable disease, and half of those visits are related to illnesses connected to contaminated water, poor sanitation and deficient hygiene (Munala, 2012).

The solution that is common in OECD countries--private, intra-domiciliary facilities making liberal use of inexpensive running water —is not likely to be implemented for residents of informal settlements. The reasons are several. Installation of private toilets would incur an expense that the population simply can't support; landlords who rent housing in informal settlements prefer to use space for tenants, not sanitary facilities; clean running water is scarce in such communities; nor is there now, or is there likely ever to be in the future, the physical infrastructure—the sewer pipes and waste treatment plants—to which private in-home sanitary facilities must connect. Because of the many and varied roadblocks that stand in the way of bringing traditional sanitation infrastructure to informal settlements, Shouten and Mathenge (2010) conclude that "communal sanitation facilities, when well-constructed and maintained, may be the only technically and economically feasible sanitation option for low income, high density slums" (p. 816). The challenge of designing such facilities is best met with systems thinking shaped by the principles of sustainability.

The term "sustainability" has been applied to such a wide variety of phenomena that some commentators propose that it no longer means anything and should be avoided. (King, 2013) We disagree, and propose a useful definition: a system is sustainable if it does not undercut its own preconditions for existence (Zencey, 2012). By this criterion pit latrines and other problematic modes of disposal of human waste are not sustainable—and their lack of sustainability is what makes them problematic.

For its part, systems thinking encourages us to look behind and beneath event to discern causal dynamics emerging from systems—"an interconnected set of elements that is coherently organized in a way that achieves something" (Meadows, 2008). If the system is mechanical, the system is designed to achieve a function; if the system includes humans, its aims to achieve a purpose. Systems thinking focuses on stocks and flows and how both either are or aren't shaped by feedback loops. A stock of humans (for instance) produces a flow of excreta, which can accumulate as a stock, which becomes a biohazard if it isn't treated or digested by biological systems.

One solution to the problem of sustainable waste disposal is a public facility called a bio-center. Developed by Umande Trust, these structures layer multiple community uses into an environmentally sound sanitation facility. In addition to providing public toilets and washrooms, bio-centers safely process excreta on site though an anaerobic process in an underground dome, which yields two valuable by-products: biogas biogas (which can be used for cooking) and bio-slurry fertilizer. Piloted in 2007, by 2014 there were 84 bio-centers in Nairobi and neighboring Kisumu. Each serves between 350 and 1000 people a day (Whitehead, 2014).

In addition to providing urgently needed sanitation facilities, bio-centers also offer to their communities an exemplary instance of a sustainable, multi-modal business. Each facility offers space that can be rented for business incubation or civic or church functions, and also provides an inexpensive renewable energy resource. Often the biogas generated is used on-site by a community kitchen, restaurant or other function in the building itself, eliminating the need for transport with its associated investment and operational expenses (Umande, 2013). Several bio-centers have successfully connected adjacent pit latrines to their anaerobic digesters, thereby accomplishing several positive outcomes: increased biogas production, conversion of those latrines to an eco-sanitation model and enrolment of their owners as allies rather than competitors (J. Omotto, personal communication, July 15, 2014).

2.1 Methodology

This research is informed by Mark Francis's (2001) definition of a case study as a "well-documented and systematic examination of the process, decision making and outcomes of a project that is undertaken for the purpose of informing future practice, policy, theory and/or education" (p 16).

The case is viewed as a paradigmatic example of ecological sanitation. Flyvbjerg (2006) defined the purpose of a paradigmatic case study as "to develop a metaphor or establish a school for the domain that the case concerns" (p. 307). The case study data-gathering activities took place from September 2013 through November 2015, and field research was conducted in Nairobi in July 2014. A variety of case study methods were utilized including site visits, site analysis, interviews, and archival material analysis (Francis, 2001).

This case study provides a unique example of an ecological sanitation model that embodies an integrated view of social-ecological systems and offers crucial lessons for sustainable infrastructure design. This article examines how by layering multiple community-service and income-generating functions into a shared ecological sanitation facility, bio-centers become anchor-buildings or nodes within communities, with a specific focus on the potential of bio-centers to facilitate positive social and ecological change.

We took note of the methodology of several case studies when assessing bio-centers. The Katukiza (Selection, 2010) case study of sustainable sanitation facilities in Bwaise III in Kampala, Uganda took into account social acceptance, technological and physical applicability, economic and institutional aspects, human and environmental health, ability to replicate and scale up, water availability, accessibility of exhaustion trucks and, recovery of nutrients and energy. Munala's (2012) survey of sanitation facilities in informal settlements revealed acceptability of sanitation technology to be dependent on availability, security at night, economic aspects, and physical capability of the users. Maintenance with regards to cleanliness is also an important consideration. Financial, technological, and participatory issues were taken into account in Schouten et al. case study of facilities in Kibera (2010).

3 CONTEXT: PRECARIOUS GEOGRAPHIES

3.1 Physio-politically Precarious

Informal settlements are often built illegally in precarious geographies, on ground not effectively administered (and often abandoned and ignored) by civic authority. Steep slopes, residues of dangerous industries, vulnerability to flooding, and past experience as an earthquake zone or landfill often make up the backdrop and ground planes of informal settlements. The challenge of basic sanitation is magnified by these geographic circumstances. Then too, informal settlements develop haphazardly and densely with no thought, space or investment given to the development of sewer networks and other elements of urban infrastructure, including simple passageway (Munala, 2012). The major capital investment needed to develop a traditionally conceived sewage infrastructure is a significant obstacle to providing informal settlements with such centralized systems. Further, to provide such infrastructure at public expense would be a step toward formal recognition and legitimation of these informal settlements—a step that governments are reluctant to take, since they are disinclined to favor marginalized squatters over owners-of-record and in any event are not keen to annex territory with a high need for civic services and a low ability to contribute to tax revenues. Even so, civic administrations near informal settlements often recognize an ecological reality: everything is connected to everything else--meaning, specifically, water pollution will migrate and pathogens do not respect politically drawn boundaries. Many informal settlements therefore occupy a legal grey space in which governments provide some support for improvement of sanitation without formally recognizing the community or its needs. This arrangement bars large-scale, comprehensive infrastructural solutions to the settlements' sanitation needs.

When informal settlements are built on land that is vulnerable to flooding or in direct aquatic communication with wetlands, the consequences of poor sanitation—and the cost of traditional methods of improving it—are magnified. This is the case in Kampala, Uganda, where Bwaise III, an informal settlement, is built on a former wetland. A study of the Lubigi wetland into which the settlement now drains found that seasonal flooding makes the contamination of drinking water from leaking pit latrines "highly likely" if not inevitable (Katukiza et al., 2010). There was of course no clean-slate design of the settlement's sanitation system, and the de facto system that evolved did so in violation of fundamental precepts of good sanitation practice. Excreta is disposed of in unlined pits that also collect greywater and stormwater; the pits easily overflow and readily contaminate groundwater even when they don't. Pit latrines, elevated to achieve a semblance of dryness, empty fecal sludge into the adjacent storm water drains during rains and when they are excavated. To empty a pit latrine residents often make a hole through its fecal sludge chamber --a cheaper alternative to full-scale excavation of the pit—compromising the chamber's integrity and function. Many residents make use of what are colourfully called "flying" toilets: they relieve themselves in plastic bags, which are then left on the ground, where the plastic is vulnerable to mechanical damage and to photo decay. While the bags effectively isolate fecal matter from the larger ecosystem, the isolation is only temporary; their use delays but doesn't forestall the health issues that stem from open-air defecation.

Not surprisingly, residents of Bwaise III are routinely exposed to and become infected by pathogens from human feces. Studies have indicated that most of the spring water sources in the peri-urban areas of Kampala are contaminated with pathogens of fecal origin attributed to these and other poor sanitation practices (Katukiza et al., 2010). The situation is similar in the informal settlements in the capital of Uganda's neighbor, Kenya. Taking its name from the Maasai, who lived there before the British came in 1899 to pin a train depot roughly halfway between the Kenyan seaport of Mombasa and the border of landlocked Uganda, Nairobi is named for the water that flows through it: Enkare Nyrobi means "cold water." Four rivers run through the city on roughly parallel courses as they make their way from their rise in the highlands in the northwest to the Indian Ocean in the southeast. Historically they have provided water for the residents—and have also served as sewage transport systems. Both uses, always contradictory, were exponentially strained by population growth over the last century as the human population of Nairobi increased from a mere 11,500 in 1906 to 3,375,000 in 2014. More than half of that growth came in the city's informal settlements, many of which are on the banks of the Nairobi River. As a recent appraisal of water quality in the area noted, "The four rivers still flow through Nairobi but, because of a century-long pollution, many people mistake them for an open sewerage system" (Weru, 2012).

A positive feedback loop aggravates the problem: human habitation is drawn to the rivers for their water-source and sewage-transport services, and this development destroys riparian flora that provide what little natural filtration services the rivers enjoy, increasing the burden of pollutants the rivers must then carry, further compromising riparian flora and diminishing public health. In places the rivers are scarcely recognizable as waterways. They have become a health and safety hazard to the increasing number of marginalized residents whose only space in the city is pressed against their edges (Makworo and Mireri, 2009).

In the mid-twentieth century, traditional approaches to water management in Nairobi brought landscape-altering infrastructure but didn't inoculate the rivers against the damage brought by a steadily increasing human presence. Constructed in 1953 to provide potable water to 15 million people (about a third of the present-day population of Kenya), an earthen dam at the edge of the city impounded a shallow lake (greatest depth of just 9.1 feet) that locals call Nairobi Dam after the structure that created it. The Nairobi River flowed into the lake; the Ngongo River exited it through a spillway. As recently as twenty years ago Nairobi Dam was a tourist draw, offering sailing and fishing close to the business center of a major African capital. But the lake is gone. The impoundment area has been filled with sediment and human fecal waste transported by the river. The resulting nutrient-rich artificial wetland is choked with water hyacinth, effectively eliminating any and all recreational use of the water (Obiero, 2013). This sedimentation is the result of Kibera, the largest informal settlement on the African continent, which sits immediately upslope of the dam. Kibera without adequate sanitation for residents cannot support a mutually healthy, ecologically sustainable relationship with the Nairobi River or the lake.

3.2 Conceptually Precarious

Effective solutions to the water-and-sanitation crisis must be multi-scalar, adaptive, and address multiple overlapping systems simultaneously. As Mostafavi (2010) explains "the city, for all its importance, can no longer be thought of only as a physical artifact; instead, we must be aware of the dynamic relationships, both visible and invisible, that exist among the various domains of a larger terrain of urban as well as rural ecologies" (p. 29). And Steffen et al. (2011), reporting Walker et al. (2009): "it is no longer useful to concentrate on environmental challenges and variables individually, but the challenge lies in the intertwining of multi-scale challenges across sectors (e.g., environment, demographics, pandemics, political unrest)" (Steffen et al., 2011). These realizations point up the qualities successful design solutions will have and the conditions under which they will emerge. These include the consistent application of whole-systems thinking to design problems; an appreciation that the relevant whole system is humans-and-landscape; an understanding that landscapes house natural processes that have to be accommodated because they can only rarely be defeated, and that in any event defeat of natural systems and processes would diminish their ability to supply valued ecosystem services; and a concurrent appreciation that effective solutions of the city's "cross sector" challenges will reach across disciplinary boundaries toward desired outcomes in several sectors at once.

3.3 Socially and Economically Precarious

Solving the sanitation problems of informal settlements is made more difficult by the socio-economic dynamics that characterize such settlements and their economies. Transience, compounded by the lack of property ownership by residents, makes it difficult to establish a collective investment in maintaining sanitation facilities (Katukiza et al. "Selection", 2007). Lack of sanitation is just one item on a list of civic, economic, and physical ills the population endures: poverty, hunger, unemployment, high crime rates, poor health, little to no access to education. Each of these challenges makes dealing with any of the others more difficult. And each is exacerbated by population growth (Munala, 2012).

An effective sanitation system provides a public good, meaning a significant amount of the benefit that comes from use of the system is not captured by individual users who pay for system services but accrues to non-payers. In the case of sanitation systems, the non-paying beneficiary is the public at large. Public health as a positive externality is the main reason that in urban areas sewer services are usually provided at public expense. As Daly and Farley caution, public goods cannot be produced and distributed efficiently or in optimum quantity through market dynamics (Daly and Farley, p. 177-80). Nevertheless, in many informal settlements access to communal latrine-based is fee based. The landlords who own the toilets are usually responsible for their maintenance and operation. While in many cases moderate investment could reduce the adverse health and environmental impacts of the toilets (as, for instance, through lining of pit latrines and more frequent emptying of their contents), the profit motive discourages investment that offers no return. Absent regulation to set minimum standards, landlords have an incentive to reduce standards to the lowest level the market will bear and to continue to impose the negative externality of fecal contamination of the environment and the resulting disease on the public at large. Public authority is ill equipped and resistant to establishing regulatory administration. Nor are the tenants themselves in a position to pay for, support, or otherwise effect the necessary changes. Those whose incomes improve move out, becoming renters somewhere else (and occasionally becoming landlords of the inferior habitation they leave behind). (Katukiza et al., "Selection", 2010). The frequently shifting population of informal settlements, the unwillingness of public authority to include these settlements in their jurisdiction and the failure of market dynamics to provide the quality of public goods these settlements need are the major impediments to improved sanitation. Within the market-based, landlord-fee model, the problem looks insurmountable. Successful intervention through the selection and deployment of an effective, ecologically sound sanitation technology may need to be rooted in an alternative, i.e. collective, ownership model.

3.4 The Precarious Present

In informal settlements, significant amounts of human excreta are deposited in unlined pit latrines. These are usually elevated in areas with a high water table so that deposition is made directly into water. "The numbers of bacteria and viruses in the soil are normally reduced to insignificant levels within a metre of effluent movement if aerobic conditions and unsaturated flow exist," but "saturated or nearly saturated flow in coarse textured or highly structured soils…can…result in rapid transmission of bacteria and viruses for considerable distances" says one authoritative analysis of septic leachate constraints. (Epp, 1984) Saturation of a latrine's working soils can easily come about through overuse, and overuse is common. In Bwaise III, the user load was found to be between 1:30 to 1:70. The recommendation by the Uganda Ministry of Health is 1:20. In the informal settlements of Nairobi -- Kibera, Obunga and Bandani -- about 68% of households rely on shared facilities with a high loading factor (average of 71 people per facility) (Munala, 2012). In Uganda's Bwaise III, studies found that 15% of the population uses a public pit latrine and 75% uses shared toilet facilities. Only 10% of the population has access to private, non-shared sanitation facilities (Katukiza et al., "Selection", 2010).

High usage increases the needed frequency of latrine emptying if the latrines are to remain effective in isolating waste from the environment. As noted, though, landlords have little incentive to provide this service. While it is possible for families near a latrine to pay for emptying it, this kind of organized community response is challenging given the circumstances of residents (Katukiza et. al., "Selection" 2010). As a result pit latrines are often abandoned when full because emptying them is expensive and narrow pathways make vehicular exhaustion difficult (Schouten et al., 2010). Mulana found that 75 % of the surveyed pit latrines were abandoned rather than emptied for reuse. Wastes from the remaining 25 % were exhausted from the pits and disposed of offsite by exhauster trucks, incurring expense that is passed on to users. Abandoned pit latrines remain a contamination risk to water bodies and drinking water. This open loop system doesn't capture and recover nutrients and is a "great economical as well as ecological loss", (Mulana, 2012).

In addition to pit latrines, flying toilets and open defecation are common in informal settlements. Small market shares are held by other approaches and technologies, including ventilated improved pit latrines (VIP), biogas toilet/latrines, compost pit latrines, lined ventilated improved pit latrines, pit latrines with urine diversion, and urine diversion dry toilets (UDDT). Pour-flush toilets, a variant on the standard toilet with fixed links for water in and sewage out, are used by a few higher income earners in informal settlements (Katukiza et. al., "Selection", 2010).

Biogas facilities do not require as frequent exhaustion as pit latrines. But if small biogas systems are to be successful, knowledgeable networks capable of maintenance must be developed, (Bond, 2011). Since the 1970s the development and use of small biogas systems have spread mostly in rural areas and are usually used with animal faeces for gas production. Since then the number of biogas systems in India and China have grown to 4 and 27 million respectively (Bond). In other countries the technology didn't proliferate as extensively and in some cases up to 50% of the plants are non-functional because of a lack of maintenance.

Predictably, open defecation and "flying" toilets score the lowest on surveys of residents' preferred methods of dealing with human waste (Munala, 2012). And while pit latrines are the most common type of sanitation facility in informal settlements, as a method of waste disposal they ranked second to last in the survey Katukiza et al. did of residents of Bwaise III. Katukiza et al. conclude, "...this implies that communities are aware of the environmental pollution caused by existing unimproved excreta disposal facilities but have no options due to lack of funds and complexity of the slum settings" ("Selection", 2010, p.60).

Many sanitation interventions by NGO's have failed because of a lack of stakeholder participation at various stages in the project. Some facilities failed because they followed models that succeeded in other areas with different, more favorable conditions: non-collapsing soils with a low water table, or appropriate legal status and ownership. "Sanitation facilities were constructed without considering sanitation as a system that comprises of collection, storage, treatment and safe disposal/reuse" This failure to think systemically caused failures in the operation and maintenance of facilities, resulting in dissatisfaction in users and environmental pollution from untreated waste, (Katukiza et. al., "Selection", 2010). Past failed interventions can be expected to diminish enthusiasm for fresh innovations—a diminishment that is, however, moderated by the severity of the sanitation crisis that these communities face. Because of that severity the communities remain open to innovative intervention.

4 THE BIO-CENTER INNOVATION

4.1 Design Fundamentals

Umande Trust, a rights based organization, developed the bio-center eco-sanitation facility model in 2007. Bio-centers layer multiple community uses into a sanitation facility. Piloted in Gitwekera village of Kibera informal settlement in 2007, there are now 84 bio-centers in Nairobi and Kisumu. Bio-centers are permanent multi-layered structures, built of locally sourced concrete, stone and brick, that use underground anaerobic digesters to process excreta on-site, producing two valuable by-products of immediate use or sale to the population near the facility: biogas for cooking and bio-slurry compost for agricultural production therefore the resource and energy efficiency and returns are high.

Bio-centers provide a sustainable business model with a variety of Income Generating Activities (IGAs) "to ensure the sustainability of the facilities and a wider socially transformative effect", (Umande, 2014). In each bio-center there are about twelve toilet stalls available to the public for about five Kenyan shillings. On the second, and sometimes third, floors spaces are to rent for businesses, banks, churches, community groups, office to hire, restaurants, and internet cafes. During the World Cup several bio-centers had success renting the space for people to watch the games. Community stoves utilizing harvested biogas can be used to cook or boil water for 10 Kenyan shillings for the duration of the cooking time. Since 2012 Umande Trust has partnered with Kopo Kopo to provide a "web based application that allows bio-centers to accept and track transactions made through mobile money (MPesa)." This partnership further supports the micro and small businesses being developed.

The construction of bio-centers is overseen by Umande Trust, which guides a community group or collective through the process of building, financing and managing the facility each new bio-center. The bio-centers are then managed by community groups, which own the centers. After the construction of a bio-center, the management groups operate bio-centers independently, but remain connected to Umande Trust through a collective upgrading fund and sharing of best practices. In this way all the bio-centers benefit from continuous improvement. For example Katwekera, the first bio-center ever built, was designed for a capacity of 400 people a day. Currently 800 people a day use it. So Umande Trust added three additional overflow domes and a baffle filter to increase the capacity of the bio-center. Around 60% of the profits generated by bio-centers goes to the management and/or operation group, 30% to operational costs, and 10% go to a collective fund for the upgrading and maintenance of all the Bio-centers.

In 2007 Athi Water Service Board provided some initial investment for 20 bio-centers. These bio-centers, financed by AWSB, were assessed to gather best practices from the highest achieving centers in 2013. AWSB's report looked at 20 bio-centers in three settlements Kibera, Mukuru, and Korogocho. (Umande, 2013)

4.2 The Bio-center as a Manifestation of Systems Thinking

Sustainable systems can be conceptualized as being formed of loops and arrows. The loops describe both material movement and information flows. Because matter can neither be created nor destroyed, the movement of material in a system has to be circular. If it isn't, the system will perpetually accumulate matter in one portion of the system and perpetually source that matter from another. But perpetual accumulation and perpetual extraction of matter is impossible on a finite planet. The circular information loops are feedback loops—closed systems in which information about the effect of a process is used to regulate the process. Absence of feedback (or absence of timely feedback) can lead to system collapse. For instance, it remains to be seen whether human civilization can respond rapidly enough to the relatively sudden feedback we've been given—feedback that emerged gradually over the past twenty years--that now that we are several centuries into the Fossil Fuel Era we have deposited more CO2 into the atmosphere than it can hold without undergoing systemic change.

Arrows describe any transformation of energy, since these can operate in only one direction: energy flows from low entropy (high usefulness) to high entropy (low usefulness), never the reverse. A stream tumbles from the highlands down to the ocean, ever downward, never up. (Water does rise out of the ocean for transport to mountaintop, to fall again as rain; this hydrological cycle requires fresh input of energy in the form of solar powered evaporation.) Life colonizes the downward fall, from sunlight through herbivore, carnivore, detritivore, and so on, until all the solar energy captured by photosynthesis has been dissipated into the metabolic processes--the muscular motion and bodily heat--of successive consumers.

The one-way flow of energy is relevant to the design of Bio-centers because excrement of any sizable animal contains a store of energy that is useless to the animal itself but which can be used by niche specialists. Human excrement contains such energy, and because we are a tool using species we constitute an exception: while we cannot survive by eating our own wastes (no animal can), we can harvest the unused energy in our waste and put it to work for us instead of releasing it for dissipation into microbial life in the environment. As can be seen, then, Bio-centers are instances of sustainable design because they offer closure of a material flow, mending the nutrient-food-waste-nutrient cycle, and allow us to colonize a greater part of the one-way flow of energy through our alimentary systems.

4.3 Investment, Ownership, Operational Economics

Management groups generally view expenses as a positive part of operating the facility, which leads to income and job creation. Groups from Mukuru described the income and expenses of the facilities they managed "as a tree, with the roots representing the expenses and the fruits representing the incomes, really capturing the essential nature of these items as fertilizer that is used to grow incomes" (Umande, p. 4). This perspective of the economics of bio-centers mirrors the ecological relationship of bio-centers to their place. This embeddedness and place based wealth generation marks a significant difference from other sanitation facilities which don't integrate as deeply in the ecology or economics of the places in which they operate.

Most bio-centers display upward trends in income and decreasing or stabilization of expenses over time as management groups streamline operations and the surrounding community becomes more familiar and accepting of the facility. Revenues and expenditures correlate across highest and lowest earning bio-centers, averaging to around 30-40% of income spent on regular operational expenses including tissue, electricity and water and the infrequent costs of exhausting the dome of bio-slurry, manual maintenance and caretaker labour, and facilities upgrading. While it varies, the average net income or profit for the AWSB bio-centers was 23,400 KSh/month or 280,800 KSh/year (Umande, 2013).

Table 1. Financial Summaries of AWSB-financed Bio-Centers (AWSB, 2013)

	Monthly						
	Avg Revenues	Avg Expenses	Avg Profits	Annualized Profit	Construction Cost	Return on Investment	Internal Rate of Return IRR
Bunkers	4,833	685	4,148	49,776	-1,520,651	3.3%	-8%
Heshima Disabled	14,686	4,534	10,152	121,824	-1,106,855	11.0%	11%
Kisumu Ndogo	22,599	8,373	14,226	170,712	-1,529,680	11.2%	11%
KYU	19,598	7,138	12,460	149,520	-1,478,495	10.1%	9%
LindiUsafi	10,168	5,745	4,423	53,072	-1,298,820	4.1%	-5%
Nyaharwa	24,002	9,202	14,800	177,600	-2,310,767	7.7%	4%
Tegemeo	39,808	13,348	26,460	317,520	-1,515,218	21.0%	24%
UwezoMpya	21,793	8,298	13,495	161,940	-1,330,822	12.2%	13%
Average (unweighted)	**19,686**	**7,165**	**12,520**	**150,246**	**-1,511,414**	**10%**	**7%**

Of the AWSB bio-centers surveyed, all have attained somewhat positive cash flow on a monthly basis making profits off the initial investment, though the extent of profit varies by bio-center. The rate of Return on Investment ranges from 3.3% for Bunkers bio-center to 21% for Tegemeo bio-center. (Umande, 2013) Even those centers with the lowest RoI can successfully pay back initial construction costs (in some cases taking up to 30 years). Given this the construction of bio-centers can be considered viable investments independent of the benefits of improved sanitation and health, *renewable* energy production, and infrastructural development.

The primary source of bio-center income is the toilets, constituting an average (unweighted) of 52.2% of sales of the twenty centers surveyed, which had complete records. The second largest source of income is water contributing an average of 26.9% of income, showers 9.4%, rent/hall usage 8.1%, sale of biogas and other various incomes make up the remainder. The most profitable service offered is rental of space for gatherings and businesses as there are little to no operational costs. (Umande 2013) This revenue demonstrates and supports the bio-center as a community anchor or node for other, often wealth generating, community building activities. Of the AWSB bio-centers surveyed the average gross income was 21,400 KSh/month (700 KSh/day) or roughly $235 USD/month ($7.7 USD/day).

4.4 Placement, Use & Autonomous Infrastructure Development

The daily usage of Bio-center services, (toilet, shower, stove, gathering space) varies widely in relation to placement and availability of other sanitation options. Korogocho settlement, which had the lowest average weekly users, has a generally higher level of existing sanitation coverage. LungaLunga Bio-center, with the largest weekly average served 3830 users largely because of its adjacency to a busy market area (AWSB, 2013). Considering placement of Bio-centers in relation to circulation of commerce is advantageous to ensure the economic sustainability of centers, which enables and proliferates the ecological services they provide (Table 2).

Table 2. Average Weekly Users of Bio-Center Services (AWSB, 2013)

Bio-center Area	Users
All AWSB Bio-centers	1370
Bunkers	203
LungaLunga	3,830
Residential	1,190
Market	2,210
Mukuru	1,950
Kibera	890
Korogocho	840

Several bio-centers have begun piping biogas to surrounding houses for a monthly fee, generating a new income stream and extending the autonomous renewable energy infrastructure anchored by the bio-center. Kawekera bio-center provided biogas to five households for a monthly fee starting in 2014 (Figure 1). LindiUsafi bio-center connected 3 pit latrines to the digester. This provided an additional 4,000 KSh of income per month for the center (Umande, 2013).

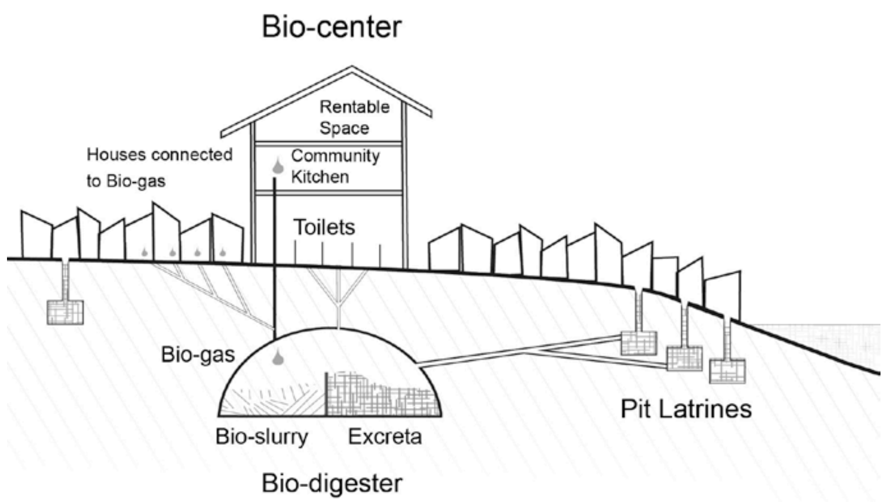

Figure 1. Expanded Bio-center renewable energy and sanitation infrastructure (Andrea Godshalk, 2015)

These three toilets, which serve 60 families, extend the reach of the sanitation infrastructure provided by the LindiUsafi bio-center without significant investment, create an additional income stream and convert an existing latrines to an eco-sanitation model without competing with the owners of those latrines. In this case the depth of the pit won't limit the timeframe of operation, since the dome that collects the waste is being emptied of the compost regularly. This means that the life expectancy of these buildings is only limited viability of the construction material (Munala, 2012). As bio-centers expand their capacity to network biogas connections to surrounding households for fees, revenues will increase along with the establishment of renewable energy infrastructure services to their communities.

There are several other models of ecological sanitation—though they lack the scope and reach of Bio-centers as a sustainability-purposed whole-systems design. The two main examples currently being utilized in Kenya are Peepoo bags and Sanergy's Free Life Toilets.

The company Peepoople launched the Peepoo bag in 2010 to address immediate needs for sanitation (Peepoople, 2015). The Peepoo, an ecological iteration of the flying toilet, is a single use bag treated with enzymes to biodegrade feces into fertilizer when buried. It disintegrates into carbon dioxide, water and biomass. While this is an improvement on the "flying toilet", the business model creates dependency for the bags, which are produced in Germany. Peepoo bags address needs for immediate sanitation, but doesn't contribute to place making.

Sanergy, founded by three MIT graduates from the Sloan MBA program, designed the "Fresh Life" toilet for the informal settlements of Nairobi, Kenya (Sanergy, 2015). Using an ecological sanitation model, which utilizes feces and urine as a resource for fertilizer, biogas and energy, Sanergy began their enterprise in 2010, and operates as a non-profit with a franchise business model that aims to build a network of local entrepreneurs who manage low-cost toilets. Waste is collected from these and processed off site at a centralized location to produce electricity and fertilizer (Likoko, 2013). As of 2014 there were 299 locally pre-fabricated Fresh Life Toilets in operation and approximately 11,000 daily users (Sanergy, 2015). Users can pay by visit, week or month, including family memberships. The Sanergy team is 90% Kenyan, 60% of them live in the communities where Free Life Toilets are installed and 50% are under 27 years old. Sanergy holds weekly 1-on-1 meetings, monthly advisory council meetings and quarterly network forums to support Fresh Life Operators (FLO). Team members are provided with contracts, medial and life insurance and pensions. FLOs are supported with training, access to financing, operational and marketing support, and daily collection of containers from individual toilets and provides clean containers to replace the full ones.

Because the sealed containers can be moved by foot truck and the toilets take up a small space they can be installed in dense areas. FLOs are to collect waste daily from the toilets they manage. In the first four years 1,426 metric tons of waste were collected. The waste is transferred offsite and processed at a centralized facility, where it is composted into biogas and fertilizer (Sanergy, 2015). There is high demand for the fertilizer from the farmers in the region, many of whom are otherwise reliant on synthetic (i.e. petroleum-based) fertilizers imported from abroad. Like Bio-centers, then, Sanergy's Fresh Life toilets help reduce the outflow of money from Kenyan farmers to international fertilizer companies, re-localizing to some extent the agricultural economy. The energy produced is sold to the national grid. The profits from this are being reinvested to build the infrastructure, more could be done to have that energy and fertilizer going back to the communities it was harvested from and contribute to place building. Sanergy's model is centralized and franchise toilet managers remain dependent on that centralized network. It is a strong network that provides support and training, yet it also operates to extract resources from the community. Bio-centers, in contrast, function as stand-alone, autonomous entities networked in order to trade information; resources and services are not traded between outpost and center as they are in the Sanergy model.

4.5 In Relation to Other Eco-sanitation Models

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5 EXTERNALITIES OF SOCIO-ECOLOGICAL SANITATION

Bio-centers have socio-political benefits that exceed those of other eco-sanitation technologies. All sanitation technologies offer the significant externality of improved public health as a by-product of use, and both the Bio-center and the Sanergy model offer the capture of energy that would otherwise be wasted. But Bio-centers have additional positive externalities that become clearer when the following criteria are used to assess performance of the overall system:

- Involvement of stakeholders (both users and owners);
- Net flow of resources into/out of the community;
- Effect on social capital through place-making and improvement in living conditions.
- Ability to sustain the infrastructure, with skills, materials and knowledge, locally

Successful socio-ecological sanitation facilities expand waste-to-wealth strategies and community place building to maximize social and economic benefits in the communities in which they are situated, while simultaneously addressing the health and environmental damage from a lack of adequate sanitation. Eric Swyngedouw (2003) defines the aim Urban Political Ecology "to enhance the democratic content of socio-environmental construction by identifying the strategies through which a more equitable distribution of social power and a more inclusive mode of environmental production can be achieved" (p. 898). Ecological sanitation models are able to generate wealth in the form of compost and biogas both of which can be sold. For these models to make a significant impact the wealth accumulated from the harvested resources (or unprocessed excreta) should benefit the communities from which they are gathered. In the same vein, the organizational structure of the leadership, management, and ownership of facilities should be representative of the community being served by the facilities to contribute to the long-term wealth building.

Communications technologies allow for rapid global dissemination of design innovations, yet given the history of colonial exploitation, well intentioned westerners bearing innovative solutions would do well to build partnerships that empower local ownership and management. "We own, you work" is an outmoded developmental model. "We design, you build" can be equally problematic, especially if the fundamental purpose of sanitation facilities is to allow a population to fulfil elemental needs and begin the work of recognizing and defining higher-purpose needs, such as economic self-reliance, political efficacy and political and social autonomy. A technology that meets a first-order need (like sanitation) at the expense of diminishing the ability to meet higher order needs is not a sustainable technology.

6 CONCLUSION

By layering multiple community-service and income-generating functions into a shared facility, bio-centers become anchor-buildings or nodes within communities. In addition to providing urgently needed sanitation facilities, bio-centers also offer to their communities an exemplary instance of a successful, multi-modal business. Bio-centers provide a variety of Income Generating Activities (IGAs) “to ensure the sustainability of the facilities and a wider socially transformative effect”, (Umande, 2014). Each facility offers space that can be rented for business incubation or civic or church functions, and also provides an inexpensive renewable energy resource. Often the biogas generated is used on-site in a community kitchen, restaurant, or other function in the building itself, eliminating the need for transport with its associated investment and operational expenses (Umande, 2013). Several bio-centers have successfully connected adjacent pit latrines to their anaerobic digesters, thereby accomplishing several positive outcomes: increased biogas production, conversion of those latrines to an eco-sanitation model, and enrolment of their owners as allies rather than competitors (J. Omotto, personal communication, July 15, 2014).

Of 20 bio-centers surveyed, all had attained positive cash flow on a monthly basis, making profits off the initial investment (Umande, 2013). Even those centers with the lowest RoI can successfully pay back initial construction costs (in some cases taking up to 30 years). Given this, the construction of bio-centers can be considered viable investments *independent* of the benefits of improved sanitation and health, renewable energy production, and infrastructural development. As bio-centers expand their capacity to network biogas connections to surrounding households, and pit latrines for fees, revenues will increase along with the establishment of renewable energy infrastructure and ecological sanitation services to their communities.

The most important lesson from the Umande Trust bio-centers is not one of technology but rather about the benefits that come from integration of humans and natural processes into a metabolic cycle. The technology shows that such metabolic integration can be generative at a local scale. Mike Davis (2006) notes that “urban theorists, beginning with Patrick Geddes, have long recognized, both environmental efficiency and public affluence require the preservation of a green matrix of intact ecosystems, open spaces and natural services: cities need an alliance with Nature in order to recycle their waste products into usable inputs for farming, gardening and energy production” (p. 134). Cities must utilize localized metabolisms to process excreta and utilize by products to uplift the dignity and wealth of those most vulnerable and disenfranchised.

Developing ecological infrastructures to process human excrement and harvest resources, both biogas and compost, can make deep impacts on the wellbeing of humans and their social and ecological communities in rapidly urbanizing cities around the world. Bio-centers increase health and entrepreneurial and generate renewable resources, rather than exploiting, or damaging them.

Bio-centers, and the way they are collectively built and managed is an essential model for developing effective, multi-purpose, community-building sanitation facilities in circumstances that are among the most physically and economically challenging on the planet. But bio-centers do more than that: they shine compelling insight into effective innovative design premised on an integrated view of social-ecological systems. The development of an ecological urbanism is crucial for the long-term sustainability of the human project on Earth.

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