Ecological Sanitation Networks: Bio-Centre Innovation Through Systems Thinking Design

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Abstract

Bio-centres, piloted in 2007 and expanded to 84 installations by 2014, address urgent sanitation challenges in concert with other social and economic needs. Bio-centres are multi-layer structures that use anaerobic digestion to process human excreta on-site, producing two valuable by-products of immediate use to the population near the facility: methane for cooking and bio-slurry compost for agricultural production.

Localized metabolisms enable cities to process excreta and utilize by-products to uplift the dignity and wealth of those most vulnerable and disenfranchised. With toilets, showers, kitchens, and rental spaces for community and commercial purposes, Bio-centres layer multiple income-generating uses into a communal ecological sanitation facility, and in turn becomes an anchor or node in the community.

Developing socio-ecological infrastructures to process human excrement and harvest resources, both biogas and compost, make deep impacts on the health and well being of humans and their communities. A systems thinking approach enables effective engagement with the overlapping ecological, geographic, and economic challenges associated with developing advantageous sanitation solutions in informal settlements. By engaging all to these spheres in the placement and operations of Bio-centres the benefits of these facilities can be maximized.

1 Introduction

The rapid increase of urban populations in informal settlements constitutes an unprecedented challenge in the 21st century. Currently around 2.5 billion people lack access to safe sanitation. Diarrhea, a disease caused by poor sanitation, causes around 2.2 million deaths a year (MUNALA 2013, 2). Because of the challenges in informal settlements, "communal sanitation facilities, when well constructed and maintained, may be the only technically and economically feasible sanitation option for low income, high density slums" (SHOUTEN & MATHENGE 2010, 816). These circumstances require responsive design guided by systems thinking and the methods of geodesign. Bio-centres, developed by UMANDE TRUST, layer multiple community uses into an ecological sanitation facility. In addition to providing public toilets, bio-centres safely process excreta on site though an anaerobic process in an underground dome, which yields methane biogas used for cooking, and bio-slurry fertilizer. Piloted in 2007, there are now 84 bio-centres in Nairobi and Kisumu, each one serving between 350 and 1000 people a day (WHITEHEAD 2014).

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Bio-centres serve as a sustainable business model, which provide, in addition to urgently needed sanitation facilities, business incubation, renewable energy sources and infrastructures. Several bio-centres have successfully connected adjacent pit latrines to existing anaerobic digesters thereby converting them to an eco-sanitation model while enrolling pit latrine owners as allies rather than competing with them. This paper utilizes systems theory to situate bio-centres within the acute and overlapping economic, social, and ecological and energy circumstances present in informal settlements. The rapid and prolific success of the bio-centre model relies on the fact that UMANDE TRUST addresses all of these spheres simultaneously. The paper develops an empirical case study of design innovation stemming from systems measurements in design thinking.

Bio-centres provide an important example of high-density urban nutrient cycling, which harvests sustainable resources while ameliorating mortiferous circumstances. The density of informal settlements and their common proximity to significant ecological sites often leads to disproportionate impact on surrounding systems. This is evident in the discontinued use of the Nairobi reservoir as a result of the eutrophication and water hyacinth invasion resulting from excreta from Kibera. Bio-centres can build on the foundation of responsive design innovations originating from a measured understanding of the systems in which they operate to develop more advantageous relationships to waterways in regards to flooding and wetlands.

2 Context: Informal Urbanism

2.1 Physical

Informal settlements develop densely without sufficient space or investment for sewer networks (MUNALA 2013, 5). The major capital investments needed to develop large-scale sewage infrastructure is a significant obstacle to developing and maintaining centralized systems. High population density and flood prone locations of informal settlements increase the problem of contamination of waterways by overflowing pit latrines and the washout of flying toilets. Studies have indicated that most of the spring water sources in the peri-urban areas of Kampala are contaminated with pathogens of faecal origin attributed to poor sanitation practice (KATUKIZA et al. 2010, “Selection” 53, 57, 59).

Taking its name from the Maasai, who lived there before the British came in 1899 to pin a train depot between Mombasa and Uganda, Nairobi comes from *Enkare Nyrobi* meaning “cold water”. The city is named after the river, which runs through it. Four rivers flow through the city and provide the water for the residents. The pressure on these resources has grown exponentially over the last century with the population increasing from 11,500 people in 1906 to 3,375,000 people in 2014. Much of the population growth has happened in informal settlements and along river edges. This presents several challenges to both the waterways and the populations settling along them. “Currently about 56 percent of the city residents live in 46 highly congested informal settlements with many located along the Nairobi River banks (WERU). Development on the edges of rivers causes damage to vegetation along the banks, reducing the filtration services and flood mitigation of riverside plants. The rivers have become so impacted and damaged by that settlement that they have become a dangerous hazard to an increasing number of marginalized residents whose only space in the city is pressed against the edge of those waterways.

Constructed in 1953 to provide potable water, the Nairobi Dam is shallow, with a depth of only 9.1ft. The Nairobi River flows into the Dam and outflows into the Ngongo River through a spillway. Currently there is little out flow because the Dam has been inundated with solid waste and water hyacinth which has eliminated the sailing and fishing for which the Dam was known a mere 20 years ago. The Nairobi Dam is supposed to provide water for around 15 million people or about a third of the Kenyan population. Though the Dam is essential to the population of the city, the most marginal residents live adjacent to it. Kibera sits right upslope the Nairobi Dam. One of the largest informal settlements on the continent of Africa, Kibera is plagued by a lack of infrastructures that would support a healthy relationship with the Nairobi river or Dam. In addressing increasing complexity, Walker et al. (2009) argue that "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, 753).

2.2 Absence of Sanitation

Human excreta is predominantly disposed in informal settlements using unlined pit latrines which are usually elevated in areas with a high water table so they drain directly into the water. The user-load of pit latrines is often higher than recommended therefore pit latrines fill up rapidly. Full pit latrines are often abandoned because the cost of exhausting them is both physically difficult in the narrow pathways and cost prohibitive. 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 2013, 6). In Bwaise III, in Kampala (Uganda) it was found that 15 % of the population uses a public pit latrine; 75 % uses a shared toilet; and 10 % has private, non-shared sanitation facilities (KATUKIZA et al. 2010, "Selection" 52, 56). MUNALA's study uncovered 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 (SCHOUTEN et al. 2010, 818). Abandoned pit latrines remain a contamination risk to water bodies and drinking water. As pit latrines full up and are abandoned new ones are dug, weakening the ground around built structures surrounding pit latrine holes. This exacerbates the vulnerability of foundations of precarious, resident built buildings. This open loop system doesn't capture and recover nutrients and is a "great economical as well as ecological loss" (MUNALA 2013, 8). A study conducted by UMANDE TRUST, COHRE and Hakijamii Trust reported that between 50-90 % of the households in Kibera, in Nairobi, can't access to adequate sanitation.

2.3 Social

In Nairobi over 60 % of the city's population lives in informal settlements (MUNALA 2013, 2). The social dynamics of informal settlements also make sanitation upgrades challenging. People move in and out of these settlements rapidly, this, compounded by the lack of ownership of residents, make it difficult to establish a collective investment in maintaining sanitation facilities (KATUKIZA et al. 2010, "Selection", 60). The frequently shifting demographics of informal settlements create a challenge for sanitation upgrading. Successful interventions in selecting and establishing sanitation technologies must engage collective ownership models. Ecological sanitation models that prioritize economic benefits incentivize the development and management of facilities.

Many sanitation interventions by NGO's have failed because of a lack of stakeholder participation at all stages of the project. Facilities have been implemented based on systems applied in other areas. "Sanitation facilities were constructed without considering *sanitation as a system* that comprises of collection, storage, treatment and safe disposal/reuse" (KATUKIZA et. al. 2010, "Selection" 59). This cause failures in the operation and maintenance of facilities resulting in dissatisfaction in users and environmental pollution from untreated waste. Since 2009 Map Kibera has trained residents to gather data and report on conditions in their community. This data has been used to develop an online database about conditions in the informal settlements on Nairobi. The database has been used to engage residents in the development of action plans for neighbourhood upgrading and to advocate for those upgrades (Map). User "input is imperative for selection and adoption of sanitation technologies" (KATUKIZA et. al. 2010, "Selection" 56, 60).

2.4 Systems Approach: Socio-Ecological Sanitation

A systems thinking approach enables an effective assessment of sanitation systems. The overlapping ecological, geographic, and economic circumstances of informal settlements require simultaneous engagement. Eric SWYNGEDOUW frames of Urban Political Ecology as an "integrated and relational approach that helps untangle the interconnected economic, political, social and ecological processes that together go to form highly uneven and deeply unjust urban landscapes… The political program, then, of urban political ecology is 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" (898). Ecological sanitation, which safely metabolizes excreta yielding compost and in the most advantageous models biogas, can expand waste-to-wealth strategies and community place building, while addressing severe health and environmental damage from a lack of adequate sanitation. The most useful models of ecological sanitation maximize social and economic benefits in the communities in which they are situated.

In assessing eco-sanitation systems priority is placed on waste to wealth strategies and community wealth accumulation. When resources (excreta) are harvested from sanitation technologies those resources should benefit the communities from which they are gathered. This means it is important to look at the organizational structure utilized to implement and manage eco-sanitation facilities. Are stakeholders, both users and managers, involved? Does the facility contribute to place making? If projects are to be sustainable they are more likely to be embedded within the community of users. Practical issues around management need to be considered for the long-term sustainability of projects in the drastically fluctuating circumstances of informal settlements. Are the resources to construct the facility sources locally? Are they affordable? Can the community develop the skills to fix and manage the facility without being dependent on outside organizations? What other benefits, social, economic, environmental, does the facility offer in addition to sanitation?

3 Bio-Centres

Bio-centres 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"(AWSB, 3). The bio-centres are layered, beginning underground with the anaerobic digester dome, above that is the ground level public toilets and showers. In each bio-centre there are about twelve toilet stalls available to the public for about five Kenyan shillings. Spaces on the second, and sometimes third, floors are available to rent for businesses, banks, churches, community groups, office to hire, restaurants, and Internet cafes. During the World Cup several bio-centres 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 allow bio-centres to accept and track transactions through mobile phones. Kopo Kopo supports the micro and small businesses that are being developed at bio-centres. It costs around 100 Kenya Shillings (Ksh) for a month of use of a communal toilet (MULALA 2013, 7). 100 Ksh is equivalent to about $1.16 USD The monthly income of an unskilled laborer in Kenya is around 5,000 Ksh or $58.00 USD. Residents of informal settlements often pay much more for food and water by virtue of access to these basic resources.

The maintenance operations are more time and labour intensive as the facility consists of toilets, showers, and methane extraction. Bio-slurry is treated on site and then used as fertilizer; therefore the resource and energy efficiency and returns are high. The timeframe of operation isn't limited because management teams are continually emptying the dome of processed compost. This means that the life expectancy of these buildings is only limited viability of the construction material (MUNALA 2010, 7, 9).

The construction of bio-centres is overseen by UMANDE TRUST, which guides a community group or collective through the process of building, financing and managing the facility. The bio-centres are then managed by community groups, which own the centres. After the construction of a bio-centre the facility remains in a connection to UMANDE TRUST through a collective upgrading fund and sharing of best practices. Of the profits generated by the bio-centres, around 60 % 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-centres. They apply lessons learned to both new bio-centres and to the refinement of previously built facilities. Katwekera, the first bio-centre 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-centre.

Kawekera bio-centre began piping biogas to five households for a monthly fee in 2014, generating a new income stream and extending the autonomous renewable energy sanitation infrastructure anchored by the bio-centre. LindiUsafi bio-centre connected 3 on-plot toilets to the digester. This provided an additional 4,000 KSh of income per month for the centre (AWSB 11). These three toilets, which serve 60 families, extend the reach of the sanitation infrastructure provided by the LindiUsafi bio-centre without significant investment, create an additional income stream and convert existing latrines to an eco-sanitation model. This economically aligns bio-centre owner-operators and pit latrine owners thereby accelerating the conversion of pit latrines into an ecologically, and socially advantageous sanitation typology.

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"(AWSB, 4). This perspective of the economics of bio-centres mirrors the ecological relationship of bio-centres to their place. This place based wealth generation marks a significant difference from other ecological sanitation facilities which often don't integrate with the ecology or economics of the places in which they operate.

3.1 Economics and Siting

Most bio-centres 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 (AWSB 8, 10). Of the AWSB bio-centres surveyed, all attained somewhat positive cash flow on a monthly basis thereby making profits off the initial investment, though the extent of profit varies by bio-centre. The rate of Return on Investment ranges from 3.3 % for Bunkers bio-centre to 21 % for Tegemeo bio-centre (AWSB 13). Even those centres with the lowest RoI could successfully pay back initial construction costs (taking up to 30 years) and can be considered viable investments *independent* of the benefits of improved sanitation, health, renewable energy production, and infrastructural development.

The primary source of bio-centre income is the toilets, constituting an (un-weighted) average of 52.2 % of sales for the twenty centres surveyed with complete records. The second largest source of income is water, contributing an average of 26.9 % of income; washrooms 9.4 %, rent/hall usage 8.1 %, sale of bio-gas and other various incomes make up the remainder. These numbers align with the primary goal of bio-centres to provide sanitation and water (AWSB 5).

The most profitable service bio-centres offer is rental of space for gatherings and businesses, as there are little-to-no operational costs (AWSB 5). This revenue contributes to the bio-centre as a community anchor or node for other, often wealth generating, activities. As bio-centres expand their capacity to provide biogas connections to surrounding households for fees, revenues will increase along with the establishment of renewable energy infrastructure services. The daily usage of bio-centres varies widely in relation to the general location, specific placement of the facility, and the availability of other existing sanitation options. Bio-centres in Mukuru had a higher average of weekly users (1950), compared to Kibera (890) and Korogocho (840). Korogocho has a generally higher level of existing sanitation coverage (AWSB 6).

Of the AWSB bio-centres surveyed the average gross income was 21,400 KSh/month (700 KSh/day) or roughly \$235 USD/month (\$7.7 USD/day). There are outliers, most notably Tegemeo bio-centre which benefits significantly from it location in a busy market area, capturing more clients from the increased pedestrian circulation compared to bio-centres in residential areas which rely largely on the immediate residents. Bio-centres in residential areas average 1190 users. The increased foot traffic of busy market areas increases average bio-centre users to 2210 (AWSB 6). Placement of bio-centres in relation to circulation of commerce must be considered along side circulation of storm water to ensure the economic sustainability of centres, which enables and proliferates the ecological services they provide.

When siting a Bio-centre, opportunities for multiple income streams should be considered to maximize economic sustainability. Adjacency to busy commercial corridors will maximize profits from toilet use and increase demand for room rentals. In addition, opportuneties to connect existing pit latrines to anaerobic digesters should be considered as a way to convert them to ecological sanitation facilities and generate income streams. The ability to provide biogas directly to households provides another income stream and weaves a Bio-centre into the community as a source of renewable energy. These considerations along with adjacencies to vulnerable and damaged waterways could target the ecological restoration of these systems.

3.2 Conclusion

Localized metabolisms enable cities to process excreta and utilize by-products to uplift the dignity and wealth of those most vulnerable and disenfranchised. Developing socio-ecological infrastructures to process human excrement and harvest resources, both biogas and compost, make deep impacts on the health and well being of humans and their communities. A systems thinking approach enables effective engagement with the overlapping ecological, geographic, and economic challenges associated with developing advantageous sanitation solutions in informal settlements. By engaging all to these spheres in the placement and operations of Bio-centres the benefits of these facilities can be maximized. Bio-centres provide opportunities to address the lack of adequate sanitation while developing closed loop systems that build wealth in the community. Bio-centres increase health and entrepreneurial opportunities in dense informal urban settlements while generating compost and bio-gas. Bio-centres become nodes for social and economic organizing while developing autonomous renewable energy infrastructures.

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