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## ARTICLE

# Navigating heterogeneous sanitation configurations: How off-grid technologies work and are reworked by urban residents

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## Abstract

A range of innovative off-grid sanitation technologies have been developed and deployed to improve sanitation in cities where networked sanitation by publicly managed sewers is insufficient. Studies of such technologies tend to consider toilets as static, where technologies are chosen once, at the project onset and in isolation from each other. In this study we explore off-grid sanitation as heterogeneous infrastructure configurations of people and toilets, roles and responsibilities, costs and benefits. Using two cases from Kampala, we emphasise that there are relationships between the different parts of infrastructure, and that these relationships vary over time and space. Urban residents rework configurations by changing a toilet and changing which toilets are used in order to meet their diverse sanitation desires. We demonstrate technological diversity, connect this diversity to the preferences of users by showing linkages between toilets that are proximate to each other, and show the importance of considering relations between toilets over time. Our analysis demonstrates how operations, cultural orientations, payment mechanisms, and limitations have a significant bearing on feasibility, scalability, and integration into city-wide sanitation, and that this is often not foreseen in planning phases. We thus conclude that sanitation configurations that enable flexibility rather than trying to predict needs may well enable more reliable infrastructure.

## KEYWORDS

African cities, heterogeneous infrastructure configurations, Kampala, sanitation, technology

## 1 | INTRODUCTION

Despite much political and scholarly attention to networked infrastructure, developing countries remain characterised by diversified sanitation practices and technologies. Insufficient funding for investment in or expansion of sewer systems, even in some developed countries, has resulted in exclusion of marginalised groups, heightening inequality (Deitz & Meehan, 2019). Further, malfunctions and technical difficulties across the north and south make reliable infrastructure

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difficult to achieve and maintain, while weather extremes due to climate uncertainty have affected sewerage treatment plants through floods (Zouboulis & Tolkou, 2015).

In this context, there is growing attention to off-grid technologies such as septic tanks, aqua privies, biogas latrines, composting or dehydrating toilets, and pit latrines; these are often called onsite, off-grid, or non-sewered as they are not directly connected to publicly managed sewer networks. While some see these as not-quite-proper infrastructure, others are more optimistic about the potential for non-sewered approaches in redressing sanitation challenges in developing countries (Vliet et al., 2010).

Here, we analyse the use of two sanitation designs in Kampala: a pour-flush water-borne toilet and a bio-fill toilet. We aim to understand the workings and limitations of off-grid infrastructure to enable improved sanitation. Most studies of off-grid infrastructures consider toilets in a rather static way: technologies are chosen once at the start of a project and toilets are viewed in isolation from each other. In this paper, we draw on the idea of heterogeneous infrastructure configurations (Lawhon et al., 2018) to consider how sanitation configurations work and change through negotiation of actors, relations, and environment, both in space and time.

We not only demonstrate technological diversity and connect this diversity to the preferences of users but also show linkages *between* toilets that are proximate to each other, and the importance of considering these relations between toilets over time. In doing so, we hope to shape further inquiries into the use, expansion, improvement, and regulation of heterogeneity for urban sanitation. We also raise lines of inquiry on broader questions of temporality, multiplicity of designs, and actors as part of the urban sanitation configurations.

## 2 | HETEROGENEOUS CONFIGURATIONS OF SANITATION INFRASTRUCTURE

Studies on urban infrastructure in Africa, from energy to transport, continue to demonstrate that there are different modes, artefacts, and experiences of service delivery (Jaglin, 2014). Many of these operate across formal and informal practices, involving actors such as the state, corporate entities, and individuals across different service levels and spatial scales. These actors both influence and are influenced by power relations embedded in social customs, political domains, and state structures. The infrastructural configurations are also comprised of many economic arrangements (Coutard & Rutherford, 2016; Jaglin, 2014), all of which bring in value, dividends, and accumulation of assets. In this paper, we consider these as heterogeneous infrastructure configurations, emphasising that there are relationships that vary over time and space between the different parts of infrastructure, even when it is 'off-grid'; sanitation is no exception here.

Most of Africa's sanitation practices are off-grid, and the proportions of urban residents not connected to networked grids varies between 50% and 60% in North Africa to 90% in the Sub-Sahara (United Nations, 2014). Pit latrines are the most common alternative, although other options like septic tanks, bio-toilets, and eco-sans are significant, suggestive of the multicity of configurations. Onsite technologies normally require periodic emptying, but the methods for how this is done are as numerous as the technological options themselves (Gambrill et al., 2020).

There has been growing support for these technologies in cities, starting with the UN Decade for Water Action (United Nations, 2014). Citing Nairobi's Kibera, Kampala, and Durban, Cartwright (2015) suggests that off-grid systems offer more affordable alternatives, and reduce maintenance and extension costs of bulk infrastructure, as well as comparable services to flush sanitation systems to residents located on the urban periphery. Bhagwan et al. (2019) postulates that for development targets in Sub-Saharan Africa, off-grid technologies can be scaled at a level to match the pace of urbanisation in this region. The Sustainable Development Goals also reflect this optimism. Targets A1 and B1 of Goal 6 'Clean Water and Sanitation' show commitment to support as well as build capacity for sanitation-related programmes and to strengthen participation of local communities in improving water and sanitation management respectively in developing countries. These targets are not limited to expansion of networked infrastructure. The World Bank for instance launched Citywide Inclusive Sanitation (CWIS), a strategy for 'leapfrogging' towards sustainable infrastructure in growing cities (Gambrill et al., 2020).

Yet there remains much uncertainty over what this diversity and experimentation can mean for cities (Baptista & Cirolia, 2022). Sanitation, and particularly off-grid sanitation, has received much less scholarly and political attention than other infrastructures in and beyond geography (Black & Fawcett, 2008; Jewitt, 2011). Many technologies have failed to achieve the goals of public health and environmental protection, coverage of service, acceptability, and affordability. The reasons for this are many, including but not limited to taking local customs, preferences, habits, and practices into account. The so-called Poo Wars in Cape Town make clear that not all forms of technology are politically acceptable in all times and places (McFarlane & Silver, 2017). Understanding what works and what does not work, and why, remains difficult.

Considering people's everyday practices has been argued to be an important step to understanding uses, risks, and shifting power relations (McFarlane et al., 2014; Smiley, 2020). Yet part of what is challenging in studying sanitation in many African cities is that practices are so dynamic; they regularly change and are adapted to changing circumstances. In this context, understanding practices is not just about getting a sense of what is typical, but also charting people's navigation of changing (uses of) infrastructure. In this context, drawing on Lawhon et al. (2018), we examine sanitation as a heterogeneous configuration; like better studied infrastructures, sanitation is made up of people, artefacts, and relations. Our key contribution here is to emphasise how these relations are reworked to meet changing technological, socio-economic, political, and ecological needs. For, while these technologies are off-grid, we show that they are still part of a configuration, 'networked' even if not through pipes. These connections change over time as people can both change technologies to meet their needs and use other proximate toilets if a technology is deemed unsatisfactory. Thus, understanding infrastructure as part of a configuration means considering its relations, and that these change not only during construction and maintenance but as some users rework and reject particular toilets. This lens, we suggest, might help us better answer questions of inequality, socio-ecological justice, diversity, and inclusion in response to technological and ecological change.

### 3 | CONTEXT AND METHODS

Kampala's biophysical environment, coupled with population pressure, makes sanitation both critical and challenging to manage. On-site options have become widely adopted due to rapid population growth in the city, especially since they cost less to construct and are relatively simple to build (Nakagiri et al., 2016). Onsite options account for 90% of all sanitation facilities, and of these around 80% are pit latrines (Musabe, 2015). Other onsite options include urinary diversion toilets that separate urine and faecal waste and bio-fills whose containment chambers contain living organisms that feed on faecal waste, among others (see KCCA, 2017).

These different technological artefacts have been the subject of controversy and, like many other global southern cities, Kampala has experienced major cholera outbreaks linked to poor sanitation (Eurien et al., 2021). The national government continues to identify a goal of total sewerage coverage through its sanitation utility company (NWSC) to ensure public health by guarding against pollution (Ministry of Water and Environment, 2013), yet in Kampala there is a growing experimentation and, potentially, a new vision for safe sanitation (Lawhon et al., 2023). Importantly, there is an emergent sense that not all off-grid technologies are problematic, but that failures in planning, management, and/or use of off-grid technologies cause problems. In other words, there is a growing acceptance that residents and sanitation providers need more support to enable safe use of a range of sanitation technologies. Increasing the safe collection of faecal matter, rather than expanding the sewerage network, has been at the centre of the municipal government's sanitation intervention programme (Lawhon et al., 2023; Lwasa & Owens, 2018). These progressive efforts have resulted in 32 times more faecal waste being collected and safely treated (Lwasa & Owens, 2018).

Our work here is informed by a wider project investigating the practices and politics of waste and sanitation in Kampala. This paper draws on data collected through focus group discussions with users of a pour-flush community toilet at Bwaise-Kalimali in Kawempe Division and a bio-fill facility serving a market population at Lungujja-Kitunzi in Lubaga Division. Two separate focus group discussions for men and women were held in the community hall above the toilet in Bwaise. In the briefing meeting prior to the focus group discussion at Bwaise, a potential male participant suggested two separate focus group discussion meetings for female and male participants. In his argument, he stated that this would create a conducive atmosphere for him to share his experiences. All other attendees (both men and women) unanimously supported this argument to reduce possible tension and enable a thorough discussion. In contrast, at Lungujja-Kitunzi, there was a consensus, due to time constraints by the nature of the participants' jobs, to hold a joint focus group discussion for men and women. Here, the women agreed to stay a few more minutes to follow up on these. We thus deferred to the reported preferences of our participants at both sites. Gloria also conducted in-depth interviews with the NGOs ACTogether and National Slum Dwellers Federation because of their role in initiating and facilitating alternative modes of sanitation in these communities.

### 4 | THE POUR-FLUSH TOILET IN KALIMALI

The Kalimali facility is a community-based model constructed on land donated by a resident. This community member is also a landlord who rents parts of her property; she had long wanted a shared facility, but reportedly lacked finances to

build one. When an NGO (National Slum Dweller's Federation, NSDF) came into the area looking for a way to support sanitation improvement, she offered this space for a toilet. In our wider research in Kampala, we have found that this is a common practice: community participatory approaches led by NGOs have enticed many landowners with space to donate them for the construction of community toilet facilities. Unlike situations where the toilet blocks are profitable (Ayee & Crook, 2003), this landlord does not directly profit from the facility.

The facility was designed in conversation between NSDF and members of the community, with the aim of responding to the collective socio-economic conditions of residents. The facility would both extend piped water from the municipal grid and provide a community centre above the toilets, especially for vocational skills training. It was not clear from focus group discussions whether community members chose this toilet design. KCCA requires all community and public toilet blocks in the city to be water-borne, and this likely shaped the range of possibilities.

This facility was built with several toilets units and separate sides for men and women. They were ceramic flush toilets built to be squat over rather than seated, connected to a septic tank. There was also a handwashing point with flowing water and a water standpipe outside from which nearby households could collect water for their daily needs.

Over time, cisterns broke down: the handles failed to release water and flush material away. With limited funds for repair and maintenance, the toilet management committee resolved on an alternative approach: the pour-flush. Rather than releasing water from the cistern by pulling down a handle, users of this facility poured water into the squat-toilet bowl; they used small jerry cans holding 3–5 L of water to flush bodily waste through drains into the septic tank. The jerry cans were filled by the toilet caretaker and made available at the entrance of the facility for users to find them easily. Sometimes, users filled empty jerry cans at the standpipe when the caretaker was busy with cleaning or attending to other clients.

Three key benefits of the pour-flush were revealed: less water was needed for the typical flush, and thus water usage was reduced; maintenance costs were reduced, including eliminating the possibility of needing to replace broken cisterns and handles; and finally, it reduced disruptions from broken toilets, meaning that the toilets were more likely to be regularly available to users.

Problems with broken equipment also motivated technological adaptations to the shower facilities. Running water was cut from the showers and instead sourced from standpipes into 5-L jerry cans. As above, these were filled by the caretaker and placed inside the facility for the next user. Again, the motivations here were to reduce water costs and the likelihood of breakage, reducing costs and increasing the reliability of the infrastructure. Unfortunately, respondents in the focus group discussions noted that in the case of the showers, these technological adjustments often led to a messy facility that necessitated an attending caretaker.

For some, it might be imagined that these technological adjustments would make the toilets less desirable. Yet respondents in our focus group discussion commented that they quickly adjusted to the technologies. Further, the act of pouring water was a visceral reminder of how much water was used in showers and toilets. People reported that they, and other users, usually cleaned the floor themselves if water happened to spill from the jerry cans during flushing, demonstrating a degree of attunement and willingness to work with the technology. One participant, in fact, referred to the arrangement as 'one of the best standards so far'. There were however instances that strained this arrangement, such as long water outages and clogging of drains such that simply flushing could not wash faeces away; such problems are pervasive across the city across all toilets that rely on water.

The men's and women's wings were differently equipped to handle bodily processes of urination and menstruation; only the women's side had a bin for other kinds of waste. There were, however, instances in which the respective use of the wings was altered. These instances, such as when there were long queues on one side and unoccupied facilities on the other, a blockage, or cleaning in progress, form part of the acceptable normalcies in the routine of 'adjusting' sanitation modes. One male focus group discussion participant who had once changed a baby's diaper, for example, was allowed to dispose of it in the bins for solid waste on the women's side.

The toilet was built to serve the whole community, including nearby households or passers-by. A small fee would be paid for use (200 Uganda shillings (Ush) for the toilet and 500 for the shower). This fee would be paid to a caretaker (who was a previously unemployed community member) and guaranteed the provision of toiletries, including toilet paper and bath soap for individuals.

As many have argued about community infrastructure, it is important to distinguish this local economy from the privatisation of infrastructure that has been the subject of much political critique. This new 'commodity' was deeply embedded in the community and a range of social norms guide the associated economy, including differentiation in how this fee was paid. First, the tenants and family of the landlady who donated space for the facility (including any person related either by blood or marriage, such as grandchildren and their spouses) were exempt from payment. Second,

children also did not pay to use the toilet, although they were expected to provide their own toilet paper. Third, some paid a flat monthly fee of approximately 5000 Ush; this was paid by households living close by the facility. These households were allowed to pay either at the beginning or the end of the month, and their balances and payments were recorded in a register. From the focus group discussions, we ascertained those members of these households were tenants, renting out from another landlord whose property did not have a toilet. Finally, there were individuals who paid per toilet visit. Importantly, participants in our focus group discussion emphasised that all payments were flexible; even those unknown to the community could leave behind some form of identification until they paid what they owed. This benefited people who would otherwise go without a safe place for their sanitation.

A further instance of heterogeneity relates to infant faeces. There is a widespread cultural belief in Uganda that the faeces of infants without teeth should not be mixed with that of adults. These children typically either defecate into diapers or on the floor, raising questions over where this waste ought to be taken. One mother reported, 'my boss told me that I can collect the diapers in a plastic bag and take them with me at work. We leave the plastic bag together with waste generated at work on the street for the KCCA cleaners in the night to take them away'. Another said, 'my baby also does poo on the floor and afterwards I dump it in the waste collection bags by the roadside'. Such observations raise important follow-up questions, including the interconnections between different kinds of infrastructure, the tacit awareness of flows of faecal matter in ways that would be unexpected to an outsider, and new challenges associated with safely managing solid waste if it also contains infant faeces. In some ways, this configuration is surely preferable to depositing plastic bags with faeces into toilets, a well-established concern that routinely causes problems with flushing or emptying (see Nakyangaba et al., 2021). When children begin to develop teeth, whether they are 'potty' trained or not, their faecal waste joins the adult flows. According to mothers, children continue to defecate on the floor, and this is taken in a bag where it is dumped (ideally, without the bag) into the toilet. Around age two or two and half, they begin using the toilets with adult supervision. We interpret that users' experiences with blockage of the pour-flush toilets contribute to their choices *not* to attempt flushing plastic bags here.

Unlike for children, there is no tolerance for adult faeces outside the toilet. Yet it too sometimes takes more circuitous routes. For example, the toilets are closed during the night, and most families have a movable bucket that may temporarily be used to hold faeces and urine. Buckets are also regularly used during an illness that limits adult mobility. These buckets are emptied and cleaned in the toilet, either by the users or the adult's caretaker, forming part of the whole toilet configuration. It was viewed by participants in the focus group discussions as nearly criminal for an adult to be identified as improperly disposing of bodily excrement, such as open defecation or failing to flush the toilet after use.

Thus, this Kalimali facility demonstrates heterogeneity in a range of ways. The toilet itself changed from using a cistern to being a pour-flush in response to breakages and financial constraints. This shows that even a particular toilet can change over time in response to users' understandings and needs. Similarly, there were also a range of payment types and flexibility associated with these payments that respond to heterogeneous users and user needs that change over time. We also found different ways in which faecal matter entered the toilets, and justifications for flows of this matter through other infrastructures. In this context, we emphasise that this is not a static system made of rules, but a dynamic configuration constituted by heterogeneity, a configuration that flexibly accommodates changing social, economic, and environmental conditions.

## 5 | THE BIO-FILL TOILET IN LUNGUJJA-KITUNZI

The bio-fill at Lungujja-Kitunzi was initiated by a section of market vendors organised in a savings group under the NSDF programme who persuaded others to experiment with a bio-fill toilet. KCCA had on several occasions issued vendors warnings about their first pit latrine, which was unhygienic, and threatened to lock down the marketplace. Therefore, vendors were quite eager to have a toilet that complied with regulations. With limited funds, coupled with land tenure challenges, a section of the market vendors (organising under the NSDF savings groups) reached out to the organisation for assistance. After assessment, ACTogether, the technical arm of NSDF, determined that a bio-toilet was good enough for the market.

Users must determine beforehand whether they need the toilet for urine (in the vernacular, a 'short call') or faeces (a 'long call'); there are separate units for these different bodily wastes. Red earthworms were kept in the containment chambers of toilet units meant for the 'long call' to feed on the faecal waste. In our interview with a representative of NSDF, it was indicated that the intention of this design was that the toilet chamber never fills up and thus does not require emptying. This bio-fill also had dimensions carefully crafted to meet its desired maintenance span; it had a 7-year

period between its construction and when it should be refilled with worms, if used according to the associated design guidelines. These guidelines included a daily faecal requirement for up to 16 people and always ensuring a dry toilet.

This sanitation facility was meant to serve only vendors working at this market and their customers. Adults could use urinals for free and these were kept unlocked while the market was open. The toilets collecting faecal waste were locked, and payments had to be made before access. One participant said, 'When someone wants to go for long call, they go to pick a key and toilet paper from the caretaker.' However, as mentioned above, this facility required strict observation on the number of daily users. The toilet did not have a dedicated caretaker (the keys are left with different vendors), and this broader pattern of operation created challenges for its maintenance: there was no dedicated person keeping track of users, or cleaning the toilets.

Initially, four toilet units were provided for long calls. Yet, according to the ACTogether representative who facilitated the construction of the toilet, a few months after the facility was opened, they went back to check on the site. He explained, 'we realised they had opened one stance for men and one for women. Worms feed on faeces and if you don't provide them with what to eat, they will die. The chambers [where the worms live] for stances that were locked were found to be dry with dead worms.' He continued that the NGO expected the toilets would have many users and had initially not been concerned about underuse.

In the focus group discussions, market vendors explained that some were reluctant to use the bio-fill toilets. Some people reported discomfort with the idea of worms, imagining the possibility of worms creeping out of the chamber and creating a fear of using it. Most female participants noted that they were able to avoid them since the market was close by their homes (except under emergency cases like diarrhoea). The men, on the other hand, had no preference as to whether they used this toilet or others.

This bio-toilet, for its successes and limitations, helps us to complicate and add nuance to our understanding of providing off-grid sanitation. First, we emphasise that this technology shows us the *configuration-ness* of sanitation: according to our respondents, the availability of other adequate, workable, and proximate sanitation options was crucial to their choice not to use the bio-toilet. Second, despite its promise for reducing costs and easing the management of the facility using worms (and thus not having a dedicated caretaker always present), the success of this technology was deeply entwined with social practices and knowledge about the relationship between users and the facility. It appears that greater attunement to the worms was needed: some kind of oversight, whether through a caretaker or more regular checks from the vendors and users, might have enabled the reconfiguration rather than the closure of many of the toilets. Third, heterogeneous use continues to be a struggle; there are limits to some technologies to handle unexpected flows, including *less* than expected usage. Here, ironically, the fact that people use a toilet is what empties it, reversing the common imagination of usage filling the toilet.

## 6 | CONCLUSIONS

While visions of a fully networked future continue to inform policy and practice in some cities, much ongoing experimentation with sanitation is pointed in other directions. Looking at two non-sewered options enables us to see ongoing sanitation configurations, configurations made up of different elements. Our analysis shows how different users access sanitation, why certain technologies are selected in given circumstances, and how infrastructure is navigated by users. It also helps us to think through the difficulties of ensuring safe, affordable, and reliable sanitation through heterogeneous configurations.

Our examination of pour-flush and bio-fill toilets affirms that many sanitation technologies require more daily management, calibration, and recalibration than flushing toilets connected to sewers. In Kalimali, a collective decision was made to remove technologies that could not be fixed locally and to replace them with practices that required users to attend more directly to their bodily wastes. Doing so, perhaps ironically, enabled a greater sense of control and increased the reliability of the toilets. In Lungujja-Kitunzi, the bio-fill toilet was shown to be deeply entwined with other toilets: the fact that there were other, preferable toilets nearby for many users meant that this toilet was underused. In this case, underuse led to the failing of many units, reducing the overall viability of the facility. This underscores the importance of thinking about sanitation not as a disconnected set of toilets, but as configurations in which the presence and usability of one toilet impacted what happened elsewhere.

Beyond the flush and bio-fill toilets, our consideration of configurations speaks to how operations, cultural orientations, payment mechanisms, and limitations have a significant bearing on feasibility, scalability, and integration into city-wide sanitation. These changes are generally not foreseen in the planning phases, but emerge over time

through engaged use and emergent knowledge about the intersection between technology and use. In this context, sanitation configurations that enable flexibility – rather than trying to predict needs – may well enable more reliable infrastructure.

## DATA AVAILABILITY STATEMENT

Research data are not shared due to concerns with ethics and privacy. The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research supporting data is not available.

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