Sanitation Innovation for Urban Slums: the Blue Diversion Toilet

Christoph Lüthi[1]**,** Tove A. Larsen[1]

[1] Swiss Federal Institute of Aquatic Science and Technology (Eawag)

Presenting author's email address: tove.larsen@eawag.ch

Session Number: [TH1-SE01-01] Water and Sanitation Technologies for Sustainable Urban Development

Full paper

Keywords: urban sanitation, source separation, blue diversion

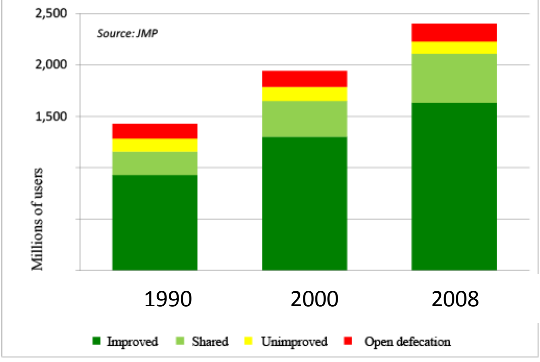
Abstract

This paper presents the development of a new human-centred applied research project to 're-invent the toilet' funded by the Bill and Melinda Gates Foundation since 2011. The Blue Diversion toilet developed by Eawag and the design studio EOOS, features a stand-alone, grid-free dry diversion toilet with three separate waste streams: faeces, urine and wash/flush water. Advanced technologies such as membrane separation and electrochemical treatment are combined with robust processes and an attractive toilet design. The paper stresses the importance of field testing and reality checks in the development of an aspirational end product that meets users' needs and at the same time performs in a sufficiently robust way. The resulting prototype is now undergoing final trials in Nairobi's informal settlements before further steps towards industrialization of a toilet model that can be tested at scale in various locations across Africa and Asia.

Introduction

The provision of safe and affordable sanitation in poor urban areas is one of the formidable challenges for rapidly growing cities in low-income countries. Even where urban sanitation improvements have occurred, these have largely been in more formal housing areas. It is in the poorest urban areas where millions of people live in densely-packed slums that the least progress is being made. The public health and environmental consequences of inadequate sanitation have a greater impact here than in dispersed rural areas, where simple on-site solutions can be sustainably implemented (Fig. 1).

Figure 1: Urban sanitation use in developing countries



It is estimated that a billion people already live in urban slums, a number which will rise to 2 billion by 2030, or, put in another way, the world population of slum dwellers is growing at around *1 million per week* (UN-Habitat 2003). This constitutes a huge and unprecedented challenge, whilst the means to address it at scale remain elusive. The number of sanitation 'success stories' in urban slums to date are few, of limited scale and have not yet been widely replicated.

The urban environment, in contrast to rural areas, is highly heterogeneous and dynamic, which makes the type of consensus building for community-led improvements more challenging (Lüthi *et al.* 2011). Wide variability in household incomes, housing types and ownership, land tenure, ground conditions, and the standard of urban infrastructure (roads, drainage, etc.) means that a whole range of sanitation solutions is needed to match a series of highly diverse requirements. Constant expansion to new areas, densification of existing areas and changing land-use mean that these solutions must also change over time, as well as between areas.

There are two main technical approaches to providing urban sanitation services – on-site and off-site sewerage. Due to the complexity and high cost of centralised sewer systems, most cities in low-income countries must intensify efforts to improve their on-site sanitation systems in the decades to come. Innovation within the sanitation sector is, therefore, currently focusing on toilets that are economically accessible for the world's bottom billion poor, are entirely free of utility connections (e.g., municipal water, sewerage or electricity) and are easy to service and/or empty (Lüthi and Panesar 2012).

The Bill & Melinda Gates Foundation (BMGF) program 'Re-invent the Toilet Challenge (RTTC)' is funding toilet interface development and on-site faecal sludge treatment processes in a multi-phased international design challenge. The BMGF requirements are ambitious: to provide a toilet that is affordable (at a price of 5¢/p/d), improves people's health, reduces the environmental impact and ensures dignity and self-esteem. The toilet must be without connection to running water, grid electricity or sewers. Furthermore, the (waste) products from the toilet must be recovered in the form of valuable resources or energy.

The Blue Diversion Toilet by Eawag/EOOS

The Blue Diversion toilet developed by Eawag and EOOS features an attractive grid-free, dry diversion toilet (separately diverting undiluted faeces, urine, and wash/flush water), which provides water for flushing, comfortable personal hygiene and for hand washing. The toilet presents a next generation model of the urine diverting dehydrating toilet (UDDT), which is usually not very popular amongst users. The toilet was amended with a flush function (for the front part), a wash basin for hand washing, and a shower head for personal hygiene (for anal cleansing and menstrual hygiene). Furthermore, EOOS developed an attractive design language, allowing for easy and cheap industrialization by rotational moulding (Fig. 2).

Figure 2: The Blue Diversion Toilet developed by Eawag/EOOS (first prototype)

Since the toilet will not be connected to piped water or a sewer, on-site treatment and re-use of water is key. The on-site water recovery technology is based on a gravity-driven ultrafiltration (UF) unit originally developed at Eawag for producing drinking water from polluted river water (Peter-Varbanets *et al.*, 2009). We included aeration, thus designing a new type of membrane bioreactor (MBR) that produces hygienically safe water (by ultrafiltration) at low energy consumption (filtration is entirely gravity-driven) and without maintenance (in the low-loaded filter, grazing by higher organisms keeps the filter open). This reactor type is attractive for on-site implementations. To prevent regrowth, the treated water is chlorinated by electrolysis in a commercially available electrolysis module modified for higher energy efficiency. At the moment, total continuous power consumption of the toilet is 3 W_e/p, but the target of 1.5 W_e/p (15 W_e/toilet) is within reach. This small amount of electrical power is generated by a solar panel on the roof of the toilet building, combined with a small battery. Although the Blue Diversion toilet can be used in many settings, including private homes, we developed a business model (Figure 3) and a business case for urban slums in order to provide an economically, ecologically and socially sustainable solution for sanitation in these critical areas.

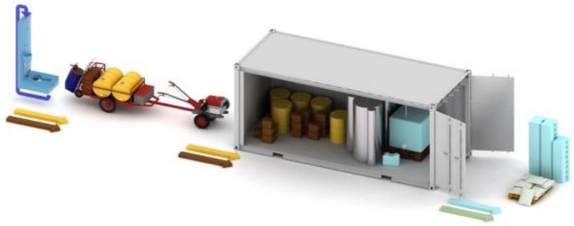


Figure 3: The Blue Diversion Business Model: marketable end products such as fertilizer are produced in the Resource Recovery Plant (right)

Field Testing in operational environments

After 2½ years of applied research work[1], the development of the Blue Diversion toilet has now reached the prototype stage, or "Technology Readiness Level (TRL) 7", meaning that a system prototype can work in a relevant environment like an informal settlement. From the early stages of technology development the importance of "reality checks" in low-income urban settings was underlined. A series of field-based reality checks were conducted to ensure that the new technology set-up meets users' needs and is robust and low maintenance. The key parameters that were analysed during the field trials included:

- user evaluation of the technology and service concept;
- willingness to pay for the service;
- other potential barriers to renting the toilet.

The unique feature of the Blue Diversion toilet is that advanced technologies (membrane separation and electro-chemical treatment) are combined with simplicity (membranes are operated without chemicals and without process control), providing a robust and reliable solution. Involving industrial designers and local stakeholders from the start ensured that the toilet responds to user needs. This new paradigm of a more robust (and, ultimately, more sustainable) application of advanced technologies is relevant not only for the Blue Diversion toilet, but also for water and wastewater treatment in currently un-served areas. It combines the best of both high and low-tech in a user-friendly and attractive interface.

First Reality Check October 2011 in Kampala, Uganda

The first field visit was conducted in Phase 1 of the project to test the key assumptions of the Blue Diversion toilet: (i) user's acceptability of the water recovery concept, (ii) would users feel comfortable about the collection services linked to the business model?, (iii) are users willing to share the toilet with two families?, and (iv) do users like the basic design concept with the water wall? The mock-up model of the toilet presented was made of Styrofoam and a wood structure and featured a camping toilet as a place holder. The mock-up model did provide running water and users were able to use the hand shower and hand washing facility. Additionally, a separate membrane bioreactor (MBR) filter was presented to explain the water recovery principle (Fig. 5). The half day workshop was conducted at a community training centre and was open to all interested residents of Kisalosalo slum, where the test took place. The workshop was divided into three sessions: a plenary session explaining the main features of the toilet (Fig 4), focus group discussions around the service and logistics concept and a show and tell session where users were able to 'touch and feel' and ask specific questions. All events were hold in the local language. These key elements of user research and participatory design allow for contextual solutions that meet people's needs and aspirations.

The first reality check conducted in Kampala allowed the research team to gain crucial insights for the subsequent development of the first working model of the toilet. Three main tasks were performed: A functional toilet was designed by EOOS, a functional membrane bioreactor for water recovery was developed and tested by Eawag, and these two systems were continuously integrated in an intense cooperation process between EOOS and Eawag.

[1] Phase 1 of the BMGF-funded challenge began in August 2011.

Figures 4 & 5: Community workshop in the Kisalosalo slum of Kampala; explaining the main toilet features, October 2011.

This resulted in a first Blue Diversion working model (Figure 6) with the following main features:

i. A squatting pan was chosen and optimized based on the preferences of the potential users in Kampala;
ii. A sink for hand washing and a shower for personal hygiene;
iii. The water cycle was ‘kept alive’ by a foot pump, pumping not only 1.5 litres of clean water to a ‘show glass’ at the front of the water wall, but at the same time also the soiled water from the past toilet visit to the treatment reactor.

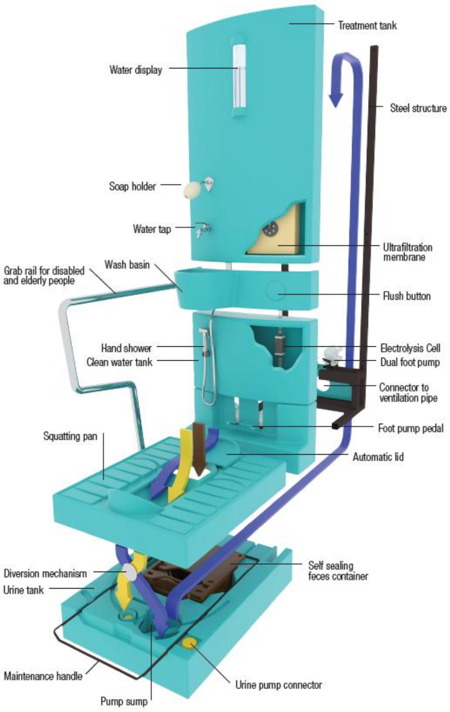


Fig. 6: The first Blue Diversion working model with the different system components

The membrane bioreactor could be simplified to fit into the water wall and optimized for producing around 75 litres of clean water per toilet and day (supplying around 1.5 Litre of clean water per toilet visit if 10 people use the toilet five times a day each). As expected, it failed to remove all colour and all organic material from the water and consequently, we tested electrolysis for polishing. For hygienic reasons, we chose to design the electrolysis to provide residual chlorine, which would act as an additional barrier to pathogens entering the system through water tap and shower head (the ultrafiltration membrane removes all microorganisms entering the treatment reactor). The electrolysis module was not ready for the second field test (see below) and consequently, we added chlorine to the treated water in order to remove the colour and secure hygienic water for the users involved in the field test.

Second Field Test April/May 2013 in Kampala, Uganda

The second field test was also conducted in the same slum in Kampala, this time with a fully functional toilet featuring a toilet pan, diverting urine from faeces, a hand washing facility and a hand shower for anal cleansing. A purpose-built toilet superstructure was set up on a private property to house the toilet during the test phase. Over 400 people used the toilet during the two months period, and a total of 1500 detailed interviews were conducted to assess user experiences and attitudes. Over a one month period first two Christian then two Muslim families shared the toilet to simulate the “real life” toilet usage over time. All family members were repeatedly interviewed to assess their user experiences (Fig. 7 & 8).

Initially, the research team faced a serious malodour problem of the recycled water which intensified the more the water was reused. Based on a detailed water analysis by the fragrance company Firmenich (Geneva) we quickly identified urine as the main cause. In the field, we were able to solve this problem by applying a separate activated carbon filter, but only a later reengineering of the separation mechanism was able to solve the problem in a sustainable way.

Overall, the two month field test was instrumental in improving the functionality of the toilet and identifying some of the weak points that still needed rethinking or redesigning. However, the toilet remained “open for business” during the entire field test phase in Kampala. The “real world” experience allowed the behavioural scientists of Eawag to conduct a full-scale social acceptance survey with 1500 interviews, providing empirical evidence on what people liked and disliked about the Blue Diversion toilet. The feedback and critical issues gathered during the working model test phase can be summarised in three points:

- Improve functionality of the faeces lid to better conceal previous users’ droppings;
- Reduce size (height) of water wall to ensure that it fits into existing toilet superstructures;
- Rethink the footpump which is considered too strenuous to use for children and the elderly.

Figures 7 & 8: Field test with the first working model in Kampala, April-May 2013.

Following the experience and feedback gathered during the Uganda field tests and thanks to additional ‘acceleration money’ granted by the Gates Foundation, the ETHZ spin-off engineering company *Tribecraft* assisted us with re-engineering parts of the toilet. With the help of Tribecraft, we were able to produce a very robust prototype that is already close to industrialization. The hydraulic of the toilet was totally re-engineered, resulting in a smaller and more user-friendly interface and no foot pump. Since Tribecraft has a solid expertise in mechanical and electrical engineering, they were able to transform the first functioning working model into a professional product. Especially for the separation of water and urine, a very effective solution was found. The integration of simple and robust electronics allowed to simplify the hydraulics, which will make it possible to reach the target production costs through a massive reduction of small parts. Furthermore, the prototype will be equipped with data loggers, allowing for more reliable (and totally anonymous) information on overall water use (e.g. flushing, hand washing and use of the shower for personal hygiene) during the first phase of piloting at scale.

Third Field Test February - April 2014 in Nairobi, Kenya

The third field test was still under preparation at the time of writing. It will be conducted in Nairobi’s second largest informal settlement in Mukuru, next to Nairobi’s industrial area. Working together with Sanergy (a locally based NGO) we will be conducting field tests with the first prototype Blue Diversion toilet (Fig. 2) starting in February 2014. As in Kampala, the toilet will be tested with selected families and several one-time users at different locations within the slum (Fig. 9). At the centre of the field investigations are again questions of social acceptability, but also critical issues like theft or vandalism which are vital for proving the viability of toilet operation in slum conditions.

Figures 9 & 10: One of the locations for the Nairobi field test; the TRL 7 prototype ready for shipment.

The three field tests conducted between 2011 to 2013 provided crucial reality checks and ensured that the Blue Diversion concept is firmly grounded in reality and developed in close cooperation with local stakeholders from academia (Makerere University) as well as potential users from various informal settlements in East Africa. Figure 11 shows the iteration between lab-scale testing, field testing and re-engineering that led from concept to the initial working model and finally to this first prototype ready for the third field test in early 2014.

Two additional project highlights are the international "*Re-invent the Toilet Challenge*" Fairs organised by the Bill & Melinda Gates Foundation in Seattle (August 2012) and New Delhi (March 2014). All Gates grantees are invited to present their research results and innovation milestones during a one week fair that allows close interaction with all teams working on cutting-edge toilet and treatment technology.

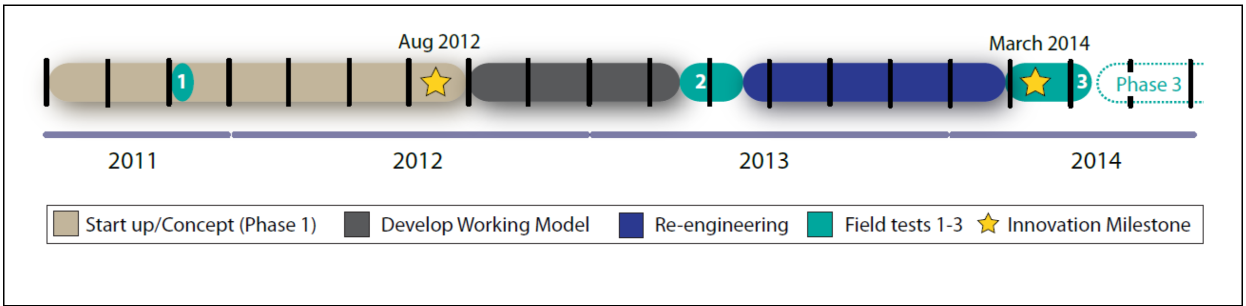


Figure 11: Timeline of the Blue Diversion toilet research (Aug. 2011- March 2014)

The Eawag/EOOS effort was made possible thanks to a unique inter-disciplinary team of scientists, designers and engineers working closely together. Experts included process engineers, environmental engineers, mechanical and electrical engineers, logistics and business model experts, urban development experts, psychologists and industrial designers. It is this mix of know-how and fusion of disciplines that allowed a functional Blue Diversion toilet to be developed in a record 2½ years.

Phase 3: Industrial Production by 2015

Building on the successes of the previous phases, the Eawag-EOOS team in cooperation with Tribecraft is now preparing for third phase involvement which, by the end of 2015, will lead to a robust and functional toilet that can be industrially produced and assembled. Three areas will merit special attention and further research in the further development of an industrial product:

(i) the overall energy consumption (currently at 3 W_e/per user) in order to minimise the solar panel surface area needed for each toilet.

(ii) Further development of the business model including collection logistics and the processing of waste streams in the (as yet untested) Resource Recovery Plant.
(iii) Simplification of the electrical systems in the same way as the hydraulics was optimized

In Phase 3 the Blue Diversion toilet will see the first pilot schemes at scale (> 50 toilet units) in selected informal settlements in Kenya – the last step of the product development before going for large scale production..

Conclusions

The iterative toilet development process used to develop the Blue Diversion toilet is a human-centred approach to sanitation that views people's aspirations as the central priority. The high importance attached to field testing in relevant environments and the empirical evidence gathered through surveys of regular and one-time users helped to create a user interface that match people's preferences.

Central to this research project has been the seamless collaboration between the three main project stakeholders: the aquatic research institute Eawag, the design studio EOOS, which brought top-notch toilet design to the project, and our research partners at Makerere University who enabled the "ground-truthing" of the initial toilet concept and working model. This provided a sound basis for the last and most challenging step ahead for the product development: moving from single prototype production mode to a mass-produced industrial toilet for the world's urban poor.

References

Lüthi, C, & Panesar, A. (2012) Source separation in middle- and low-income countries. In: Larsen, T. A., Udert, K. M. and Lienert, J. (Ed.), *Source Separation and Decentralization for Wastewater Management*. IWA Publishing, London UK.

Lüthi, C., Panesar, A. and Schütze, T. (Ed.), (2011) *Sustainable Sanitation in Cities- A framework for Action,* Papyroz Publishing House, The Netherlands.

Peter-Varbanets, M., Zurbrügg, C., Swartz, C. and Pronk, W. (2009). Decentralized systems for potable water and the potential of membrane technology. Water Res. 43(2), 245-265.

UN-Habitat (2003) *The Challenge of Slums: Global Report on Human Settlements*. Nairobi, Kenya.

Brief biography of presenting author

Tove Larsen is a chemical engineer with a PhD in process engineering from the Department of Environmental Science and Engineering, Technical University of Denmark. At present Tove Larsen heads a group on 'Concepts' in the Department of Urban Water Management at Eawag in Switzerland. Tove Larsen leads the Eawag project '*Blue Diversion*', which won a special recognition price in the Reinvent The Toilet Challenge competition, launched by the Bill & Melinda Gates Foundation.