Dry sanitation concepts with inspiration from nature

Torben Lenau and Thomas Hesselberg

ABSTRACT

Poor sanitation is a major problem for health and water resources in many developing countries. Inexpensive but also attractive toilets could be a way to fight these problems. However, radical new ideas are needed to identify innovative solutions. Such novel ideas might be found by using systematic design methods that search nature for animals and plants that solve similar problems. The paper describes how four conceptual sanitation solutions for dry toilets solving problems with smell, cleaning and flies can be made in collaboration between a design engineer and a biologist using biomimetic design methods. The solutions have the potential to offer significant improvements compared to conventional non-water-based sanitation.

Key words | biomimetic design, cleaning, dry toilets, flies, smell

INTRODUCTION

The motivation for focussing the present study on sanitation is the fact that it is a global challenge with huge potential to improve life for many people. It is, furthermore, a commercial market area that is still very open in many parts of the world, making radically new solutions more realistic. Sanitation is a major global problem since about 2.5 billion people lack improved sanitation and do not have access to toilets (WHO 2014). Diseases related to bad water, sanitation and hygiene habits cause the death of about 2.4 million people every year (Prüss-Üstün et al. 2008). The solution is better sanitation that can be achieved using either water-based or dry toilets, which are both safer solutions than traditional open pit holes, defecation in waterways or in the open. Water-based toilets are used in most of the rich countries but suffer from three problems: water is a scarce resource in many areas, large investments in sewers are required and wastewater is often not treated properly. Dry toilets are attractive alternatives from both an economic and hygienic point of view. They require only a minimum of infrastructure and waste materials can be kept separated when handled correctly. This makes waste treatment much more straightforward. A basic understanding of the sanitation area was achieved through a literature survey (Winblad et al. 2004; Kar et al. 2008; Tilley et al. 2008) and contact to key players within the sanitation area. The volume of urine and faeces that need to be transported to a disposal site are manageable compared to other transport tasks like garbage and daily goods. The average yearly faeces and urine production rates per person found in the literature are approximately 47 kg for faeces and 440 kg for urine (Almeida et al. 1999; Del Porto & Steinfeld 2000; Zavala & Funamizu 2006). However, a number of basic problems are not solved properly for dry toilets including smell, cleaning and flies. Therefore, they are often regarded as less attractive compared to the water-based alternatives, especially for the large groups of people in developing countries that gradually become wealthier.

METHODS

Ideas to new innovative solutions can potentially be found using biomimetic design where inspiration is found in nature. The basic approach used here followed the iterative
procedure described by Lenau et al. (2010). Three specific dry toilet problems were generalised and keywords formulated to allow a search for analogies within the biological domain, as shown in Table 1.

To focus the search, the keywords were first used to browse general biology books and making observations in zoological and botanical gardens. This was followed by searches in the online literature databases, Asknature.org, ISI Web of Science and Google Scholar, and in cited literature within identified articles. Search terms covered the keywords, relevant synonyms and antonyms.

Each of the biological phenomena identified was analysed, and the functionality of the basic biological mechanisms were described and generalised as technical principles. These principles were used to generate design ideas and develop conceptual product solutions.

### RESULTS

Results include identification of relevant biological analogical phenomena and the conceptual design of bio-inspired solutions.

#### Biological analogies

A large number of biological analogies (phenomena) were identified, as shown in Table 1, and 21 of the search results were considered relevant.

#### The smell problem

One of the main challenges for a wider embracement of dry toilets is the strong odour emanating from faeces and urine. The smell is caused by the interaction and relative intensities of a

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<tbody>
<tr>
<td>Smell</td>
<td>- Remove smell</td>
<td>Smell (22), Odor (51)</td>
<td>Milkweed protect against predators using chemicals</td>
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<td></td>
<td>- Hide smell</td>
<td>Odor eliminator (51)</td>
<td>Many animals include pheromones in faeces to signal reproductive status.</td>
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<td></td>
<td>- Contain/camouflage smell</td>
<td>Remove smell (58)</td>
<td>Smell in faeces comes from bacteria so use of antibacterial substances?</td>
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<td>- Reverse: enhance smell</td>
<td>Hide (34), camouflage (44) or Enhance (80) smell</td>
<td>Terra preta</td>
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<td>Hygiene, toilet cleaning</td>
<td>- Cleaning surroundings</td>
<td>Clean (29)</td>
<td>Cats burying their faeces</td>
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<td>- Cleaning oneself</td>
<td>Cleaning (46)</td>
<td>Leaf cutter ants water management</td>
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<td>- Avoid getting dirty</td>
<td>Washing (5)</td>
<td>Desert insects water extraction</td>
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<td>Self-cleaning (28)</td>
<td>Removal of faeces from bird nestlings</td>
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<td>Contamination from flies</td>
<td>- Keep flies away</td>
<td>Repel flies (53)</td>
<td>Soil does not adhere to earthworms</td>
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<td>- Contamination from direct contact</td>
<td>Contamination (16)</td>
<td>Gnavers keep soil out of mouth</td>
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<td>- Reverse: pollination</td>
<td>Infection (34)</td>
<td>Lotus flower, Cicada wings</td>
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<td>- Reverse: attract flies</td>
<td>Attract flies (64)</td>
<td>Eye lid in horses wipes the eye</td>
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<td>- Catch/kill flies</td>
<td>Fly predation (75)</td>
<td>Gecko eye cleaning</td>
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<td>Natural fly control (419)</td>
<td>Lotus effect/insect wings. How do dung beetles and maggots stay clean?</td>
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<td>Flies find food using their olfactory system</td>
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<td>Blowfly feet taste food</td>
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<td>Giraffe has repelling skin secretions</td>
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<td>Catnip repels insects</td>
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<td></td>
<td>Smell attracts flies</td>
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<td>Herbs in starling nests keep fleas away</td>
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<td>Flies are prey for lizards, spiders, etc.</td>
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<td>Picher plant</td>
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wide range of volatile compounds, arising from the breakdown of organic matter by primarily aerobic bacteria (Sweeten 1986). One way of handling the smell is the terra preta principle, which works by maintaining an anaerobic environment by mixing the faeces with charcoal and adding lacto bacteria in an airtight container. The terra preta method was developed following a recent re-discovery of the practices of ancient South American civilisations (Factura et al. 2010). Another possible way to reduce smell is the feacal sac principle: bird nestlings make small parcels by wrapping portions of the faeces in a biologically degradable membrane that can be flown away in order to increase nest sanitation and reduce predation (Weatherhead 1984; Guigueno & Sealy 2012).

The cleaning problem

Another problem with dry toilets is how to keep them clean without rinsing them with large volumes of water. This might be solved using the animal eyeball cleaning principle using an intermediate removable substance (the tear film) that adheres to dirt particles (Walls 1942; Braun & Fitt 2003; Jones et al. 2008).

The fly problem

Flies are attracted to both food and faeces and can, in addition to being a general nuisance, constitute a serious health risk by transmitting diseases. The pitcher plant attracts flies using volatile substances, including 2-phenylethanol (Chapman et al. 1998; Di Giusto et al. 2010) and prevents them escaping once trapped using a special slippery surface (Gaume et al. 2004). Platelet shaped wax crystals form a sponge-like layer with a pore size of about 1.5 μm, which generate a mechanical stable surface with a roughness that is too high for the hairy pads found on insect feet to adhere to, while simultaneously being too low for the insect claws to work efficiently on, as shown in Figure 1 (Scholz et al. 2010).

Bioinspired solutions

The technical principles are used as input to the creative part of the design process. We propose conceptual solutions for four principles.

Avoiding smell using the terra preta principle

An anaerobic environment is expected to be maintained if an airtight container is used, as shown in Figure 2(a). This only requires an airtight lid that closes the entrance to the toilet container when it is not used. In use the lid needs to be opened, but this will only be for a short period of time. Charcoal, stone dust and lacto bacteria could be stored in separate containers behind the toilet similar to the water...
tank in conventional toilets. The right doses of these materials could then be added into the toilet when ‘flushing’ after using the toilet.

Reducing smell and cleaning problems using the nestling faecal sac principle

Similar to the way nestlings encapsulate their droppings in thin dry membranes, a toilet solution might use a biodegradable plastic bag that covers the toilet bowl and is closed and sealed after use. It might be possible to automate the process by using a mechanism driven by the opening and closing of the lid (Figure 2(b)). When the lid is opened a new bag could be spanned over the toilet bowl and when the lid is closed the bag could be sealed and removed into a collection chamber. Slightly modified conventional garbage bags with built-in closing wires could be used.

Toilet cleaning using the eyeball cleaning principle

A solution based on the blinking eyeball cleaning principle could use an intermediate substance to collect the excrements. Two sliding cover plates could form the barrier between the bowl and the collection chamber. To avoid that the cover plates gets dirty and to collect liquid substances, it is proposed to cover them with a thin layer of gravel. Gravel and excrements will slide into the collection chamber when the cover plates are opened. After closing the cover plates, a mechanism could spread new gravel onto the cover plates similar to the eyelid blinking. The potential solution is illustrated in Figure 2(c).

Avoiding flies using the pitcher plant principle

A trap using the pitcher plant principle could lure the flies into a chamber from where they cannot escape and will eventually drown. This solution could be placed as an external object attached to the wall or hanging from the ceiling. The trap could be made as a vertical cylinder that is closed at both ends and provided with holes at the top just big enough to allow the entrance of flies as shown in Figure 2(d). The inside of the cylinder could be covered with a micro-structured surface that hinders the flies to attach to it. The bottom part of the cylinder could be detachable to allow it to be filled with a liquid with a smell that attracts the flies while being acceptable to humans.

DISCUSSION

A relevant question is whether the extra work in applying a formalised design method is worth the effort. Design researchers normally justify such work by looking at the results and assessing if they are better than reference solutions (Shah & Vargas-Hernandez 2003). The new solutions should be more innovative and useful to the users.
The novelty aspect of the terra preta solution is the chemical reaction used within the toilet to reduce smell and decompose the waste products, i.e. a decentralised waste treatment that eliminates the need for costly infrastructure. The novelty aspect of the nestling solution and the blinking eyelid solution is the reduced need for cleaning caused by the use of membranes and gravel. The advantage compared to a water-based toilet is the avoidance of flush water and sewer infrastructure. However, the disadvantage is that the nestling solution requires plastic bags and the blinking eyelid solution needs gravel or sand. The novelty aspects of the pitcher plant fly trap are the slippery surface and the closed container. One potential advantage compared to ordinary flypaper is the closed container that hides the dead flies and functions as a multiverse product that can be emptied and used many times.

All potential solutions represent improvements regarding both novelty and usefulness. The work suggests and illustrates how biomimetic design work can be carried out with success and presents suggestions for how to overcome a number of difficulties in the design work of new sanitation solutions. A procedural model for biomimetic search and design has been demonstrated by applying it to suggest solutions to some of the basic problems with dry toilets. Thinking in terms of biological analogies produced a large number of relevant ideas.

CONCLUSIONS

The sanitation problems in developing countries have been addressed and are proposed solved using dry toilets where urine and faeces are handled separately. However, such separation toilets are potentially less attractive due to poor handling of a number of problems. We examine three of those problems: smell, cleaning, and contamination from flies by using a biomimetic design approach. A large number of analogical solution principles were identified by searching in nature. Conceptual designs were made using four of the principles thus proposing possible solutions. The solutions are feasible and would most likely not have been arrived at if biological inspiration and biomimetic design procedures had not been employed during the design process.

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REFERENCES

Braun, R. J. & Fitt, D. 2003 To minimise shear stress and to avoid solid to solid contact between the eyelid and the eye surface, the latter is covered by a thin tear film. Math. Med. Biol. 20, 1–28.
Eawag, Dübendorf, Switzerland. www.wsscc.org (as of 14 November 2014).

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