Design for Sustainability: Case of designing an urban household organic waste management system

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Abstract: Beyond product design, if the notion of product lifecycle design enforces the consideration of requirements from all the lifecycle phases of products, design for sustainability enforces the consideration of lifecycle design in the context of the lifecycles of other products, processes, institutions and their design. Consequently, sustainability requirements that need to be met by design are very diverse. Categorizing human excreta, urine and kitchen waste as household organic waste, this article demonstrates the nature of designing for sustainability taking the case of designing a household organic waste management system that uses less water and closes the loop reclaiming used water and nutrient.

Keywords: urban waste management, urban sanitation, household organic waste, design for sustainability

1 Introduction

Sustainability is the ability to meet our needs without compromising that of the future generations to meet their own needs[1]. The imperative for sustainable products and technologies arises from the enormous consequences (and all negative) that anthropogenic activity has on the present and future habitability of earth. Sustainability is anthropocentric; meaning sustenance of human development trumps everything else. Sustainability is normative, both, as defined in the original context of humanity being collectively able to develop sustainably[1] and in the context of being a right to development[2]. Motivated by real concerns with measuring development and fundamental issues with human rights, developmental literature since Sen[3], has been shifting the paradigm focusing on means rather than on ends by re-defining 'human development' as the expansion of individually chosen and valued human capabilities. Entailing this shift is the re-design and design of existing and new institutions respectively based on requirements for human development and its sustenance. The industrial revolution being a significant contributor to crossing planetary boundaries[4], it becomes important to re-design and design technology to continue to satisfy needs that humans self-determine and value for their sustenance. By re-design or design, design is central to addressing sustainability requirements. These requirements spread many disciplines and demand a systemic view of design for demonstrating which this article takes the case of designing an organic waste management system for urban households.

2 Methods

Literature covering peer-reviewed sources and popular articles was reviewed to assess the urban trends in the demand and supply of water and sanitation, particularly of Bangalore city. A survey was conducted among households in Bangalore and Chennai to understand the composition of organic waste generated daily. In the view of popularly established systems of water, sewerage and sanitation a questionnaire based survey and semi-structured interviews were conducted amongst sixty respondents

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spread over Bangalore, Chennai, and Trichy to understand public perception of various aspects of a new system of handling household organic waste. Needs and insights obtained from these two surveys were used to frame requirements for designing the new system. In addition, a comprehensive market survey (Table 3.1) of existing sanitation products was conducted online to understand various features of solutions, their acceptability and potential in meeting urban Indian requirements. Based on these surveys, the systemic function of managing organic waste is decomposed into sub-functions. These are used to guide the identification of possible stakeholders to consult and elicit systemic requirements. Conceptual solutions for each of the functions are generated using ideation methods like technical and biological analogy, synectics and collective brainstorming[5]. Using a morphological chart, concept solutions compatible with others across functions have been combined into systemic candidate solutions, and critically evaluated using the weighted-objectives method. The criteria for evaluation are drawn from the list of requirements arrived from the surveys and their weights in consultation with a few likely urban customers before arriving at a solution that meets most of the urban requirements.

3 Design for Sustainability

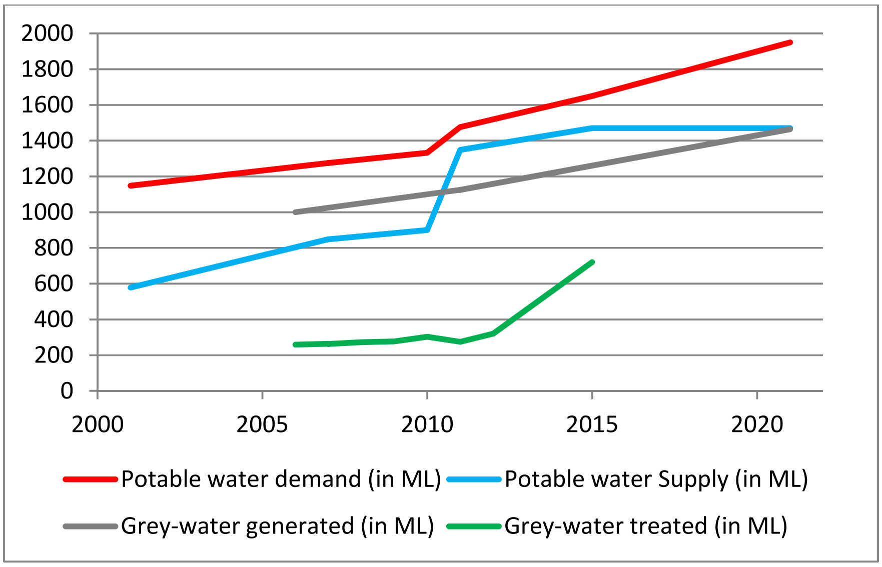
Design broadly comprises problem identification and need validation, conceptual design, evaluation of concepts and selection, embodiment design and design specification. Design is iterative in nature and accommodative of requirements and their evolution incrementally as well as disruptively (if implementing methods in the conceptual design phase). Both, continuous improvement and radical innovation come under design's purview. Beyond product design, if the notion of product lifecycle design enforces the consideration of requirements from all the lifecycle phases of products, design for sustainability enforces the consideration of lifecycle design in the context of the lifecycles of other products, processes, institutions (systems in general) and their design. Demonstrating the nature of systemic requirements that D4S has to address, this article systematically considers various aspects involved in the design of an urban house-hold organic waste management system.

3.1 Problem identification and need validation

Empathizing with and perceiving real human subsistence problems as needs rather than imagined problems with systems that do not directly contribute to subsistence is a criterion to validate the importance of needs to be satisfied and hence to be designing for. Rather than designing reactively to solve real problems, fact and evidence based forecasting of problematic trends with human needs vital to different strata can validate needs and motivate pro-active design for preventing unsustainability.

Water is a public good and it is the responsibility of the state to supply 150 liters of potable water per individual at a reasonable cost[6]. Popular technology in household toilets uses 20-40 liters per flush of potable water to transport sewage into the septic tank. Both, the western commode, that has not changed for over 200 yrs, and the Orissa pan are gravity based and depend on the availability of water to transport sewage. Considering the need to flush the latrines clean after every use, the water

Figure 1 Bangalore's Water and Sanitation situation and projection



Data courtesy: VC Kumar, EE, BWSSB and Mallick et al[23], 2008

requirement goes up by 50-150%. The problem gets compounded as fresh-water supplies become scarce and people continue to use current water-intensive solutions that also pollute potable water indiscriminately. Despite shortage in meeting the demand unaccounted for water supplies, use of prevailing technologies and a growing migratory population generate sewage that is only 30-40 % treated at the sewage treatment plants (Figure 1). About 60% of the world's population is urban, and it is expected to double in the coming decades. About 96% of this urban growth is projected to occur in the developing and underdeveloped countries[7]. It is estimated that close to 10 million people migrate from rural to urban India every year making this the largest migration of this century[8]. Catering to these puts huge pressure on urban infrastructural systems e.g. water supply, sanitation, and sewerage, which must change rapidly[9].

Management of waste in urban India is problem-ridden from collection to disposal. Bangalore generates over 3000 tons of solid waste everyday and 70% of this is organic. Drives to segregate organic and inorganic waste at source have been active though their implementation has faced issues from educating households and the collectors. Land-filling and other forms of treatment[10] face problems of acceptance by the locals. Management of sewage and sullage is currently separated from that of kitchen refuse. Where underground drainage system is available, black water is directly is emptied into covered sewers. However, due to the seasonal fluctuations in availability of water in cities such as Bangalore, sewers do not get sufficiently drained, resulting in their drying up and clogging[11]. The 150 litres of water needed per individual to flush the waste down to the gravity-based central sewers pose a huge stress on the supplying capacity of Bangalore Water Supply and Sewerage Board's (BWSSB), for three reasons: first, this water is drinkable and can be better used than for flushing toilets; second, the the cost of making water available from far-off rivers[12] is highly subsidized by the state; and third, 45% of water being supplied is lost in transmission[2]. As a result, an increasing amount of groundwater is being used; in many localities agricultural bore wells are used to meet this shortfall, supplying water to residential areas. This has led to a significant loss in groundwater table, with major water shortage in many localities in the summer[13].

Over 800 sq. km of Bangalore has piped water[2] supplying an estimated 150 liters per person, even though about 475 sq. km has no sewerage system[14]. Peri-urban and some urban households deal with this by constructing un-lined storage tanks inside or around their plots. The tanks store black water and are emptied periodically by private mobile sanitation tanks that take the waste and dispose it off, without any treatment, to farmlands of consenting farmers. The practice of honey-suckers operating outside of law and legislation in Bangalore is exemplary in this regard[5]. The untreated toilet waste is harmful to agricultural laborers who come in direct contact with the waste or to consumers of agricultural produce soiled by the waste. The World Health Organization (WHO) recommends that at least a year must pass for separated faecal sludge to be used in farms, the typical time required for the pathogen proportion to be reduced to tolerable limits for humans and agricultural uptake[15]. Human excreta is a rich source of nutrient for plants and according to an estimate, the amount of food grain necessary for sustaining an individual can be grown from a crop fertilized by the nutrient from that individual's waste[16]. Areas assigned by the Bruhat Bangalore Mahanagara Palike (BBMP) and BWSSB for disposal do not attract private players, as they levy a fee and are better off disposing waste in the lands of consenting farmers nearby. Considering these, there is a strong case for resolving the issue of irresponsible disposal of toilet waste, ensuring least impact on natural resources and the amount of water used. This paper proposes the design of a sustainable system for handling household organic waste, while taking into account the needs of all its stakeholders.

This calls for redesign of the system for managing household organic waste that eliminates the use of potable water for transporting waste and minimizes the use of grey water in transportation taking into account culturally sensitive requirements. The final design is meant to be a domestic appliance with supported by existing infrastructure or minimal changes to it.

3.1.1 Identifying stakeholders and their requirements

To understand the views of urbanites a survey was conducted among urban households aimed at assessing water usage, gauging customer demands and wishes of a new product/system such as a waterless toilet and obtaining a quantitative understanding of critical constraints such as space, time, and investment. The households belonged to middle and upper middle classes in Bangalore, Chennai, and Trichy. Further aspects of popular rural dry toilets under the name EcoSan were briefed to the urban residents to understand their perception of a dry composting toilet for the urban households. Ecological Sanitation (EcoSan) is an approach striving to 'close-the-loop' in offering safe solutions that promote health by treating pathogens and retrieving nutrients from black water to put them back to the earth for safe uptake by agriculture and horticulture. Salient findings of the surveys conducted are:

- 90% of the respondents wanted to use the new toilet system.
- 40% of men do not prefer to sit (as in a Western commode) to urinate.
- People living in apartments preferred the treatment system to be underground or in the basement; while those in independent houses preferred it underground or their backyard.

- Even if the sewage is treated safe, few respondents were willing to store or treat this in-house. Respondents stressed that treated safe compost should be hygienic, without smell and completely safe to handle.
- Respondents were willing to spend a minimum of INR 3,000 and an average of INR 10,000 for the new toilet system. Respondents preferred the system to work with little or no electricity.
- Agricultural laborers spent 80% of their monthly income (INR 1250) for building a dry toilet.
- The elderly preferred a portable toilet.
- The preferred that solid waste should not be visible after flushing (by whichever means it is achieved in the new system).
- The system should preferably be easy to clean once every six months.
- It was preferred that the system should be easy to operate, with minimum maintenance, and should automatically handle and discharge waste.

The above stakeholder requirements were interpreted as the following system/technical requirements:
- Pathogens should be rendered harmless to humans. Ablution water needs to be handled and cannot be done away with. Pungent odors of H2S, Indoles, Mercaptans should be removed.
- Waste generated should be transported, first out of sight, and second to the treatment centers, with minimum user involvement.
- Moving parts should be avoided as much as possible to reduce maintenance.
- Toilet-pans should be accessible to people unable or unwilling to sit for urinating.
- Menstrual waste should be handled by the same toilet pan.

An extensive online market survey was conducted and 25 products in the sanitation market identified to understand how they meet different customer requirements technically. This survey also provided the basis to decompose the system into functions which further guided stakeholder identification (Table 1).

Table 1 Stakeholder identification across sub-functions

Sub-Function	Functional description	Possible Stakeholders
Collection	Collect all types of muck effectively at point A	Manufacturer; users of different genders, abilities and capabilities; cleaner/maintainer/servicing personnel; civic sewerage, water supply, pollution control, and town planning bodies
Conveyance	Transfer collected muck completely to point B	Manufacturer; private players; householder; apartment association office bearers; civic sewerage, water supply, pollution control, public health, and town planning bodies
Sanitisation	Render muck harmless to humans henceforth	Manufacturer; private players; householder; apartment association office bearers; civic sewerage, water supply, pollution control, public health, and town planning bodies; local residents
Treatment	Convert safe muck into a form acceptable to earth (i.e. that which could be taken up by agriculture without despoiling aquifers, water bodies etc.)	Manufacturer; private players; householder; apartment association office bearers; civic sewerage, water supply, pollution control, public health, and town planning bodies; local residents
Despatch	Conversion into a saleable or portable form and delivery	Agriculturists; horticulturists; farmers; private players; nurseries; householders; public health and safety, pollution control bodies

The following stakeholder requirements were identified, some of which were raised by the stakeholders surveyed and interviewed, while the others were perceived by the authors based on prior experiences.

Users of different genders demanded that the system handle menstrual waste at the collection stage as well as the existing system does. As mentioned earlier, men preferred not to sit while urinating. Unless using an Indian commode or what is called the Orissa Pan, children below three feet height cannot use the western commode, resulting in them urinating in the bathwater sewers or open drains. These requirements from men and the children indicated the need for the urinal to be usable by both kinds of users. This seems to indicate a con-contact solution, with the added advantage of higher hygiene. A further benefit of this feature is aiding the elderly and women during the collection stage, potentially reducing the amount of water required to flush. However, a significant amount of stigma was observed against changing the existing system of collection and storage in spite of the respondents accepting these being water intensive and needing replacement.

Manufacturers, as stakeholders, included those manufacturing any aspects of the system end-to-end. For example, within the existing system, they included manufacturers of pans, commodes, and flushing tanks such as Parryware and Roca at the collection stage, and manufacturers of plumbing, storage, and holding tanks at the storage/treatment stage. Apart from timely surface cleansing, the ceramic ware of existing commodes do not generally require service within their lifetime though plumbing may need maintenance 2-3 times in the lifetime of the commode. As the plumbing work is separated from the ‘pans’ and ‘western commodes’, this maintenance is performed by plumbers (and in their absence, by masons) who are locally available. The current practice is to follow masonry procedures similar to that for construction of water retention tanks. This means that problems of seepage to the water-table might occur. Besides, installation of the pans/commodes currently carried out by masons whose availability and skill levels are reportedly on decline[17].

The private players included entrepreneurs who made the concrete rings required for building septic tanks or storage tanks, the architects and civil contractors who designed and built tanks onsite or on adjacent public spaces, those who privately made the PVC plumbing and holding tanks, particularly for holding toilet waste, and those who periodically collected the faecal sludge from these tanks and transferred these to farmlands or composting sites. People who transfer products for treating faecal sludge and the farm produces grown using this fertilizer to prospective markets also belong to this category. Agriculturists producing edibles, and horticulturists and nurseries producing non-edibles are some other stakeholders whose interests vary widely in using treated faecal sludge.

The public benefits of improved sanitation are enormous. In Bangalore, existing sewage treatment plants (STPs) operate below their maximum limit; new STPs are planned to be installed by 2016 to treat all sewage completely. Post-treatment, water is let out into natural water bodies or open storm water drains. Disposal of inadequately treated water into water bodies is a major cause of infant mortality from water-borne diseases. Pollution of water bodies is a significant public health issue and the Karnataka State Pollution Control Board (KSPCB) has often reprimanded BWSSB, BBMP, and the Bangalore Development Authority (BDA) for inappropriate disposal of sewage, lack of monitoring of dumping yards, and insufficient standards in granting No-objection-certificates to plots that have not constructed toilets[18]. Due to lack of sewerage coverage in the peri-urban areas in Bangalore, individuals and commercial establishments resort to storing sewage in unlined pits[19] and release their sullage into open storm water drains[20] .

4 Conceptual Design and Selection

Considering as many alternatives as possible for evaluation during design phase is important as it avoids fixation with seemingly favorable solutions or choosing whatever is present due to lack of imagination that may indeed prove counter-productive as systemic solutions. Table 2 below shows the wealth of concepts generated across functions and evaluation criteria used for selecting amongst these.

Table 2 Selection criteria for the various concepts generated

Functions	**No of concepts generated**	**Evaluation criteria**		**Candidate solutions and System solution (path)**
Collection Putting it out of sight Rendering it odourless	6 11 6	Space requirement Power consumption Visibility of sludge Cultural acceptability	Post-collection compatibility Handle different waste-types Maintainability	
Conveyance to sanitisation centre	12	Space requirement Efficiency of transfer Power consumption	Water consumption Hygiene Maintainability	
Killing pathogens (temperature) ph Humidity	13 4 15	Space requirement Power consumption Time of treatment Cultural acceptability	Post-processing compatibility Maintainability	
Conveyance to composting centre	12	Space requirement Efficiency of transfer Power consumption	Water consumption Hygiene Maintainability	
Digestion	2	Space Requirement Power consumption Water consumption Visibility of sludge Chance of Stench Nutrient recovery efficacy	Intrusiveness Cost and Acceptability Maintainability Compatibility to existing Time to digest Products of Digestion	
Despatch/Delivery	4	Acceptability		

5 Embodiment Design and Specification

Since the main nutrient resides in urine, a pan that separately collects urine is selected. Though some field experts of SKG sangha viewed this to be unnecessary, it is still chosen as this separation affords the freedom of using just urine. Further, the pan has a facility by which its urine collection part can be taken out and use for aiding men, the infirm, differently-abled, and women. The mode of collecting faecal matter is the same as in any vacuum toilet. As the stigma attached to handling of waste is strong, it is proposed that the odour be neutralised before being masked by masking sprays or de-odourisers. A two-stage digester that occupies the space that was otherwise used for holding tanks or septic tanks onsite is proposed. The volume of the digester has been designed around the volume of toilet and kitchen waste generated in an average household of five living on a 1200 sq. ft. plot and by taking into account the retention time for sludge prescribed by the WHO. It is proposed that after partially treating it onsite, the faecal sludge would be collected by municipal authorities or licensed private operators, who would transfer it to treatment centres for complete treatment before it can be used at farms.

Waste from kitchen is mixed with toilet waste and gravity flushed into a macerator, where it is macerated and pumped into the primary phase of anaerobic co-digestion. The primary phase occupies less space; it is situated above ground level and over the secondary phase of partial co-digestion lying underneath. The mixture of faeces and kitchen garbage requires an equal amount of water for the bacteria to digest properly, which would be provided by the ablution water and urine during defecation. The primary digester has a feature to centrally facilitate addition of neutralisers and bacterial potions that remove stench and enhance co-digestion. A neutraliser (generally cow dung) of 10% by weight would be added to neutralise the shock to which the bacteria may be subjected in case the composition of feed material varied significantly. Addition of new waste can continuously take place over a period of 30 days. The difference in the densities of old and new sludge ensures that the older material floats up. A tank, therefore, is positioned beside the digester to collect the overflow of 5 to 6 litres a day for a pre-specified number of days (depending on the space available onsite) as needed. The primary digester, secondary digester, and the annular volume in between ensure sufficient retention time for the generated waste to be partially safe by the time it comes out and collects in the holding tank. This faecal sludge can be sucked out by licensed private players or the BBMP personnel, wherefrom it should be rendered completely safe. Similar to the model of subsidy provided for adopting EcoSan in rural areas by some state governments, the cost of this system requires fillips for adoption[21]. The responsibility and the costs of treatment would then be divided between the two major stakeholders, that is, the waste generators (households) and government, intent on preventing diseases and promoting public health.

The total organic waste per day per family of five is about 8.5 kg comprising the following: Kitchen waste = 300 g (from survey of households in Chennai and Bangalore); faecal matter per individual = 300 g (i.e. for five = 1500 g); ablution water per individual = 1000 mL or 1000 g (for five= 5000g); and urine per toilet use = 300 mL (assuming one use at work, school, etc., i.e. for five = 1500 mL). Further, 8.5 kg or litres of such waste would give 1 m^3 of bio-gas. This contains about 600 liters of combustible methane, with a calorific value of 23 MJ. With a thermal efficiency of 65% for stoves in general, 0.5 m^3 of biogas is sufficient for cooking on a single burner stove for 1 hour (tapped energy) providing about 12 MJ. This is sufficient for cooking for three people for a month. Based on the amount of space available onsite, the digester volumes co-digest waste generating methane gas over a cycle time of about 30 days, beyond which the partially digested sludge is emptied into the holding tank where it is retained for more days before collection by the authorities. The fully digested waste would be a rich soil conditioner containing N, P, and K, and is proven to produce a good harvest of e.g. harmless banana crop[22].

6 Discussion

The past and the present governments of India have re-emphasized the need for sanitation leading to awareness campaigns urging the development of individual and shared community latrines. The *Swacch Bharat Abhiyan* of the present government has taken this commitment further involving the Indian corporate organizations' institutionalizing their CSR activity to utilize 2% of their profits for developing sanitation facilities. Positively, this results in new incentives for innovations in collecting, transporting, storing and treating faecal matter in ways other than existing problematic ways.

Ecological sanitation as a concept, needs to be encompassing ecology more to reap the rich understanding of interactions between not just plant and animal activity as it is defined now but also animal-animal interactivity as is also the proper domain of ecology. Such expansion can potentially lead to exploring interconnected paths and hence alternative ways of closing the loop. For example, in the conventional definition of Eco-san the agricultural or horticultural uptake of nutrient in human waste so as to convert it back into food for humans themselves closes the loop involving humans as the generator and consumer of the waste and waste-converted-to-food respectively. However, expanding the EcoSan definition in the ecological domain can mean using cows as digesters of kitchen waste due to which the organic waste which gets converted to dung becomes more convenient to handle within the anaerobic digester as its pH is stabler than that of the kitchen waste directly dumped into the digester. Similarly, exposing the faecal matter to larvae that can voraciously feed on nutrient and the pathogens together sanitizes the sludge using the guts of the larvae. The larvae can be further used as chicken or fish feed to route back into the human food chain, thereby closing the loop in a much interconnected way. Another possible way is to culture bacteriophages that can mutilate pathogens inside out and sanitize the muck by handling the viruses in a manner that is more convenient than killing pathogens. Consequently, implications of these larger interconnections need to be researched and sensitive matters related to ethics and animal rights need to be dealt with based on a case-based evaluation of risks, costs and urgency.

The necessity to have 24X7 water supply in urban areas requires water transmission to be continuously monitored so as to cull down transmission losses that result in 345% loss by volume. Water is a public good connecting many vital nutrient and ecological cycles. Consequently the role of the state is divided into catering to the immediate per capita water needs while ensuring equitable distribution and the long-term goals of sustaining water supply sources like lakes, rivulets, acquifers, rain-water, watersheds etc. in a holistic manner. Business models need to evolve around the circular thinking rather than tending to use or tweaking linear thinking models. Addressing the challenge of adoptability in the urban scenario may require creating aspirational product classes based on the affordability of the urban populace thereby tying necessity with aspirations of different strata of society.

7 Conclusion

Systemic requirements while designing for sustainability are demonstrated taking the case of designing an urban household organic waste management system. A major, unique feature of the proposed system is that it divides the responsibility of managing toilet waste amongst the major stakeholders, that is, the generators and the civic bodies interested in public health. The importance of inclusive handling of household organic waste at source is a major motivation behind the project. The solution proposes co-digestion of kitchen and toilet waste using urine and ablution water as ablution is culturally ingrained and cannot be done away with and urine is a source of nitrogen required to maintain the C:N ratio of digestion within desirable limits. However, a urine-diverting pan is still provided as a feature, to aid children and the infirm during collection. There is a perceived requirement for a pan which further cuts down usage of water used for cleaning the pan after each use. Also, the products of digestion need to be piped or packaged separately, as the stigma around it remains strong even in rural areas. The associated stench while burning the biogas requires the stove to be in the open, which in turn, dramatically brings down the thermal efficiency of the stove. Hence, solutions for on-site storage and utilization for heating water or direct sale of the gas generated are possible future considerations.

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