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Bypassing the flush, creating new resources: analysing alternative sanitation futures in London

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The flush toilet is an illogical form of sanitation from the point of view of water conservation, nutrient recovery and water pollution. Places such as London, with one of the oldest flushing toilet and sewer systems in the world, bears witness to the limits of its universal applicability through dwindling freshwater resources and polluted waterways. It is therefore important to develop new forms of sanitation infrastructure. An actor–network theory coevolution framework is used to explore and gain insights into the coevolution pathways for new types and paradigms of sanitation in London, where waterborne sanitation is currently prevalent. This approach shows that while flushing toilets are currently stable network configurations, there are coevolution pathways that would shift the system towards dry sanitation. The quantity of freshwater resources available for toilet flushing was the main actant cited for the development of these coevolution pathways.

Keywords: actor–network theory; coevolution; sanitation; flush toilet; sustainability; urban design

Introduction

The flush toilet, first invented for Queen Elizabeth I, has been used by generations of Londoners (George 2008). The flush toilet and the related infrastructure required for its operation is considered by many as one of the hallmarks of modern living and modern cities (Tarr and Dupuy 1988, Melosi 2000, Hard and Misa 2008). It is a desired sanitary system for people all over the world (United Nations Human Settlements Programme 2003). But it is also one of the most illogical forms of sanitation because it uses clean freshwater resources to transport waste. This causes the degradation and pollution of aquatic environments because it abstracts freshwater that would otherwise support aquatic life forms and discharges water that has been used to transport waste into other aquatic environments, despite treatment, this water contains nutrients, chemicals and heat that would not otherwise be present in these water environments.

Using water to transport waste dilutes and mixes different waste products some of which are sterile nutrient rich fertilisers making it difficult to harvest this resource efficiently

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or effectively (Novotny and Brown 2007). It also alters aquatic environments by draining water from upstream or from groundwater and discharging water of a different temperature, chemical quality and velocity downstream. This changes the quantity, quality and location of water and consequently all the ecosystems related to this water flow. These factors mean that this type of sanitation cannot expand universally without a strain on the availability of freshwater resources or the ruin of aquatic environments. In places such as London, dwindling freshwater resources and polluted waterways bear witness to the limits of the wide applicability of this system of sanitation (Environment Agency 2006, 2008).

An additional problem in London is the age and design of the waterborne sanitation infrastructure. The major components of this infrastructure were designed and built in the Victorian era (Halliday 1999) and could not have anticipated the rise in water consumption *per capita*; the growth of population in London; nor the increase in impervious ground surfaces draining water into the infrastructure because of the expansion of urban areas to accommodate the growth in population. This has led to what was designed to be an exceptional event of sewage overflow into an aquatic environment, to become a regular event that occurs about 50 times a year (Thames Water 2008). London waterways, therefore, bear the additional pollution from untreated sewage due to the overload of the capacity of the waterborne sanitation system.

Furthermore, in England approximately 30% or 50 L/person/day of the household drinking-water supply is used for flushing the toilet (Butler and Memon 2006). South-east England, where London is located, is currently designated "water stressed" for drinking-water supply by the Environment Agency, who are the statutory authority which aims to protect and improve the environment for England (Environment Agency 2006). Water stress in the south-east England is projected to increase in the future. This projection lies in three factors: population growth (Greater London Authority 2009), increased water consumption (Environment Agency 2010) and rainfall variation due to climate change (Jenkins *et al*. 2009). These problems are not unique to south-east England, many urban areas around the world contend with similar problems, with or without a projected change in climate (Barlow and Clarke 2002, Gleick *et al*. 2006, UNEP 2007).

In order to make better use of the available freshwater resources and nutrients and prevent the pollution of aquatic environments, it is necessary to develop new types of sanitation infrastructure. However, sanitation infrastructure is not just a technological artefact that needs to be altered, it is also equally entrenched in the culture of practices and values of people who use it (Gandy 2004, 2006, Shove 2004, Geels 2005, Van Vliet *et al*. 2005). This is a relational network that is made equally between the material and the social.

The waterborne sanitation system only comes into being when people use it to flush toilets, drain basins, sinks, washing machines, dishwashers, roofs and paved areas. Its formation also requires people to constantly maintain the material fabric of the system, fixing the pipes, operating the wastewater treatment plant and so on. Without people, their practices and expectations the waterborne sanitation infrastructure system would not be, but equally these people's practices and expectations are formed by the waterborne sanitation system that they use. People's continual enactment of the system and the established material configuration enables the waterborne sanitation infrastructure to be a stable set of relations.

To adapt, alter or replace, this system therefore requires an exploration of both how people and the material configurations of infrastructure could change. Two complementary theoretical perspectives, actor–network theory (ANT) and the socio-technical perspective, offer insights into how this might be explored. These two relational frameworks reveal the relations between the social, natural and technical, which bypass the traditional divide between the social sciences which only concentrates on the human; the natural sciences which concentrates only on the nonhuman; and engineering which only concentrates on the technical. By bypassing these divisions, it shows how things in each discipline are related, which is important to investigate the waterborne sanitation system which is made by things that cross over all these boundaries.

ANT offers an ontology that posits a symmetrical relationship between people (humans) and things (nonhumans) that creates all phenomena and knowledge that people experience and understand in the world. It then follows that this approach seeks ways to comprehend how humans and nonhumans interrelate to form these experiences and knowledge. This approach can be applied to exploring sanitation infrastructure in London. An ANT perspective also offers a way to understand the formation of new relations between humans and nonhumans and thus describe and project the development of new networks of relations. The socio-technical perspective is interested in the interrelations between society and its technologies. It has shown that these new networks of relations are formed from trajectories that are related and coevolved from pre-existing network relations between people and the technologies that are used. Thus, this research combines these two theoretical perspectives to find ANT coevolutionary pathways for alternative sanitation infrastructure in London where waterborne sanitation is currently the norm.

This paper first explains the aspects of ANT and socio-technical coevolution that are used to develop the method and analysis of this research. It then describes the method of interviews, group discussions and designs that were undertaken to formulate the coevolution pathways for an alternative sanitation system. The results of coevolutionary pathways for alternative dry sanitation systems in London are then described and the implications are discussed. The paper then concludes with how the resulting coevolutionary pathways from the ANT coevolutionary framework offer a perspective for the possibilities of infrastructural change.

ANT coevolution framework

The ANT coevolutionary framework combines the insights from ANT, which views the world as being composed of relations enacted symmetrically between humans and nonhumans, and those from a socio-technical perspective, which is also relational, but shows the long-term coevolving relationships between people and technologies.

ANT has its beginnings in the field of Science and Technology Studies and is heavily influenced by anthropological methods. It was developed to understand how scientific knowledge and technical innovations were created and accepted by the society. ANT has an ontological stance that assumes that both scientific knowledge and technologies are phenomena that come into being by a set of symmetrical relationships between humans and nonhumans. Both humans and nonhumans are identified by the common term "actant" to describe their effect in networks of relations. This leads to a view of the world that is endlessly changing and translated, made equally of human and nonhuman actants (Law 2004, Latour 2005). It also means that nothing that humans know is free from the cultural and political biases of the human, but equally these cultural and political biases are formed from the material world that surrounds the human (Latour 1993, 2005, Law and Hassard 1999).

ANT has since been used beyond understanding scientific knowledge and technical innovations, to also bring insight to phenomena such as urban areas, design and planning (Doak and Karadimitriou 2007, Hommels 2008) and also to water infrastructures (de Laet and Mol 2000, Latour and Hermant 2006, Dinckal 2008, Disco 2008) where this research is situated.

Using an ANT perspective to understand water infrastructures allows it to be seen as the interaction between material and social relations, which are inclusive of all types of actants such as rivers, boats, water sources, tides, pipes, vegetation, chemicals, people, items of trade and buildings all of which are equally important to its ongoing assemblage. It also shows it as a system that is only temporarily stable. Within the multitude of relations there can be betrayals between actant relations, such as a flooded river, which alter the assemblage of the system. However, the majority of this ANT research looks at how these changes occurred within short, snapshot, time frames. It mostly focuses on controversies where actant relations are in a moment of dramatic change, rather than the slow mutations that occur over a long time frame.

When ANT has been used to understand how scientific knowledge is created, Callon (1986) structured the analysis around four stages which describe different types of effects actants have on each other in order for the scientific knowledge to be created. These relations are problematisation, interressement, enrolment and mobilisation. Problematisation is when an actant frames a matter of concern. Interressement is when this actant seeks to define the roles of other potential actants within a network through actions which demand a response. During this moment, these other interested actants also actively define their roles in relation to one another. Enrolment is the successful result of interressement, when actants have simultaneously defined their relative roles. Mobilisation is the moment when the negotiation between the actants is stabilised and the network of relations is enacted. If these relations continue to be enacted between actants, then stabilisation is achieved and the actor–network is an accepted piece of scientific knowledge whereupon it becomes a black box. A black box is where the assemblage is considered normal and its existence is no longer questionable; a matter of concern becomes a matter of fact. The case studies that have been used to illustrate these stages have been formulated around a particular problematisation or matter of concern which necessitates the use of a short time frame.

While ANT has not looked at a long time frame of change between actants, the socio-technical perspective has done so. By looking at long time frames, the socio-technical perspective has identified that there are coevolutions between technological actants and human actants in changing water infrastructure and water use (Shove 2004, Geels 2005). Shove (2004) shows how laundry practices change over time from the advent of the washing machine and equally how the washing machine also changes over time with new practices influenced by the washing machine. These two actants coevolve simultaneously such that it is impossible to say which actant initiated the changes over time. Geels (2005) illustrates a similar socio-technical coevolution with an example of bathing practices and the introduction of piped water in the Netherlands.

This coevolution of the socio-technical actants over a long time period adds to the ANT framework because it shows that actants have predefined trajectories of their relations based upon their existing relations. The socio-technical perspective agrees with ANT in that these relations are always contingent and that the social and the technical are equally important in defining each other. However, it is not sufficient as a framework on its own because it presupposes a narrow set of actants: people and technologies, which is insufficient to investigate changes to the waterborne sanitation system which is easily identified as being comprised of more actants than these two categories. It is also insufficient because it does not explain the process of change that redefines actants and how they relate to each other. ANT offers ways to bridge both these gaps, thus joining the two complementary frameworks strengthens the insights from both.

This combined understanding of ANT and socio-technical coevolution has been used to develop the method and analysis of research into the possibilities of an alternative sanitation system in London. These two views extend one another: ANT to examine a wider range of actants beyond the human and the technological, within a particular set of relational effects and the socio-technical coevolutionary perspective to examine the coevolutionary trajectories of actants to continue shaping properties of one another.

Developing an ANT coevolution method

The research method aimed to find the network of interrelations that create existing sanitation systems; to find how these interrelations might have different levels of stability; and which actants might be unstable within the network. This would find actants that could be used for water conservation and therefore improve dewatered aquatic environments. The research method used a combination of semi-structured interviews, group discussions, photographic diaries and design to investigate the network interrelations between humans and nonhumans in an iterative process.

The first stage of the research was semi-structured interviews and group discussions that explored existing interrelations between humans and nonhumans in the water cycle. Differences in the existing network of interrelations showed areas where the network was unstable and potentially coevolving. The interviews and group discussions also tested the continued enactment of these interrelations by problematising the water actant by asking participants what they would do if piped water was no longer available. This problematisation found actants in the network that were reliant on this water source.

After the interview or group discussion, participants were asked to use a disposable camera and notebook to take photographs of their interactions with water over a 24-hour period, water interactions that they did infrequently and water interactions that had meaning for them, in this order of priority until the film of the 27 exposure camera was complete. This photographic water diary captured and verified the nonhuman actants that were part of the water cycle, but were not recalled in conversation or difficult to spell out in detail.

The human actants for this first stage were a mix of 23 water professionals and 30 environmentally aware citizens. Only environmentally aware citizens participated in the group discussions. All the water professionals and two environmentally aware citizens were individually interviewed. The individual interviews of the environmentally aware citizens were to ensure that the results from the group discussions were comparable to those collected in the individual interviews.

The results of the interviews, group discussions and the water diaries were then used to test for interressement between some of the unstable actants in the water scarce problematisation by using design to reconfigure the unstable actants to create greater water flow to aquatic environments by lowering water abstraction. The network relations of the initial design proposition began at this coevolutionary point in the present and then extrapolated to a proposition 25–50 years hence.

These new nonhuman actants attempted to be enrolled and renegotiated into new network relations with the human actants through the second stage of semi-structured interviews and group discussions. The results of these were once more coevolved into another iteration of nonhuman actants through a further design proposition that enrolled new actants that were suggested in the second stage of the interviews and group discussions. These design propositions were then renegotiated with a new set of human actants in the third stage of group discussions.

The human actants in the second stage of interviews and group discussions were the same participants as for the first. There were slightly less people in this stage as 10 people decided not to return. The third stage of group discussions involved the addition of new human actants who were not involved in the first two stages, which further tested the coevolutionary potential for the enrolment of the reconfigured nonhuman actants. There were a total of 35 participants in this stage, which were comprised of 7 water professionals and 27 environmentally aware citizens. Five water professionals and 16 environmentally aware citizens participated in all three stages.

Mobilisation is never really achieved for the design proposition actants in this research method because there is no stage of implementation of material change to the existing water-cycle relations. However, a degree of mobilisation may occur if the representatives of the human actants chose to alter their effects on the urban water-cycle as the result of participating in this research.

The methodology has used the relational aspect from both the ANT and coevolutionary frameworks. It uses ANT in presuming that the water-cycle phenomena are made symmetrically by both human and nonhuman actants, thus both types of actants need to be investigated. Taking insight from socio-technical coevolution, it encompasses a longer time span to develop propositions of how the changing practices of the present day and imagined adaptive strategies might influence future coevolutions of practices, technologies, ecologies and urban landscapes. The methodology extends both these research frameworks by going beyond understanding existing networks to finding areas of changing relations in order to test ANT coevolutionary pathways for future change.

ANT coevolutionary pathways

The reconfigurations proposed were driven by the problematisation of degraded water ecologies due to water abstractions, additional nutrient load from treated wastewater and sewer overflow events. The existing ANT coevolution pathways that were developed in these reconfigurations are reduced toilet flushing and replacing the flushing sanitation technology with waterless sanitation.

The water diaries verified that the flushing toilet was an actant that was very common and stable material configuration. The 37% of people's first documented water-cycle intervention was flushing the toilet and nobody photographed any alternate forms of sanitation. Despite this seeming stability from the water diaries, reconfigurations of the water quantity used for the flushing the toilet were specifically mentioned in the interviews and group discussions. Many people described installing saver flushes, hippos and bricks in the cistern of the toilet, the installation and use of new low flush toilets, the reuse of bath or shower water to flush the toilet and alterations to flushing practices. These reconfigurations show that while the flushing toilet is stable because it is commonly used, it is also in a process of being coevolved to suit people's water values which were different from those held by the people who designed the toilet that they were using.

The alteration of toilet flushing practices was by "yellow mellowing". This was practised by eight participants who only flushed after passing solid waste. This is captured in the often stated ditty "If it's yellow let it mellow. If it's brown flush it down." A further nine people imagined that they would practise this behaviour in times of water scarcity. This coalescence of similar practices in order to conserve water demonstrates that this is a likely ANT coevolutionary pathway.

Furthermore, seven people imagined a replacement of flushing sanitation with an alternative system in times of water scarcity, which was a progression of this pathway.

The majority of the technologies mentioned were composting toilets, but night soil collection and a chemical toilet were also put forth as options.

These ANT coevolution pathways were used in combination with the existing urban fabric and combined with pre-existing toilet technologies and known ways to reuse and treat human waste to come up with water-cycle assemblages that reconfigure the system for the sanitary disposal of human waste in London. These designs were then used to interressement human actants.

Yellow mellow rain refrain

This was the first part of the first design interressement that was to occur in the immediate time frame. The first design interressement was to modify the practices of how people used the wastewater infrastructure by extending "yellow mellow" practices. This practice could be more widely applied to lower the volume of water in the wastewater pipes during rain events by asking people to desist from using the wastewater infrastructure until the weather is dry, thereby allowing more room for the transport of rainwater thus preventing some sewer overflows into aquatic environments. Not using wastewater pipes includes not only toilet flushing, but also all forms of non urgent wastewater producing uses such as washing machines, showers, dishwashers and kitchen sinks.

The modification of wastewater infrastructure practices was encapsulated and made memorable by an additional two phrases to the already well-known "Yellow Mellow" ditty:

> If it's yellow, let it mellow. If it's brown, flush it down.
> If it's raining, keep refraining. When it stops, then it drops.

The new verbal actant highlights the connection between people's water use and the environment.

The human interressement in relation to this actant was mixed. The larger portion of people stated that they would be happy to mobilise this behaviour. Six people said that they would not "yellow mellow" and thus would not enact this water-cycle assemblage. Eight people thought that while they would assemble this water cycle within their home, they would not be willing to do so if they lived in a shared household or if they were using public facilities. This shows that shared facilities are an actant that stabilise different water-cycle assemblages than those of private facilities in relation to the flushing toilet. Even though this new water-cycle assemblage was not thought of as generally applicable or acceptable in public, a large proportion of people were happy to modify their behaviour in their own home. This indicates modifying flushing practices as a strong potential ANT coevolution pathway.

Some people explicitly speculated how this new behaviour might or might not be mobilised by other humans. Five people thought that other humans would not be happy to "yellow mellow; rain refrain", while four people thought other humans would be happy to "yellow mellow; rain refrain". Two people who thought that this would not be mobilised by others were still positive that they would do so themselves, while three would not. Four comments queried the number of human actants that would need to mobilise this practice in order for it to have a significant impact on combined sewer overflow (CSO) events. These conjectures about other people's mobilisation and stabilisation in this water-cycle assemblage imply that the magnitude of similar material relations is an actant that can strengthen or weaken this ANT coevolution pathway.

Daniel (pseudonyms used throughout) noted that he thought that this reconfiguration of the flushing toilet was vulnerable to media attack because it altered the contents of the toilet bowl from always clean water to sometimes water and urine. This introduces a new actant in relation to the enrolment, mobilisation and stabilisation of the water-cycle assemblage. The media is an actant that has an influence over what relations are delineated to people as matters of concern or matters of fact; therefore, it has the ability to persuade or dissuade some people to enact or betray this water-cycle assemblage. However, it is an actant that is temporary within the flushing toilet network. It functions to articulate the problemmatisation to multiple human actants, which influences the trajectory of the coevolution pathways because it affects the interressement of human actants.

For example, five people mentioned that they thought that the ditty was an effective actant to communicate the idea of not using the sewer while it is raining. Tom and Elsie commented that this would be particularly memorable for children. This shows that the ditty had effectiveness to problematise and interressement new human actants to enrol them to mobilise this new water-cycle assemblage. If the media communicated this problematisation and interressement as a trajectory of change of socially progressive and acceptable behaviour, this particular coevolution pathway may gain more interressement from human actants. Conversely, should they communicate this as a regressive trajectory, then people undertaking this behaviour may abandon this network configuration.

Adam, Anne and Qamar commented that the ditty explicated a link between their sewer use and CSO events that they had not been aware of. It was also effective at opening the black box of the drain, making the discharge wastewater an ongoing matter of concern.

There were seven comments, six of which were from water professionals that offered alternative problematisations for the cause of CSO events. These shifted the problematisation away from human water use to nonhuman assemblages. Elsie and Ruth thought that the increased amount of impervious surfaces which shed water quickly into the sewer system were the problem. Harry and Richard thought that the domestic component of the sewer system was a far smaller component than the rainwater, thus the base load would only be reduced by a small amount by this change in practice. Bill thought that the CSO event was more significantly influenced by misconnections in the sewer system. Harry and Humphrey thought that the pollution content of CSO events was from solids that were already within the sewer system. Each of these comments proposes that different nonhuman actants have a larger effect on CSO events than the flushing toilet and the domestic use of the sewer system. These different problematisations would enrol and mobilise different actants to reconfigure the water cycle.

Eight people offered alternative solutions to "yellow mellow; rain refrain" to address the matter of concern about water quality. This included the use of low flush toilets, dry toilets, composting toilets, finding new sanitation technologies, rainwater butts to retain rainwater and prevent it from entering the sewer system immediately and decentralised sewerage plants so that less transport is required before the wastewater treatment. All of these ideas involved introducing new material configurations to the assemblage, which use the ANT coevolution pathway of greater convenience to the human to stabilise different reconfigured water cycles. In this instance other people were seen as being potentially recalcitrant within the desired water-cycle assemblage, hence their practices required delegation to new material configurations in order to ensure the ongoing enactment of the required water-cycle assemblage.

The "yellow mellow; rain refrain" was a new actant that successfully interressement these human actants. The imagined reconfiguration identified that a magnitude of similar actant relations would strengthen this ANT coevolution pathway because the more acceptable and normal this practice becomes the more people would continue to enact this material relation. In addition, three new actants were suggested for interressement into this actor–network relation such that the "yellow mellow; rain refrain" would become an obsolete water-cycle assemblage. This included alternative sanitation technologies, rainwater detention and decentralised wastewater treatment.

Remove and compost

This was the second part of the first design interressement that was to occur in a time frame approximately 25–50 years in the future. This design interressement replaced the flushing toilet actant with an almost dry urine separating sanitation system.

This second design interressement follows the ANT coevolution pathway suggested by some people during times of water scarcity, whereupon several people suggested that they would consider changing their toilet infrastructure to an alternative sanitation technology in order to save water and the suggestion by other people as an alternative to the previous "yellow mellow; rain refrain". It also responds the ANT coevolution pathway of magnitude of similar practices of nonflushing.

The removal of the flush takes away the decision of what is an appropriate time to flush, thereby any person using this toilet is immediately enrolled in this water-cycle assemblage, which stabilises nonflushing behaviour. The replacement of the flushing toilet with dry sanitation occurs because the flushing toilet is a technology with a scope of reconfiguration that is limited to altering the time of flushing, the volume of water used for flushing and finding alternative water sources used for flushing. Replacing the flushing toilet technology with dry sanitation is an ANT coevolution trajectory that maximises the water conservation of the flushing toilet. Using a dry sanitation system removes human waste from the water cycle thus it removes pollutants from entering waterways during sewer overflow events. It also reduces the number of sewer overflow events because wastewater drains would not contain the volume of water from the toilet flush. Moreover, dry sanitation can repurpose human waste was a resource by concentrating the nutrients from human waste making it simpler to extract.

The human waste of urine and faeces are chemically different. Urine contains more nutrients than faeces. It is sterile and can be used as a fertiliser immediately. Faeces contain pathogens that need to be broken down through a composting process to become sterile. Hence, separate collection means that urine can be repurposed immediately and faeces can be composted to treat the pathogens. This is done by using a urine separating toilet bowl. This is similar to current toilet bowls, but has a division between the front and the back, so that the urine is physically separated from the faeces. To use this effectively all people will need to sit to urinate. This type of toilet bowl is available on the market and has been installed in an office in Switzerland (Tilley *et al*. 2008). The two types of human waste are collected in two removable canisters beneath the toilet bowl.

These canisters would be collected every two to three days, similar to the collection of recycling, solid waste or milk delivery whereby the filled containers are collected and clean empty ones are delivered simultaneously. The nutrients that are removed from the water cycle can then be applied as fertilisers to the land for agriculture or gardens.

The remove and compost system responds to the existing built form of most dwellings in London, where there is no space to store the waste from a composting toilet on site. This means that dry sanitation requires the removal of the waste to compost off site.

Overall, the replacement of the existing toilet for a new infrastructure had strong interressement as it was thought to be a good idea by most people. Thirteen people said that they would be willing to change their infrastructure given certain caveats of smell, collection and hygiene. Five people would be happy to do so if they were forced by external circumstances. Another 13 people thought that the idea was laudable, but they did not yet feel confident enough of the technology to change their toilet. Only nine people were outright negative about changing their toilet infrastructure. Ten people thought that this new actant might not be embraced by other human actants. However, Jack and Heather thought that it would have appeal to affluent environmentally aware citizens. Maria mentioned that if it were designed by a famous designer, such as Philippe Starck, it would become a desirable item for many more people. This showed that this actant had successfully produced interressement in these humans.

Roger, Phillip and Sally wondered whether or not it would be acceptable by other people to eat crops fertilised by human waste. Alan felt certain that other people would not like to do so and Anne thought that it might concern people at first, but they would soon get used to it. Felicity said that she would feel more comfortable if the crops were only used to feed animals rather than humans. This is the opposite attitude to the engineers of the nineteenth century who objected to the waterborne transportation system of human waste on the grounds that it diluted and squandered a valuable fertiliser resource (Halliday 1999, Gandy 2006). This shows that the flushing toilet helps to stabilise views of human waste as dangerous through its material disassociation once it is flushed from view.

Related to this were seven people who were concerned about the more intimate contact with human waste that this removal system requires. A few people suggested ideas such as chutes or vacuums to maintain their distance from human waste. This shows an ANT coevolution pathway for a less labour intensive or less intimate contact with human waste would create more interressement in human actants.

The proposed vehicular collection system for the waste caused some concern for a few people because of the carbon dioxide emissions from a petrol combustion engine. This introduced a set of new potential actants into the system. Daniel suggested that it could be jointly collected with the recycling. Esther suggested that biogas from the decomposing human waste could be used to run the vehicle and Alan thought that the biogas could be harvested for general use. This showed that this new actant would have further network stability if it also addressed the matter of concern for the reduction in the use of fossil fuels.

The remove and compost dry sanitation system was a new actant that successfully interressement these human actants. The ANT coevolution pathways found were for a cleaner more convenient less carbon-dioxide emitting waste removal system and a harvesting of more resources from human waste. It also showed that the formation of the actor–network might be betrayed by humans who refuse to eat crops fertilised by human waste.

Remove gas and compost

The second design interressement modifies the previous remove and compost dry sanitation system by adding uses for the gas produced by the decomposing faecal waste. It also uses a prototype of a remove and compost toilet that is currently being developed at Imperial College (Gardiner 2010) in order to provide a cleaner, odour-free way to dispose of the human waste. Unlike the first design interressement which was imagined in two timescales, this second design interressement was proposed to be implemented in the immediate time frame. This was because none of the human actants imagined themselves in a coevolving state between the first design interressements; hence, each was considered relative to the existing attitudes and material relations of the participants, which is equivalent to an implementation in the immediate time frame.

The prototype dry sanitation toilet uses a starch liner within the toilet bowl to seal and package the human waste. It separates the urine and faeces using patented manufacturing separation techniques, thus the bowl does not have a separating division for the urine and the faeces. The packaging system is operated by a hand crank that winds the waste down into the removable storage chamber below. The urine is separated from the faeces at this point in time. The packaging system means that the toilet remains odour free and the waste is not directly handled. Once the hand crank has been wound, all that remains in the toilet bowl is the clean starch bag ready for the next toilet use. The removable storage chamber can contain up to 15 kg of waste. One person produces approximately 1 kg of waste a day; therefore, this toilet needs to be emptied at least once a week for a two person household. The chamber is sealed on removal from the toilet bowl and can be taken to an anaerobic digester for decomposition. The starch bag is decomposed at the same time as the human waste, thus there is no need to open the starch storage bag prior to its deposit in the digester. The storage chamber is reused.

The decomposing of faecal waste produces two gases that are useful to human life. One is biogas (methane produced from a contemporary decomposition of organic matter) that can be used to drive turbines to produce electricity, used immediately for cooking or lighting, or compressed and used as a fuel to power vehicles. The use of biogas as a cooking fuel is a technology that has been applied globally, but usually in rural areas of developing countries (Tilley *et al*. 2008). The decomposition of faecal wastes also produces carbon dioxide, this can be siphoned off and used to fertilise the air in greenhouses for growing food. This is a technology being used in a combined heat and power power plant in Ontario (EBR Staff Writer 2009).

This new design actant did not show any significant additional human interressement in comparison with the remove and compost system, despite the additional actants which made better use for all the products produced from the anaerobic digestion process, as well as an odour-free system and a cleaner more convenient method of removing the waste.

Most matters of concern were exactly the same as those from the first remove and compost design interressement: smell, collection and hygiene. The main difference was that the dry sanitation system was not betrayed by a matter of concern for the human consumption of crops fertilised by human waste.

Interestingly, while three people were concerned about its social acceptability, 14 people suggested that this system would be better applied in public buildings or areas of communal use such as parks, stadiums, hotels, schools, offices and at festivals. Similar to "yellow mellow; rain refrain", it shows that the water-cycle assemblage of public toilets is different from private toilets. The interressement of a public dry sanitation use would test the technology and its acceptability to other people without risk to the individual and is an ANT coevolution pathway.

Furthermore, five people added examples of where such systems were already in use such as Mexico, South Africa, Shanghai, the National Trust in England and the Massachusetts Institute of Technology in the USA. One person said that he had used such a system for three years in Mexico. Another person said that he already did half of this as he puts his pee on the compost. These new actants verify that the remove, gas and compost system is a current ANT coevolution pathway.

Similar sorts of additional actants were suggested to this second iteration of the design interressement as the first, such as having a chute, vacuum or conveyor belt to collect the waste rather than a manual system. One person suggested that food waste could also be added to the biodigester. These new material configurations are additional actants that could stabilise the ANT coevolution pathway for the remove gas and compost system.

Three people were concerned about whether conserving carbon dioxide emissions or water was more critical to maintaining an ecology that favoured human life because the environmental impacts were different. Four people thought it preferable to conserve carbon dioxide emissions more than water use. This shows that other matters of concern are actants that affect the urban water-cycle assemblage.

Many people were concerned with how to add more actants as incentives to this actor–network in order to enrol and mobilise other people to change and thus increase the magnitude of similar actant relations. One person suggested that celebrities be used to promote the system. Two people suggested raising the price of water so that it became unviable to use water to flush. Another suggestion was to pay people for their urine and faeces. One person devised a complex scheme of points whereby people would get points for their urine and faeces, their recycling and any other environmentally helpful behaviour which would then be redeemable for more things to make them more environmentally helpful, such as seeds for plants, or gardening equipment. This shows that this actant needs to generate interressement for more actants in order to mobilise and stabilise this new configuration of the water cycle.

Overall, this design successfully produced interressement for these human actants. These new actants indicated that this new assemblage was a viable system. More actant relations beyond the water cycle were added to the actor–network including money, status and alternate building typologies where the design actant could be applied. If these relations were mobilised these could enable a stabilisation of this actor–network.

The raising of the same matters of concern such as smell, collection and hygiene shows that while a working prototype of this actant was demonstrated, this was insufficient to enrol and mobilise these human actants. The repetition of these same matters of concern shows that these actant relations were the most important in coevolving this actant. This second iteration revealed an additional coevolution pathway via shared public facilities that would verify its level of hygiene to human actants who did not want the risk of initially creating the system in their homes. It also showed that the coevolution of this design actant had reached a saturation point through drawings as the only way to verify smell, collection and hygiene is through a mobilisation of actants. This shows the limits of the documentation of the design actant. While the drawn design actant can successfully enable the exploration of actor–networks, coevolve new actant propositions and identify ANT coevolution pathways, it cannot mobilise these new reconfigurations of the network without also becoming a material reality.

Conclusion

Three design actants, "yellow mellow; rain refrain", "remove and compost" and "remove, gas and compost", were explored as possible ANT coevolutionary reconfigurations of the urban water-cycle in London. All three design actants are a response to the matter of concern to improve the aquatic environments in this area by reducing water abstractions, water treatment and the nutrient content of water returning to aquatic environments. Additionally, the harvesting of nutrient resources from human waste was explored in two of these reconfigurations. All three design actants had different levels of success at interressement in the participants; finding additional actants related to these reconfigured material relations; and discovering other ANT coevolutionary pathways for further development.

By using ANT coevolution as a framework for understanding the waterborne sanitation system in London, this phenomenon can be seen as assemblages of people and things that are constantly being enacted and thus are always in a state of coevolution. This understanding led to ways in which the assemblage of these networks could be reconfigured to achieve an improvement to aquatic environments. The intransigence of the waterborne sanitation system was tested by describing existing practices and in an imagined situation where water was scarce. This showed that there were endemic coevolution pathways which then formed the basis to make and test design propositions that coevolved material configurations to conserve water use and harvest resources.

By progressively coevolving the ANT assemblage that formed the flushing toilet by changing the time it was appropriate to flush and then the type of water that was used to flush, it was found that this actant could only be modified so far before it was replaced by the human actants, who unenrolled from this network and suggested that the flushing toilet be replaced with the dry toilet. This new actant no longer used water to move waste, and subsequently generated new relations with other actants that transported and transformed waste, such as trucks, anaerobic digesters, gas networks, crops, animals and so on, to form a new array of network of relations. While these new network configurations were coevolved from existing network relations, the replacement of the flushing toilet with a dry toilet system represents a significant step change to the network relations.

This reveals that new actor–networks are created and sudden technological change occurs when the refinement of a particular actant reaches its limits within a particular matter of concern. These new actor–networks are formulated by existing, local enactments that are in flux. The ANT coevolutionary framework and methods which were applied to this research could equally be applied to other matters of concern which are formulated from relations between the social, technological and natural, such as energy, food, transportation, air quality and so on.

This research found that by using a combined ANT coevolutionary framework with an innovative methodology combining conventional social science methods and design, the waterborne sanitation system in London was not intransigent and reconfigurations of the actants that form this system were occurring. A dry sanitation remove and transform system was one possible coevolution pathway in London. This represents a significant change to the existing waterborne sanitation system. This ANT coevolution pathway has the additional advantage of transforming what are now water and air pollutants into new resources for energy and food production. It is a result that raises hope for places which face dwindling drinking-water supplies, polluted waterways, dying aquatic ecologies, fertiliser shortages and excessive carbon dioxide emissions, due in part to the waterborne sanitation system, which at first seemed a centuries-old entrenched stabilised network.

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