Water Metering System Implementation For Urban Water Use Reduction

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Abstract

The city of Cape Town currently faces an unprecedented urban water crisis which may lead to the shutting off of the water supply by the end of 2018. Prolonged drought, antiquated urban water management models, and poor governance are just some of the factors that have led to the current state of affairs. To address the distributed inefficiencies of the current water infrastructure, particularly in individual buildings and piping, a paradigm shift in urban water management towards 'bottom-up' designed smart water networks is required. This design report explores the next generation of urban water management by designing a connected water meter system for the micro-management of urban water consumption in individual households. To improve water consumption behavior at an individual level, design models for behavioral change and strategies for sustainable implementation of consumer systems were analysed. Following which the performance requirements of the solution system were described using an intervention matrix. Based on this analysis, a design framework for the smart water system was created that describes the critical features of this intervention with particular consideration of the ethics involved with designing such a personal system. The design framework of the system can be used by businesses or governing bodies to develop a functional smart water meter system that can not only mitigate the current water crisis in Cape Town but also usher in a new global paradigm for water-sensitivity and management in the 21st century.

Introduction

Cape Town is the first modern city facing a water crisis that may lead to its taps running dry by as soon as the end of this year. Other cities like Sao Paolo, Melbourne, and Mexico City potentially face a similar crisis in the coming years (Welsh, 2018). The water management architecture of most of these cities has changed little since the beginning of the 20^{th} century. With rapid urbanisation in the 21^{st} century, the old model of elaborate reticulation systems is under increased pressure and is rife with inefficiencies (Gonzales & Ajami, 2017). In spite of having an above average efficiency in its water system, Cape Town's water distribution system has a potential loss of nearly 30% (Colvin, Muruven, Lindley, Gordon, & Schachtschneider, 2018; Mavuso, 2018). Over the past few decades, the rise of Smart Water Networks with data-enabled systems and control over all tiers of the water infrastructure, promises to be the next generation of infrastructure needed to fit the needs of the 21st century. But such a drastic remodelling of the city's infrastructure is both expensive and time-consuming (Gonzales & Ajami, 2017).

To mitigate the current crisis in Cape Town, and potentially other urban water systems, this design report takes a 'Bottom-Up' approach to address the water consumption management at its source, rather than a glacial 'Top-Down' policy of infrastructural remodelling. The domestic urban residence of a middle-class citizen in Cape Town is taken as the sub-system of interest, within which the water consumption behavior of the users and the residence as a whole is taken to be the primary parameter. In this mitigation strategy, research has been conducted on models for behavioral change of users and the intervention strategies to best realise them. Using an Intervention Mapping Matrix, the performance objectives of the designed intervention system were identified. Following which, the design specifications for an integrated system of modular, wireless water consumption meters that can analyse and recommend specific strategies for improving the water consumption behavior of the household, were described.

It was important to design the intervention for the middle class citizens of Cape Town. The Cape Town Socio-Economic Profile (2016) defines the middle class to encompass people earning between R50,000 and R404,000 annually, however this definition is inadequate at addressing their significance to South African society (Seekings & Nattrass, 2008). Because of their unique position in the socio-economic hierarchy between the upper and working classes, they have a moderating influence on the stability of democracy, economic growth, and consequently, consumption behavior (Ndletyana, 2014). Therefore, designing a solution for the middle class has the most potential for widespread adoption of the technology. Since the designed intervention is a system of technological devices, practically it may not be affordable for every household, but for a relevant impact on the water consumption behavior of the city, it must be available to a majority of the largest water consumers, which includes the middle and upper classes of society. The quarter of the population that lives in informal settlements in relatively poor neighbourhoods surprisingly contribute to only 4.5% of the city's water consumption despite inefficient water infrastructure in these neighbourhoods (Janssen, 2018). The intervention is thus designed for improving the management of the remaining percentage of urban water consumption in middle class households, with the future possibility of scaling up the system for managing the consumption behavior of the upper classes as well.

Problem description

Growing population in cities gives rise to increasingly complex socio-economic and environmental challenges for urban water management, which are further complicated by the effects of climate change on the hydrological cycle (UNESCO, 2013). Civic infrastructural systems such as that of water management are often based on a centralised 'top-down' model for the supply, distribution, and waste treatment of water, while the demand for water, generation of wastewater, and the alteration of hydrology are determined by consumption behaviors at the decentralised or 'bottom-up' level (Coombes & Kuczera, 2002).

Traditional urban water systems are designed as a combination of independent infrastructural components and managed by multiple agencies (Gonzales & Ajami, 2017). The advent of centralized municipal water supply and sanitation in the 19th and 20th century drastically improved the health of cities. But for the rapidly growing cities of the 21st century, the centralized infrastructure model will soon be unable to keep up with with the increasing complexity and demand for urban water (Brown, Keath, & Wong, 2009). As a large part of this fixed infrastructure is dedicated to transporting water and waste over large distances, growing cities require additional reticulation systems that must draw on an already saturated network (Brown, Keath, & Wong, 2009). Increasing amounts of disinfectants are required to keep this system water clean, and contamination of any source can lead to rapid outbreak of disease (Gonzales & Ajami, 2017; Brown, Keath, & Wong, 2009). Leakages or disruptions in a part of the network can compromise the system and the monitoring of network damage or contamination is most often restricted to elaborate manual field inspections (Coombes & Kuczera, 2002). Water managing institutes have little visibility of the water flows in the system, and are thus poorly equipped to manage varying requirements and pressures, especially under extreme conditions such as heavy rain or drought (Gonzales & Ajami, 2017).

Over the past few decades, in response to growing water insecurity, urban regions have shown increasing interest in alternative practices such as water conservation, wastewater recycling and desalination (Gonzales & Ajami, 2017). But more importantly, there is consensus that improving the system through such practices requires a paradigm shift in water management towards an adaptive, integrative, and data-driven model of governance for a sustainable, reliable, and resilient urban network of water (Howe, Vairavamoorthy, & van der Steen, 2012; International Water Association, 2018). The Western Cape and the city of Cape Town have had a progressive water management policy since 1999 with a focus on water conservation and water demand management (WC/WDM), water reuse, and desalination (Western Cape Government, 2012). And while significant progress has been made in the following two decades, the city still faces a water crisis today, and the need for a more resilient and secure water system is evident.

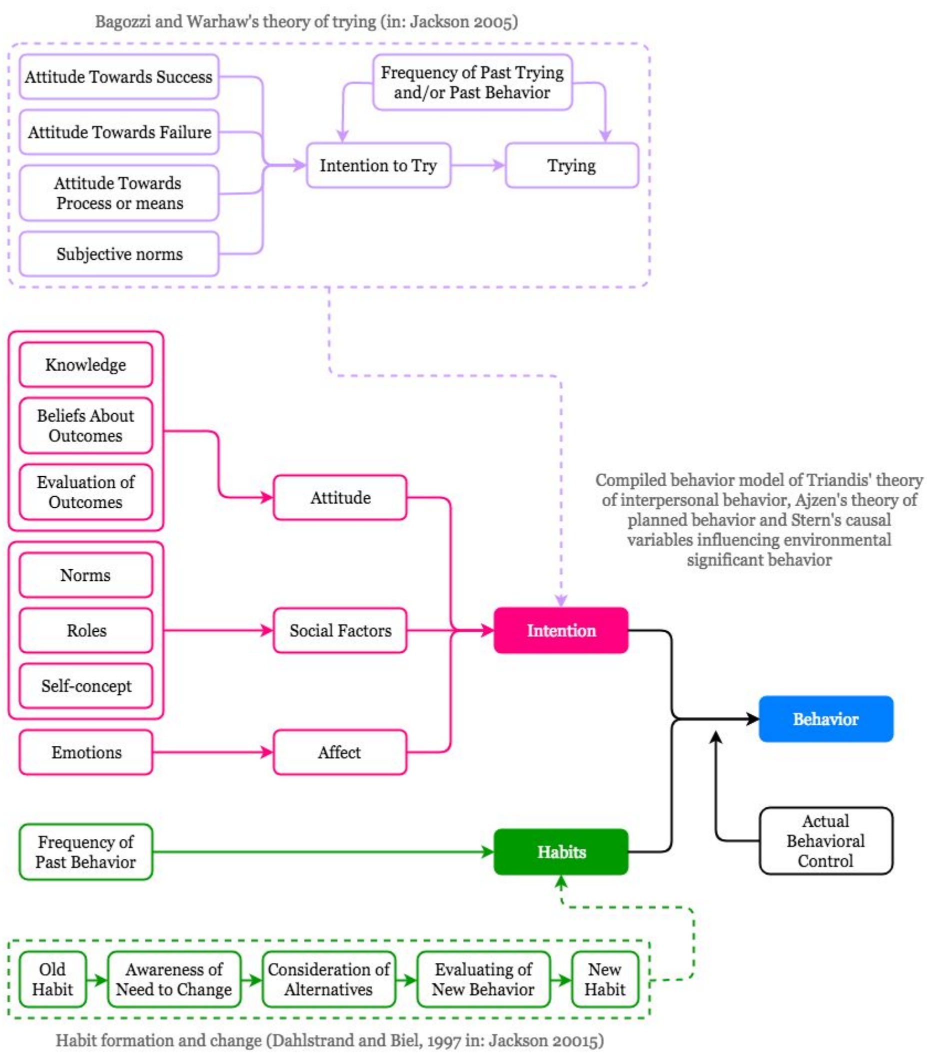
According to Cape Town University's urban water expert, Dr. Winter (2018), the future of Cape Town's water hinges on a fundamental paradigm shift in the way water is handled. He stresses the need for 'Water Sensitive Urban Design' in which the city is seen as an urban catchment, in which supply and demand is efficiently moderated through a connected, responsive system.

Intervention methods

Intentions, habits, and controls are considered important antecedents of behavioral change. Within the domain of household appliances, most of the processes ingrained into our life patterns exhibit a habitual and routine nature (Tang, 2010).

In behavioral change, there are internal and external elements. According to Jackson (2005), the internal antecedents of behaviors are: values, attitudes, intentions, habits, and personal norms; The external antecedents being: fiscal and regulatory incentives, institutional constraints, social practices, and cultural order. When using this information to design for behavioral change it's paramount that one questions these antecedents and asks whether the user has autonomy of action, and can thus take steps to control or change their own behavior, or if their behavior is completely dependent on outside factors, and is thus no longer a question of personal goals or desires.

Figure 1, as developed by Tang (2010), shows that the understanding of behavior formation and disintegration are established on the basis of the theories of Triandis (1977 in: Jackson, 2005), Ajzen (2006), Stern (2000), Bagozzi and Warshaw (1990 in: Jackson, 2005), and Dahlstrand and Biel (1997 in: Jackson 2005). As demonstrated by this model, intention, habits, and controls are considered important immediate and mediate antecedents of behavior change.



Habits

According to the Energy Saving Trust (2006), despite people's concern over the environmental impact of their household activities, these concerns are not reflected in their actions. This is because consumptive behavior is about convenience, habit, practice, and individual responses to social norms (Jackson, 2005). According to Verplanken and Wood (2006) habits account for approximately 45% of people's actions, as they are performed almost daily and usually in the same location. Habits are highly automated, performed with little to no deliberation or cognitive effort, and often with minimal awareness (Jackson, 2005; Warde, 2002). As a result, attitudes, norms, and perceived behavioral control have a lessened effect in changing people's behaviors (Tang, 2010). As new technologies and products are developed and implemented, routines and habits adapt to fit new norms (Tang, 2010).

Information Dissemination Strategies

According to Jackson (2005), there are three critical components that are imperative to the success of persuasive strategies: The credibility of a source, The message being delivered, and the thoughts and feelings of the receiver. Persuasion strategies often have the result of a heightened awareness or knowledge of a problem, but rarely ensure people's long term involvement (Abrahamse *et al.*, 2005; Jackson, 2005). Persuasive strategies work well in raising awareness and knowledge levels about certain issues, however it is equally important to inform people what they can specifically do to help mitigate the problem. In the information dependent society that we live in, this type of information often remains in a form which leaves the user unclear about what the correct action to take actually is (Moisander, 1997a).

Experience and Social Norm

Deviating from information campaigns, learning from experiences, both direct and indirect, as well as facing the consequences and reaping the rewards, is considered to be a more powerful tool for behavioral change than the information campaigns (Jackson, 2005). Even though learning by trial and error is a method more commonly used than encouraging the imitation of others to induce pro-environmental behaviors (Jackson, 2005), it has been found that the behavior of an individual is heavily dependent on the actions of others (Sustainable Consumption Roundtable, 2006). People have a natural tendency to imitate the behaviors of those around them, specifically in complex and unfamiliar situations, as well as when communicating within group environments (Dawnay and Shah, 2005). In this case both external and internal factors are present. The actions of others are seen as an external peer pressure, however they do not directly change the behavior of an individual. This behavior change comes from the internalization of the behaviors of others and the desire of the individual to be accepted, and to not be rejected by the majority.

Control

Simply giving someone information about an unsustainable behavior and telling them what to do about it is not enough. To motivate, and effectively change a behavior for the better, the user needs to feel in control (Tang, 2010). People's perceptions of their capabilities in being able to execute a certain task have a great deal of influence on their levels of engagement (Bandura, 1977, in: Tang, 2010). It is important to offer the user a multitude of options, however too much information, or too many choices can create a feeling of helplessness in the user, and lead to an unwillingness to follow any one specific course of action (Tang, 2010). According to Tang (2010), it was found that people are most motivated when they are:

- Aware of the reality and its causes;
- Engaged within the implementation of intervention or rule, e.g. to learn, discover, and explore at their own pace and answer their own questions;
- Able to participate and play a role in what is going on around them.

Emotions

Emotions are an important aspect of behaviors and can be used as a tool for committing people to certain behaviors, or behavioral changes (Tang, 2010). Guilt, responsibility, and worrying about the future wellbeing of offspring are examples of such emotional behavior-controls. These factors function as psychological incentives for users to resist “free-rider” behaviors and the denial personal responsibility (Moisander, 1997b). In design, the use of materials, colors, textures, and visual cues can evoke a sense of nature, but fail when it comes to a sense of responsibility or values relating to the environment (Tang, 2010). Emotions are a good catalyst to sustainable behavior change, however, they cannot do it all alone. When using emotions in this sense they must also be backed by other methods.

Adoption, Implementation, and Sustainability

In order to encourage people to adopt water-saving innovations, a few barriers need to be overcome. Firstly, as previously discussed, the technological intervention has to function and deal with human behavior. However, once the technology is perfected, it still needs to be diffused amongst the target group. In order to overcome the barriers that come along with the diffusion of water-saving innovations and to achieve the highest adoption rate possible, a diffusion plan is made. In the diffusion plan, a literary research on important factors that influence diffusion of water-saving technologies is combined with the Technology Acceptance Model (TAM). The literary research is used to find the factors relevant for the TAM.

Research conducted by Wejnert (2002) identifies two important factors when it comes to the diffusion of innovations. The first is regarding the target group and diffusion method, and the second is the direct and indirect costs incurred by the user.

Innovations that bring forth public consequences will affect collective actors that are concerned with societal well-being (Wejnert, 2002). If the innovation has private consequences, the individual or small collective entity adopters will be the ones affected (Wejnert, 2002). The manner of channelling information should be different depending on the target group as described above. Innovations with public consequences are communicated most effectively through the uniform spreading of imitative models and information (Wejnert, 2002). Innovations with private consequences are diffused through spatial and temporal contiguity between potential adopters and developers (Wejnert, 2002). According to (Wejnert, 2002), innovations are first adopted by either political powers or economic resources, whereafter they impose adoption of the innovation on lower status actors. In addition, regulation is the most effective way to make sure people adopt water-saving innovations because all inhabitants have to comply regardless of their own lifestyle. Subsidies can help in the diffusion of water-saving innovations that don't need to be integrated with the system already present in the house (e.g. toilet tanks) and carry (high) investment costs, where a focus on specific lifestyles for promotion campaigns should be considered (Schwarz & Ernst, 2009). The other influential factor is the direct and indirect costs or risks incurred by the user that accompany the adoption of an innovation. These costs can discourage the diffusion of innovations, especially when they exceed an actor's resource potential (Wejnert, 2002). This research shows that it is important to have a clear target group and adapt the communication method to match the target group's priorities, mostly focusing on the benefits of the innovation.

In a paper by (Karakaya, Hidalgo, & Nuur, 2014), four elements are defined as influential on the diffusion of eco-innovations: the innovation, the communication channels, the time, and the social system. Interpersonal communication channels seem to be more effective (Karakaya, Hidalgo, & Nuur, 2014), however, when it comes to water-saving innovations, attitude and perceived behavioral control are far more important than communication via social networks (Schwarz & Ernst, 2009). The adoption of water-saving innovations can be related to motives like "green" values or saving costs (Schwarz & Ernst, 2009). According to Karakaya, Hidalgo, & Nuur (2014), "Innovativeness and adopter categories" and the "Rate of adoption" are important factors of the diffusion process of an eco-innovation since it is based on the degree of innovation of individuals in combination with the characteristics of the innovation (Karakaya, Hidalgo, & Nuur, 2014). It can thus be concluded that it is important to stimulate the innovativity and attitude of an individual when focussing on private owners as a target group, and to show the positive effects on the environment and amount of money saved.

For the research on how innovations were perceived, five innovation characteristics were identified, these being environmental performance, ease of use, saving of costs, compatibility with existing infrastructure, and investment costs (Schwarz & Ernst, 2009). These innovation characteristics can be used to create an idea of what is important to take into account when evaluating and adapting the chosen technology.

The theory of planned behaviour plays a major role in TAM, which states that attitude, subjective norms and perceived behavioral control lead to intention, which, in its turns leads to action and thus behaviour change (Baumeister & Bushman, 2014). It looks at external variables influencing perceived usefulness and perceived ease of use (Davis, Bagozzi & Warshaw, 1989). These factors influence the attitude towards using the product, which creates the intention to use the technology (Davis, Bagozzi & Warshaw, 1989). In the end, this will increase the chance of a person adopting the technology (Davis, Bagozzi & Warshaw, 1989). The diffusion plan for the innovation suggested in this paper can be found in ‘’Implementation” in the intervention section.

Design Methods

To be able to design a successful technological intervention, the ATLAS Socio-Technical Design model (ATLAS model) was combined with the Intervention Mapping model. Intervention Mapping is a protocol used for developing effective behavior change interventions. It is a six step approach that describes the iterative path from problem identification to problem mitigation. This approach is based on theory and the use of existing evidence as a foundation for creating an elaborate assessment and understanding of the problem.

The reason for combining these two models is that in the scope of this research, Intervention Mapping proved more fruitful for assessing the problem than finding an actual solution for it, and vice versa for the ATLAS model. The combination of these two models included the *Matrices of Change Objectives* from Intervention Mapping, and the *Functions & Requirements* table from the ATLAS model (See *Appendix A* for the matrix and table). The *Matrices of Behavioral Change* works by combining (sub)behaviors (performance objectives) with behavioral determinants, identifying what should be targeted by the intervention strategy. The completed matrix then led to the formulation of the *Functions & Requirements* table, which is used to lay out what the intervention strategy needs to do (Functional Requirements) to achieve the goals outlined by the Intervention Mapping model, and then how that technology will go about achieving those requirements (Behaviors).

The intervention

System

Water infrastructure in cities traditionally consisted of a complex system of physical layers of pipes, pumps, reservoirs and controllers with poor end-to-end data connectivity. Water utilities are gradually increasing the data-enabled components in the system to build a cohesive network of water utilities for better visibility and control. Such ‘Smart Water Networks’ span water sources and production, transmission and distribution, consumer end-points, and internal piping. The collected data is managed through a hierarchy of systems to inform the management of water utilities, as is shown in the adjoining figure 2. And while, the higher order data processing yields the most actionable insights, the system rests on the architecture of the sensors in the field. The intervention proposed in this report is thus focussed on the sensors at the consumer end, that enable smart water networks.

Figure 2: Functional hierarchy in smart water networks. Derived from Smart Water Networks Forum (2018).

Traditional residential water meters are manually read on occasion for billing. In smart water networks, Automatic Metering Infrastructure (AMI) can support real-time communication between meter, user, and utility to understand consumption and integrate billing systems. This intervention proposes an even more intelligent personal system that monitors consumption not by residence, but by individual water outlets within the residence. By securely monitoring consumption at the most fundamental level, the system would enable the end-users to understand their individual behaviors and provide directed measures to manage consumption of water at its basest unit. It would also be able to diagnose inefficiencies or leaks in the residence and potentially recommend a suitable course of action. Such a system would feature architecture modelled after the upcoming trend of 'Internet of Things' (IoT), a model of which is displayed in figure 3. Every monitored water outlet would feed time-stamped consumption data to a virtual model of the user's consumption behavior, which can be analysed to identify potential for improving the user's water behavior. The private nature of the data necessitates it be stored securely as would other sensitive information from other IoT home-management systems.

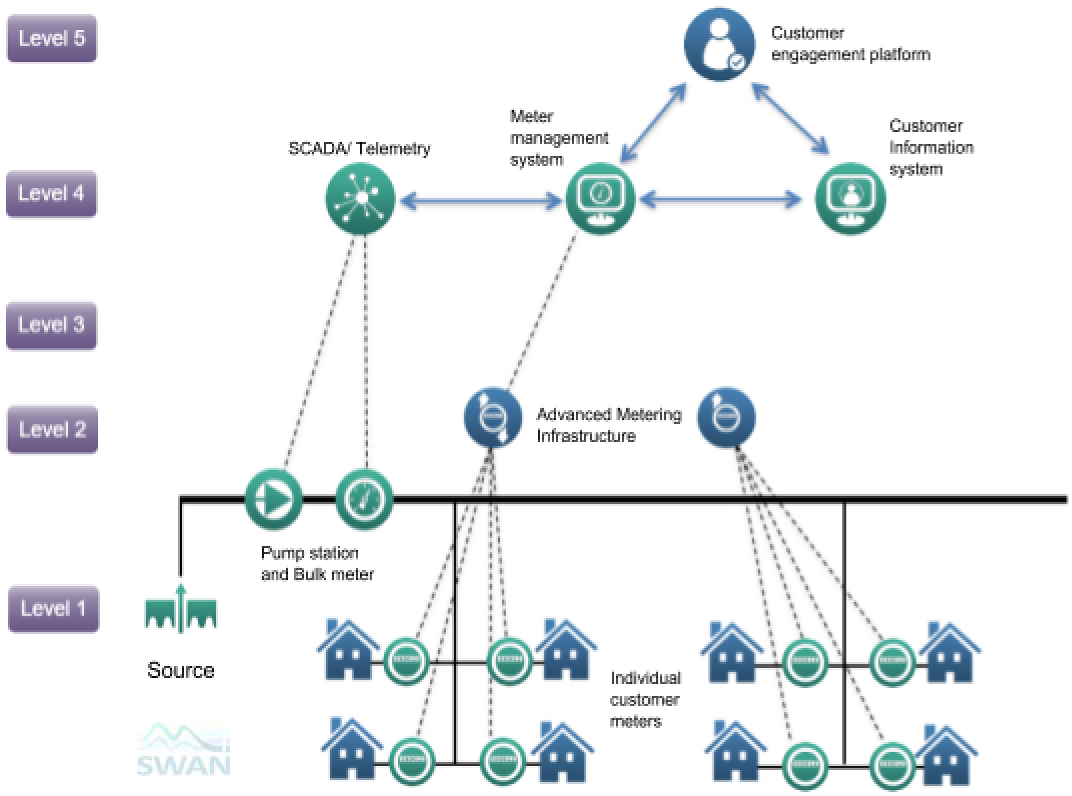


Figure 3: System overview of individual metering within a smart water network. Derived from model of Smart Water Networks Forum (2018).

Information

As previously stated, providing the user with information is pivotal to behavioral change technologies. The information aspect of this technology comes in two-fold: the first is the user's own personal data. Each device in a household is integrated into the user's profile to create an integrated user experience. The user is given raw and analyzed data on their individual consumption at each connected water source, and their total consumption of all the sources combined. This design choice is to serve as an immediate feedback source for the user. In real time he or she can view the analytics of their water consumption.

The second information aspect comes in the form of telling the user what to do with all that information. As was previously stated: providing the user with information is not enough, the user needs to be told what to do about it and how to improve. An even better approach is to provide the user with multiple options to create a sense of autonomy and control. In this secondary information provision, the user is presented with information on how to reduce his or her in-house water consumption. Based on the user's own data, the system will then prioritize certain categories and household appliances (or locations) from which excessive amounts of water are being consumed.

This information will come in three forms: text, infographics, and instructional animations. The idea behind this is to provide the user with detailed information that goes deep into the issues and provides a clear problem analysis and possible solutions all backed by sources (the information text), the most surface level information to acclimatize the users to the problems and information available in a quick, easy, and minimal effort way (infographics), and mid level information presented in an entertaining yet informative way that requires minimal effort from the user to absorb (instructional animations).

Alongside the multitude of solutions provided by the system for excessive water use, to make the user feel more in control of the devices, themselves, and their behaviors, the system information will be customizable. This allows the user to decide a frequency of information updates, and the type of information provided that facilitates the best user-system interaction for their personal lifestyle preferences. The reasoning behind this is if the user is engaged with the system, and has the feeling that they are involved in the decision making process (rather than their actions being a product of it) they will have more incentive to stay engaged with the system over a longer period of time.

User-to-User Connectivity

As previously described, in complex and new situations, we as a people have the tendency to conform to those around us (Sustainable Consumption Roundtable, 2006). The aim here is to use this social pressure to facilitate reaching the desired outcome of lowered urban water consumption. The way this works is by letting users connect to other users in their social circle. Through the user interface (described in the following section), a person's water consumption behavior (what type of data and the amount being shared can be controlled by the user) is made available to those they are connected with.

The possibilities of this are for users to be able to share tips and stories on how they consume water, ask and answer questions about how to do certain things better, and enter challenges and mini-games based on who can save the most water. The first two facilitate the user's sense of responsibility, engagement, and capability, whereas the third possibility focuses heavily on the competitive side of users, a tactic which is widely used in education and health applications, e.g. Khan Academy and FitBit.

User interface

The designed system has two types of user interface. The first is a minimalistic interface superimposed directly onto each device. The aim behind this is to provide direct feedback that requires no effort on the side of the user. Each device—connected to the user designed (customized) system—displays the percentage of water consumed that day, as dictated by the personal limit or goal described in the previous section, and the amount consumed at that individual source that day.

The secondary user interface comes in the form of a smartphone application. From this platform can be accessed the information (text, infographics, and instructional animations), personal usage data, customization functions, and user-to-user connectivity functions—all as described above. From this platform, the user will be able to customize all the information and data related aspects of their product usage. This will also serve as the remote for the shut off valves on each of the faucet attachments.

Device: Measure, Feedback, and Change Water Behavior

A water consumption meter device that could enable the system described in the previous sections is yet unavailable in the consumer market. The smart water network requires the sensor to robustly measure volumetric water flow through it, even for trickle flows. It must be able to share data securely over a wireless network. Since it is not connected over a wired network, it must be able to power itself through a small hydroelectric generator within the sensor housing. The device has to be deployed on a variety of water outlets and must therefore have a universal adapter. Water meters with such system requirements exist in the form of AMI residential water meters, but they are either too bulky for deploying at every water outlet or too expensive to be offset by the value of potential water savings.

Water infrastructure generally has a very long lifespan (20-25 years). In order to implement a water meter in the infrastructure without having to wait for the next generation to replace the existing components of the system, the device should be able to attach onto the existing water infrastructure without requiring re-piping. It must therefore be small and modular for widespread deployment and able to attach to the head of most water outlet types. Since human interaction is a key determinant for the success of this system, numerous additional aesthetic and functional requirements are imposed on the design of the device. Its dimensions must match that of the water outlet such as a faucet to not seem bulky and unaesthetic, thus restricting it to a volume of roughly 1 cubic inch. It must not only be able to record water consumption behavior but also have a minimalistic indicator to provide immediate information about the current usage of water. Apart from using simple indicative information to promote healthy water consumption behaviors, the device could also actively control water consumption by restricting the flow through the water outlet. The user can program every device to reduce or minimise the water flow through outlets without reducing the water pressure, or even set shut-off limits.

As indicated in the information section, the collected data from each device can indicate particular areas or water outlets of the residence that have poor water performance, and provide strategies for users to improve their water consumption behavior and mitigate inefficiencies in the water infrastructure at the point of consumption.

Implementation

When it comes to implementing the intervention in society, a small plan of attack is needed. This involves convincing the government, and the general population of the use of the technology and sustainably supporting its widespread adoption. The Technology Acceptance Model (TAM) is used as a guideline in this plan, to ensure that all aspects of implementation are treated. TAM sheds light upon the importance of perceived usefulness, perceived ease of use, attitude towards using, behavioral intention to use and eventually, actual use of the system.

The design process focussed on Cape Town's socio-economic middle class as the main stakeholder. From the research, it can be concluded that the diffusion of water-saving innovations that don't need to be integrated in the pipeline system and carry investment costs can be stimulated by government subsidies. Thus it is important to convince the government of the added value of the innovation, in order to increase perceived usefulness (TAM). This means that firstly, a focus needs to be on the public consequences of the innovation, where—according to research—uniform spreading of imitative models and information is most effective. In order to achieve this, the product needs to be tested, and information needs to be gained on the effectiveness and impact of the product. After that, this information needs to be presented to the government in a clear way (imitative models and information, according to the research conducted.

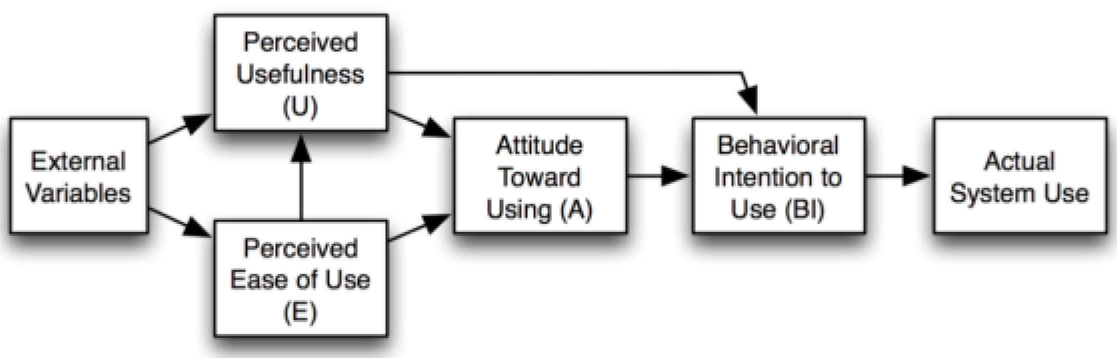


Figure 4: Technology Acceptance Model (Davis, Bagozzi & Warshaw, 1989)

According to the research, environmental performance (part of perceived usefulness, as stated in TAM), ease of use (which is also stated in TAM), saving of costs, compatibility with existing infrastructure, and investment costs are important in the diffusion of innovations. Environmental performance eventually depends on the user himself: does he or she decide to use less water?. Ease of use should be addressed by a system design that minimizes user effort in running the system and a simple and directed information interface. Cost savings could be achieved by reducing water consumption. The product is fully compatible with existing infrastructure since the sensor simply attaches to a water outlet without requiring any modification to the existing infrastructure.. Finally, the initial investment costs could be minimized by long-term, low-interest subscription plans and subsidy from the government.

Apart from showing the government the value of the innovation, the citizens of Cape Town themselves should be convinced to adopt the innovation, increasing the perceived usefulness of the product and showing the ease of use of the product (TAM). This will be done through spati0-temporal continuity between potential adopters and developers. The communication channels will focus on the individual's attitude (as found in the research, and also stated in TAM), perceived behavioral control (as found in the research, and also stated in TAM), and use motives like "green" values and saving costs. The innovativeness of the individual will be stimulated, as this was found to be an important factor in the to adoption of the innovation. In the end, this plan will increase the likelihood of the technology's widespread adoption.

Ethics

When designing this product, the ethics that are involved during implementation should be taken into account. Value sensitive design is a design-approach that strives to take ethics into account early in the design process. It accounts for the human values of privacy, ownership, autonomy, and trust (Friedman, Kahn Jr., & Borning, 2003). There are two main topics that deserve attention, being the end-to-end data connectivity in terms of privacy and the and the morality of the behavior-changing aspect of the product. In this chapter, the social impact of the technological design is considered, and the outcome should be taken into account when further designing this product.

First of all, the privacy of the consumer from two different perspectives should be of concern. Issues like intrusion, manipulation, misuse of property, and lessened autonomy may play a role (Marx, 1991). Privacy can be a key aspect of user experience when it comes to new technologies and online systems (Ackerman, 2005). The real-time two-way communication between meter, user, and utility is not a problem on its own, but can become a privacy-problem when shared with anyone apart from the user. The intelligent personal system monitors every water outlet and can thus track behavior of the consumer. Personal communication devices can be intercepted easily by e.g. scanners (Marx, 1991). This sensitive information can thus be misused if not stored securely. And although this might not even really be the case, consumers might in general feel uncomfortable about the fact that it is possible and they might be sharing their personal information with someone unknown. In addition, the product openly shares your information with other devices the user has chosen to be in touch with. The user can control what type of data and amount is shared and although it's the user's choice to be in touch with someone, peer pressure might play a role here. As a result, people might feel forced to connect with someone, leading to the feeling of privacy invasion. Thus, a balance needs to be found between privacy, and the customizability of the product, something customers also demand (Marx, 1991), and the user's privacy. In addition, a secure data storage must be provided with in order to secure privacy to the highest extent possible.

The second ethical consideration is regarding the right of a government or company to change someone's behavior. The consumption data is used to model the user's behavior and improve it in order to reduce water usage. However, how morally right is it to change someone's behavior? This is where the ethical discussions on autonomy and persuasive technology come in (IJsselsteijn, De Kort, Midden, Eggen, & Van Den Hoven, 2006).

Evaluation plan

The design process doesn't end at system implementation. Summative evaluation of the actual uptake of the designed solution and the assessment of its impact determines the efficacy of the creative design process and measures the system's performance against the functions and requirements dictated by the initial research and analysis. There are several critical features of an evaluation plan: it is collaboratively developed with stakeholders, it is adaptive to changing program priorities, and it addresses the net effect of the entire program and not just on the primary objective amongst others (Maguire, 2001). The international standard of organisation has the ISO 9241-210:2010 standard, which 'provides requirements and recommendations for human-centred design principles and activities throughout the life cycle of computer-based interactive systems', can be used to design an evaluation plan that is benchmarked against industry standards for evaluating 'human-centered design' (Earthy, Jones, & Bevan, 2012).

Describing the evaluation plan for the designed intervention plan is beyond the purview of this report, as this report only describes the design framework, and there is still more research, stakeholder analyses, and field study required to design the specific manifestation of the intervention system. Therefore this report will only briefly describe the key parameters for the evaluation plan. The first being consumer perception of the product and its need, and hence the distribution of the technology's adoption. The second could be the usage behavior of the product, this would include information about how the various connectivity, and social networking features, and what kind of feedback is most useful for users of the system. Finally, after the initial testing and tweaking of the system in the field, the system's performance on its primary objective of improving management and reducing water consumption of the user and the neighbourhood would be evaluated.

Conclusion

Within a year Cape Town's water supply may have already run dry. This crisis can be attributed to their high reliance on rainwater, a water infrastructure system that has changed little since the beginning of the 20th century, and the potential loss of nearly 30% of Cape Town's water distribution system. To lower the demand on the water infrastructure, this report outlined a "Bottom-Up" approach to address the water consumption management at its source. The designed technological intervention was directed at Cape Town's socio-economic middle class because of their position in class hierarchy, and political and economic influence. Designing the intervention for this group makes it available to the majority of Cape Town's water consumers.

To further this technological intervention, the implementation of this system should be kept under observation. As time passes and users interact more with the system, that user data can be used to further develop the design, based on user needs, to increase the efficiency and usability of the system design. Analyzing user data will show where people need the most help in lowering their water consumption. This can be used to develop new and more information strategies that focus on these specific household locations and appliances. As the system is used more and more it will show the developers where the focus of improvement needs to be placed. This technological implementation, although designed for mitigating the current crisis that has befallen Cape Town, is by no means limited to it. It's implementation in Cape Town would serve as a pilot for this system, and to shed light on any flaws in the design. Cape Town is by no means the only modern city facing a water crisis, and this technology can be implemented all over the world, in both water scarce, and water abundant environments to optimize household water consumption worldwide.

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Appendix A

Performance Objectives	Determinants		
Lower household water usage	Knowledge	Social Factors	Habits
Showering	- Health drawbacks of overshowering - How to effectively shower for appropriate frequency and time - Be knowledgable about water saving innovations (that don't impact the embodied experience of the user) (Changing.pdf)	- Not be dirty and smelly - Conform to social norms of water use in shower	- Be less resistant to having a short shower/reducing number of showers (because of importance to cleanliness and private relaxation) (Changing.pdf)
Dish Washing	- How to reuse water (from other sources) for dishes	- have clean surfaces and utensils to eat off of and with	- Not using fresh water for each item (handwash) - Not waiting for a full machine (dishwasher)
Cooking	- Proper amounts for cooking	N/A	- Washing each item with fresh water - overfilling pots
Toilet	- When not to flush - How to reduce the amount of water per flush	- not have a smelly and dirty bathroom/toilet	- Flushing small amounts of urine - Using flush to clean bowl
Gardening	- How to plant drought-resistant gardens (Changing.pdf) - Be knowledgable about water saving innovations (Changing.pdf) - Be knowledgable about DIY technological interventions (Changing.pdf) - Know how to reuse water (from different sources) in gardening	- Care less about what others think of your garden (e.g. lawn) (Changing.pdf) - Conform to social norms about garden water consumption.	- Excessive watering of plants
Laundry	- Laundry frequency/load - benefits of Eco settings	- Not have smelly clothes	- Not waiting for a full load - Not using water saving settings
Hygiene	- Necessary water amounts for proper hygiene - Be knowledgable about water saving innovations	- Not look like a dirty greasebag	- excessive use of tapwater (handwashing, toothbrushing, etc)
Tap Leakage	- Identify sources of tap leakage - Know what to do to fix a leaking tap, a broken pipe, or a wasteful appliance - Know how much water is wasted because of leaking taps	N/A	- Prolong fixing a broken tap

Figure 1: Intervention Mapping Matrix

Functional Requiremnets (What?)		Behaviors (How?)
Some GUI with which the user can interact with to gather information.		A smartphone and web app.
Personalized feedback on water consumption behavior.		Collects data on the household's water consumption (from each tap) and presents that data to the user. (like the fitbit app).
collect water usage data from multiple water outlets		Measurement device for water consumption from taps.
Information database and deliverance methods (text, video, blog, etc..)		Water consumption data stored under a personal profile that can be accessed through a home manager, smartphone, and web
Connect friend-group user data		Connect users via a smartphone application to share water consumption data and meritous water conservation behavior
Connect in-house user data		Smartphone application that allows the user to customize information and funtional apsects of the devices.
Have the system be customizable (information, reminders, limitations).		Circular shutoff valve that can cover the tap (percentage wise) when programmed to.
Direct and indirect costs of the product should be low enough to not discourage adoption, and preferably not exceed an actor's resource potential (Integrating Models.pdf)		Offers information in the form of text, info graphics, and short instructional animations.
Be able to regulate tap flow.		
Stimulate perceived behavioural control		
Stimuate attitude		

Figure 2: ATLAS Socio-Technical Design Model Functions and Requirements Table