



# Mental models of a water management system in a green building



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## ABSTRACT

This intergroup case study compared users' mental models with an expert design model of a water management system in a green building. The system incorporates a constructed wetland component and a rainwater collection pond that together recycle water for re-use in the building and its surroundings. The sample consisted of five building occupants and the cleaner (6 users) and two experts who were involved with the design of the water management system. Users' mental model descriptions and the experts' design model were derived from in-depth interviews combined with self-constructed (and verified) diagrams. Findings from the study suggest that there is considerable variability in the user mental models that could impact the efficient functioning of the water management system. Recommendations for improvements are discussed.

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## 1. Introduction

There is growing evidence from several scientific disciplines that human activities have resulted in severe degradation to multiple ecosystem services which now threaten human wellbeing in many parts of the world (Intergovernmental Panel on Climate Change, 2014). The most publicized impacts are referred to as climate change or global warming. Millions of people are now threatened by changing weather systems and the places we choose, or are forced, to live exacerbate the impacts of these natural phenomena. That these changes are due to anthropogenic causes is now beyond scientific dispute, indeed any residual dispute is mainly in the policy and not in the scientific arena (Fisher et al., 2013). One of the responses to climate change from the ergonomics community is green ergonomics. Green ergonomics focuses on the bi-directional relationships between natural and human systems in order to enable the wellbeing and effectiveness of human and natural systems (Thatcher, 2013). One of the aims of green ergonomics is to design low resource intensity systems that reduce the negative impact on the environment and where humans can benefit from these systems (Thatcher, 2013). South Africa is a water scarce country with an annual average rainfall of approximately

495 mm (United Nations Environment Program, 2010) and climate modelling suggesting that it is only likely to get drier (Intergovernmental Panel on Climate Change, 2014). Additionally, Johannesburg, the economic hub of the country, is already a net importer of water and the region is currently under considerable water stress. Due to a combination of increasing population, increased provision of access to potable water and sanitation services, together with large industrial and agricultural demand, water allocation currently sits in excess of 98% of available resources (United Nations Environment Program, 2010). Municipal mismanagement of water delivery networks and sewage treatment plants combined with a significant threat to water resources from the uncontrolled decant of acid mine drainage (Name and Sheridan, 2014) in the Witwatersrand region (also the centre of population mass, containing approximately 12.5 million inhabitants) places significant additional stress upon this already highly constrained resource. The water management system examined in this study is considered an environmentally-friendly system as it attempts to reduce resource consumption intensity, particularly when the constructed wetland (i.e. waste-water recycling) and rainwater collection components are taken into account.

Unfortunately there is a great deal of inconsistency in the literature on the meaning of the term 'mental model' which has been applied in various fields (and even within the same field) to mean different things (Staggers and Norcio, 1993; Revell and Stanton, 2012; Richardson and Ball, 2009; Wilson and Rutherford,

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1989). It is generally agreed that mental models are internal, mental representations of the external, physical world. However, authors disagree on the source, content, perspective, and function of such models (Revell and Stanton, 2012; Wilson and Rutherford, 1989). This situation is also not assisted by a proliferation of terms to describe similar and related phenomena including mental images, internal representations, situation models, and mental simulation (Richardson and Ball, 2009). Reviews of the mental model literature have provided very useful contextualisations and frameworks for understanding the various interpretations of internal mental representations (see Richardson and Ball, 2009 and Wilson and Rutherford, 1989 for comprehensive reviews). A full discussion of these nuances is beyond the scope of this paper, however. Bearing in mind the inconsistent applied meaning of mental models, in this paper we specifically look at the sources and function of relevant internal representations to frame the study and to enable commensurability.

Similarly to Revell and Stanton (2014), this study uses Norman's (1988) distinctions between a design model, a user's model, and the system image as the source of the internal representation on which comparisons will be made. The system image describes the way in which the system presents itself to the user. This would include the system interface as well as manuals, documentation, online assistance, instructions, and formal training. In this study the system image is primarily operationalised as the visual transparency of the system and the availability of the Building User Guide which explains the functioning of the water management system. A design model is the conceptual model that the designer has about the underlying features and functionality of the particular system that they designed. The conceptual model is obtained from the two experts who designed the water management system for this building (referred to as the experts' design model). The user's model is the mental model that the user has of how the system works, obtained through prior knowledge and interaction with the system image (referred to as the user's mental model in this study). In comparing the experts' design model to the users' mental model of the system it is useful to bear in mind Richardson and Ball's (2009) observation that mental models are internal representations that are held in working memory whereas conceptual models are considered to be extractions from long term memory. Obviously, in problem-solving circumstances there would be some interplay between a user's conceptual model extracted from long term memory for active manipulation of the user's mental model in working memory. In this study we examine the similarities and differences between the experts' design model and the users' mental model of a specific 'device' (i.e. the water management system).

In understanding the function of the system, this study uses Kieras and Bovair's (1984) device model. The 'device' under consideration in this study is the water management system in a green building. Kieras and Bovair (1984) describe a device model as a user's mental model of how a device works, incorporating the different components of the device and the interrelationships between these components. In practice, it is suggested that users' device models shape behaviours and actions in carrying out tasks with a system (Moray, 1990), they facilitate problem-diagnoses and problem-solving through mentally representing and manipulating relationships between components (Bainbridge, 1992), and ultimately determine the user's behaviour and performance with the system (Payne, 1991). However, device models are often characterised as inaccurate, incomplete, and unstable (Besnard et al., 2004; Norman, 1988; Sax and Clack, 2015; Thatcher and Greyling, 1998). It is generally considered that accurate device models enhance the individual's interaction with the system or device and can assist in trouble-shooting when the system behaves unusually. However, Kempton (1986) noted that there were also times when individuals

with inaccurate or incomplete mental models actually had more energy efficient behaviour when interacting with a home heating system than individuals with more accurate mental models.

Investigations of mental models have been undertaken in a wide variety of areas including transportation (Weyman et al., 2005), the military (Rafferty and Walker, 2010), domestic appliances (Sauer and Wastell, 2009), the internet (Thatcher and Greyling, 1998), complex process control environments (Besnard et al., 2004), and to promote and encourage sustainable behaviour (Lockton et al., 2010; Pampel et al., 2015; Revell and Stanton, 2014) amongst many others. No previous studies could be found that have examined users' mental models of a water management system, although there are a limited number of studies on related water systems. Kolkman et al. (2005) discussed the value of user mental models in the design of a storm surge barrier, Mathevet et al. (2011) looked at shared mental models of general water management in the Camargue Biosphere Reserve, Stone-Jovicich et al. (2011) conducted a similar study in the Crocodile River catchment area, and Owen et al. (1999) examined mental models of customers' perceptions of drinking water supply and quality. A study with the closest similarity would be Sax and Clack (2015) who examined mental models of hand hygiene behaviour. However, these water management systems are quite different to what we might find in a single building to treat and recycle water.

Theoretically, for effective use of a device or system there should be good alignment between the users' mental models and the experts' design model. Previous studies suggest that more complete and accurate mental models predict better problem-solving strategies (Besnard et al., 2004; Kim, 2012; Staggers and Norcio, 1993), fewer errors (Staggers and Norcio, 1993) and more efficient use of a system (Balijepally et al., 2012; Sax and Clack, 2015; Staggers and Norcio, 1993; Zhang, 2013). Of particular importance in the context of green ergonomics is the efficient use of a system or 'device' that reduces wasteful expenditure of scarce resources. A small number of studies have suggested that a better functional match will lead to more resource efficient behaviour for energy efficiency (Kempton, 1986; Revell and Stanton, 2014), re-fuelling error reduction (Adams and David, 2007), wildfire management techniques (Zaksek and Arvai, 2004), and fuel-efficient driving behaviour (McIlroy and Stanton, 2015; Pampel et al., 2015).

Hancock et al. (2009) argue that single case studies are increasingly important in understanding and influencing the design of human-technology systems through emphasising individual differences. Dekker and Nyce (2015) even suggest that quantitative methods create fantasy numerics that have no ontological meaning. Instead, Hancock and Szalma (2004) emphasise the importance of qualitative methods in offering unique insights into humans' interactions with technology. In this study we compare the expert design models of a small sample of designers with the user mental models of a small sample of users who interact with the water management system. Our approach closely follows that of Revell and Stanton (2014), except in this instance the users are compared to the experts as there are no existing theories on which to compare. The primary research aim is to compare the occupant's user mental models of the water management system to the experts' design model. A closer match assumes a more accurate and complete mental model for better problem-solving if the system is not functioning properly and within the context of sustainability, more efficient water resource use.

## 2. Method

### 2.1. Participants

All six employees who worked in the green office building

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