KES Transactions on Sustainable Design and Manufacturing I
Sustainable Design and Manufacturing 2014 : pp.67-78 : Paper sdm14-038

Exploring Sustainable Design Using Image Schemas

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Abstract: Sustainable design aims to minimise the impact of new product development by considering the whole product life-cycle, including product use. Sustainable design strategies encompass selection of materials and optimisation of production techniques, material use, distribution system and the product lifetime. Usability is an important aspect of sustainable design. Users' behaviour, in particular, plays a very important role because if a product fails to accommodate users' preferences, attitudes, habits and routines, it is likely to be discarded before the end of its life. This paper reports a study that uses image schemas as a means of exploring sustainable design. Image schema is a recurring pattern within the human cognitive system that structures the way people understand the world. An experiment was conducted to identify users' behaviour in terms of interactions with a product. The experiment involved forty-two users and another individual who is experienced in the use of the product and was used as a reference point for the designer intent. The contribution of this paper is the developed approach based on image schemas for capturing interactions, identifying potential design flaws and exploring usability issues within the concept of sustainable design.

1. Introduction

A significant proportion of the environmental impact of a product can be attributed to its use [1, 2]. This impact is sometimes caused by the undesirable behaviour of users [2, 3]. Behaviour in this context encompasses personal values, attitudes, preferences, beliefs, cultural settings, habits and routines [4]. Human-centred design, a concept that puts users at the centre of the design process, can help detect undesirable behaviour. Leveraging users' behaviour into design can potentially improve usability and extend the life of the product [2]. When a product is designed to influence or challenge users' stereotypical behaviour, users tend to resolve the conflict by 'trial and error' in an attempt to figure out how it works [5]. There are cases when the designer's intent is not translated correctly into suitable design features. This leads to incorrect interpretations of these features while users attempt to use the product [6]. This may lead to users' apathy towards the use of the product.

Several techniques are available to influence the user's behaviour through product design. This includes scripting [7], affordance [8], human-centred eco-design [2], eco-feedback [9], and design with intent (DWI) [10]. These approaches demonstrate that sustainable design can be achieved if the user's behaviour is put into consideration during design. Recently, image schemas have been advocated in the area of human-centred design as a means of studying intuitive interaction [11]. Image schema is a recurring structure that establishes patterns of understanding of the world [12]. This recurring pattern facilitates the transfer of knowledge acquired in one domain to a new domain.

Using image schema theory, this paper explores design for sustainability from a usability perspective. The conducted experiment aims to identify usability problems using 'think aloud' protocols and direct observation of participants during interaction.

The paper is organised as follows. Section 2 reviews the literature related to techniques that influence behaviour through product design. It also introduces image schema theory. Section 3 outlines the experimental design of the study. Results and discussions are presented in Section 4. Finally, Section 5 concludes by highlighting the implication of the findings for sustainable product design.

2. Background study

The eco-design strategy wheel, also called the life-cycle design strategy wheel, aims at minimising the environmental impact of new product development [13]. Specifically, the sixth strategy for reducing the impact on the environment is the optimisation of the initial lifetime with focus on product usability. Several strategies have been developed to study users' behaviour in order to facilitate the usability of the product and improve its sustainability.

Wever et al. [2] present a methodology for applying different sustainable strategies using a human-centred design approach. Their methodology is developed using functional matching, eco-feedback and scripting sustainable strategies. The methodology was used to redesign a previous energy meter. The experimental comparison between the previous product and the redesign showed that users operate the new product four times faster than the previous design. Moreover, users depended less on the manual and made fewer errors during product use.

Vollink and Meertens [9] present two studies that apply the use of eco-feedback to influence users' behaviour towards sustainable use. Eco-feedback is a strategy that informs the users of the impact of their action in order to persuade them to modify their behaviour. The authors assessed the impact of the feedback and goal setting on energy and water usage of a household. The studies concluded that feedback on the users' action influenced the users to modify their consumption behaviour.

Lockton et al. [10] applied the concept of design with intent (DWI) to influence users' behaviour in sustainable product design. These toolkits are: architectural, error proofing, persuasive, visual, cognitive, and security. The concept was highlighted using an everyday human technology interaction problem – users forgetting their cards in an ATM machine. The study concluded that the method has the potential for development and application as part of a user-centred design process.

It is evident from the above studies that integrating users' behaviour in sustainable design can influence the usability of the product. This research adds another dimension by using the concept of image schemas as a means of exploring sustainable design.

2.1 Image Schema

The term image schema refers to a mental pattern that structures human experiences with the world [12]. These experiences emanate from our bodily interaction with the physical world. Image schemas provide a means for representing these various experiences. This representation facilitates the transfer of knowledge acquired in one domain to a new domain via metaphoric extensions [14]. In other words, image schema can be used as a source domain to understand abstract concepts [15]. For example, the *up–down* image schema is used to provide an understanding of where more is up in the domain of quantity.

Image schema has been found to be useful in revealing the mental model of the users via the think aloud protocol [11]. A mental model in this context is what the user develops to explain the operation of the system. A good understanding of the mental model of the user can help identify usability problems during interaction. As highlighted by Hurtienne [16], "their universal character, their course of life extremely frequent encoding in and retrieval from memory and their subconscious processing makes them interesting for using them as pattern for designing user interface. Therefore, design of product features with the knowledge of image schemas increases the potential of the usability of the product. *Up–down, near–far, big–small,* and *back–front* are commonly used image schemas.

This study uses the concept of image schemas as a means of exploring sustainable design. It aims to evaluate the usability of the product using effectiveness, efficiency and satisfaction indicators of the quality of the user interaction.

3. Study design and methods

This study was designed to explore sustainable design from a usability perspective. The conducted experiment aims to identify usability problems experienced by the participants during interaction. The theory of image schema has been proven to reveal the mental model of the user, which can also be used to identify usability problems in the design during interaction.

3.1 Object

The experiment was conducted using a real product. The product chosen for the study is an alarm clock with six features – alarm, hour, minutes, time, snooze, and alarm switch – and a display. Figure 1 shows the product during the interaction of one of the participants.

Figure 1: Participant interacting with the alarm clock

3.2 Participants

Pre-screening questionnaires were used in recruiting participants from a pool of volunteers. Forty-two participants were recruited for the study – mainly from Cardiff University and Cardiff Metropolitan University. The breakdown shows 13 females, age range from 22 to 43 years (Mean = 30.54, SD = 6.05), and 29 males, age range from 22 to 45 years (Mean = 30.31, SD = 5.07). For the purpose of the analysis, the participants were split into two groups comprising those aged 20–30 years and those 31 and above. These participants represent the users in this study. None of the users had previously encountered the product used in the study. A participant who is experienced in the use of the product was also recruited. This participant was used as a reference point for the designer intent. The user study was given approval by the ethical committee of the Cardiff University School of Engineering.

3.3 Apparatus

The experiment took place in the user-centred laboratory of Cardiff Metropolitan University. Four digital cameras were employed to record the activity. One more camera from the eye-tracking glasses captured the task and scan path of the user. The scan path is the recorded path of the eyes when scanning and analysing any visual information. The Observer XT software was used to analyse the data – it is software for capturing, analysing and presenting behavioural data. Table 1 shows the variables and means of measurement used in the study.

Table 1: Variables and means of measurement in the study

s/n	Variables measured	Means of measurement
1	Task duration	Observer software
2	Number of interactions	Direct observation, observer software
3	Success rate	Observer software
4	Image schemas used	Direct observation, think aloud protocol
5	Cognitive rating	Structured questionnaire
5	Satisfaction rating	Structured questionnaire

3.3 Task

The participants were given a task that involves three subtasks. The three subtasks extracted from the product manual are listed below.

(1) Activate the alarm mode
(2) Set the hour mark
(3) Set the minute mark

The participants were asked to set the alarm time to 8.30 a.m. Prior to the task, the clock was in normal mode with the time set to 3.00 a.m. The participants were timed and video-recorded while completing the task. They were encouraged to verbalise their thoughts while interacting with the product.

3.4 Experimental procedure

The experimental procedure is divided into two parts. In the first part, the forty-two participants were observed while completing the task. The time to complete the task, number of interactions (both successful and failed attempts), success rate, and image schemas used for the completion of the task were recorded at a subtask level. The image schemas used for the completion of the task were identified through direct observation and think aloud protocol. Table 2 shows image schemas extracted from the comments made during the study by one of the participants.

Table 2: Examples of image schemas extracted

S/N	Sample quotes	Image schemas
1	“The display has been blinking and I try to press the alarm button to take me to the alarm mode, it seems not to be working. Maybe there is something I am not doing right.”	*Centre–periphery, path, compulsion, content, container and attraction*
2	“Oh, I got it. You have to hold the alarm key and press the hour key to increase the hour.”	*Container, near–far, bright–dark, constrain remover*
3	“I looked at the command, I see the controller on top. I tried to press the alarm, nothing happens. Maybe I will have to press the hour and the alarm button to see what happens.”	*Up–down, compulsion, container, near–far, content, constrain remover, centre–periphery*
4	“Aha, I got the trick, that symbol on the right side of the display is showing the pm mode.”	*Match, container, bright–dark, attraction, content*

The methodology used for transcribing the utterances from a user think aloud protocol into image schema instances is explained below.

”The display has been blinking and I try to press the alarm button to take me to the alarm mode.” The *attraction, centre–periphery, compulsion, container, content and path* image schemas can be instantiated from the utterance. The *compulsion* image schema is a *force* image schema that involves an external force physically or metaphorically causing some passive entity to move. The action word “press” instantiates the *compulsion* image schema. The *path* image schema consists of a source, goal and series of locations that link the source to the goal. “Take me to” instantiates the path from the current position to the goal (alarm position). The *attraction* image schema is a force image schema in which an object exerts a force on another object, either physically or metaphorically, to pull it to itself, mostly acting from a distance. The blinking display instantiates the *attraction* image schema. The *centre–periphery* consists of an entity, a centre and a periphery. The screen instantiates the centre while the button instantiates the periphery. [12, 17].

The observed path, as well as the features used to complete the task, was noted. Figure 2 shows the observed interaction path of one of the participants for the completion of the task. Thereafter, a structured questionnaire containing satisfaction and cognitive rating was completed.

In the second part, the procedure is repeated for the designer. The time taken, numbers of interactions, success rate, and the image schemas used were noted at the subtask level. The observed path, as well as the image schemas used for the completion of the task, was also noted. Figure 3 shows the observed interaction path for the designer.

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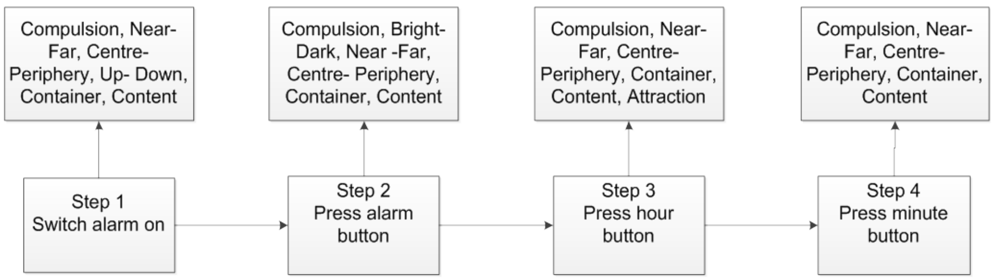

Figure 2: Interaction path for a participant

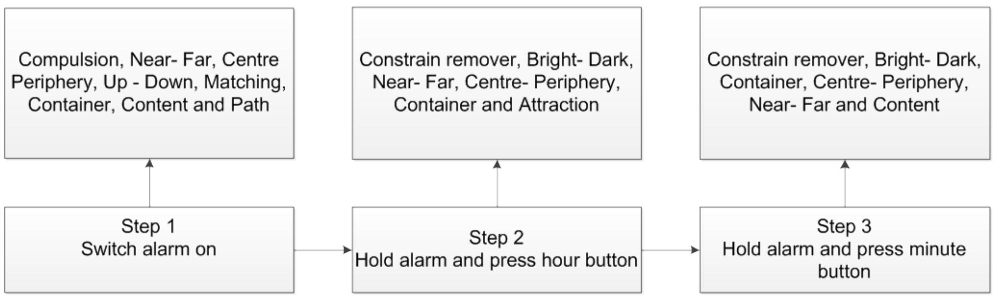

Figure 3: Interaction path for the designer

3.4 Data analysis

The data were processed using Observer XT. The number of interactions (both successful and failed attempts), the time taken, and the image schemas used for the completion of the task were analysed for the users and the designer for each subtask.

4. Results and discussion

The time taken, success rate, and the number of interactions for each of the subtasks are displayed in Table 3. The success rate was calculated from the number of interactions. It was computed as successful interaction divided by the total number of interactions. Satisfaction and cognitive rating results are shown in Table 4.

Table 3: Result for subtasks

	Subtask 1		Subtask 2		Subtask 3	
	Users	Designer	Users	Designer	Users	Designer
Average task duration (seconds)	2.44	1.04	84.90	6.12	12.50	1.36
Average number of interactions	1.0	1.0	12.90	1.00	1.20	1.0
Average success rate (percentage)	100	100	15	100	91	100

Table 4: Cognitive and satisfaction rating of the participants

Satisfaction rating	Participants	Cognitive rating	Participants
Highly dissatisfied	22	High cognitive effort	24
Average	9	Average	7
Highly satisfied	11	Low cognitive effort	11

In the first analysis, the interaction path was observed for the user and the designer for the completion of the task. The analysis reveals that the users preferred a four-step approach (1–2–3–4) from the recorded path of the interaction while the designer followed three steps (1-2'-3') for the task completion. The difference in the interaction paths is shown in Figure 4.

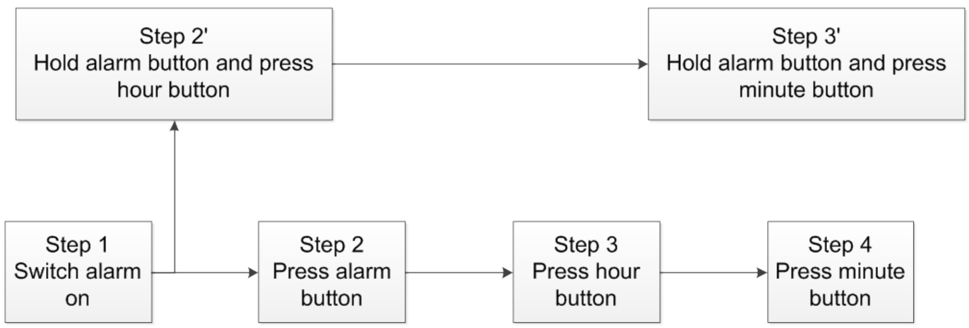

Figure 4: Interaction path for the designer and the user

Further analysis of subtask 1 shows that 40 of the 42 users successfully completed the subtask. It also reveals a match between the image schemas used by the designer and the users. The number of interactions and success rate was the same for both the designer and the users. The only difference is the time spent on the task for the users, which is more than twice that for the designer's.

Subtask 2 was problematic for the majority of the users in terms of the impact of usability attributes. The analysis shows that 19 of the 42 users successfully completed the subtask. The 19 participants that completed the task had attempted more than one interaction before the task was successful. There appears to be a sharp divergence in interpretation of the features and how they function in this subtask. A close look at the image schemas employed for the completion of the task reveals that participants prefer a single button press (*compulsion*) compared to a combination of buttons (*constrain remover*) to complete the task. This can be seen in Figure 4 where the single key press (*compulsion)* introduces an additional step for the completion of the task, which seems comfortable to a majority of the participants. This aspect of the subtask had an adverse effect on the usability of the product. This can be seen from the large difference between the users' and the designer's task completion times (User Mean = 82.95, SD = 57.70, Designer = 6.12) in Figure 5. A significant difference between the users and designer was also noticed in the number of interactions (User Mean = 12.74, SD = 7.6, Designer = 1.00) and success rate (User Mean = 15.00, SD = 14.55, Designer = 100).

In terms of the users, the time to complete the task for male and female participants was: Mean time = 23.10, SD = 21.00 and Mean time = 22.51, SD = 29.70, respectively. No significant differences were noticed in the performance of the male and female participants, $t(40) = 0.074$, $p < 1$. Similarly, the t-test revealed no significant effect on the performance of the age groups, $t(40) = 1.075$, $p < 1$. The time to complete the task for participants in age groups 20–30 and 31 and above was: Mean time = 18.81, SD = 21.45 and Mean time = 26.64, SD = 25.40 respectively. In terms of the satisfaction rating, more than half of the participants were highly dissatisfied with the use of the product. Their reasons for the dissatisfaction are connected to the user's preferences during interaction. The cognitive rating also reveals that 24 out of the 42 participants in the study rated the product as highly challenging to use.

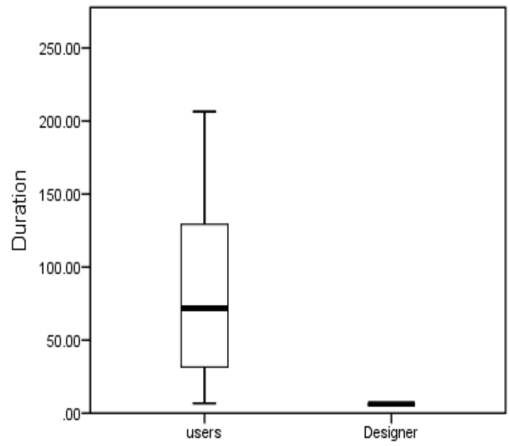

Figure 5: Boxplot of task duration of users and designer

5. Conclusion

The study uses the eco-design strategy wheel as a means of reducing the impact on the environment with emphasis on the usability of the product. This is the impact a design solution has on the usability of the product. This impact was mainly explored on the basis of the users' preferences shown while interacting with the product.

The goal of the study was to use image schemas as a means of exploring sustainable design from a usability perspective. Image schemas were used in the study to reveal users' behaviour in terms of preferences via the think aloud protocol and direct observation. Specifically, it was found that users' preferred interaction path for the completion of the task could be significantly different from that of the designer. The analysis of the mental models via the think aloud protocol shows that the users' preferred option of *compulsion* against the *constrain remover* image schema substantially affected the usability of the product. It was also observed that the majority of the users expressed some level of frustration when they failed to complete the task after multiple failed attempts. Those that successfully completed the task affirmed that it was based on 'trial and error'.

Overall, the users had a negative attitude to the use of the product. If this attitude is sustained, the chances are that the users will discontinue the use of the product. This will invariably have an impact on the initial life of the product. In a society that is consumption dependent, this will have an overall effect on the environment.

The methodology adopted in this study has the potential to build a strong product user relationship if the observed behaviour is accommodated into the design of the product. This in turn could optimise the product life cycle.

Acknowledgement

This research was supported by the Tertiary Education Trust fund (TETFUND) in Nigeria. The authors would also like to acknowledge the support of the Advance Sustainable Manufacturing Technologies (ASTUTE) project, which is part funded from the EU's European Regional Development Fund through the Welsh European Funding Office.

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