Evaluating novel technologies through the notion of affording situations

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SUMMARY

User interactions with novel technologies have been explored with different approaches. Traditional approaches seem to focus on the abstract form of the artefact. This paper introduces the notion of affording situations as a context-based evaluation approach.

KEYWORDS

Affordance, interaction design, context, situation, constraints, TUI

Introduction

Novel technologies exhibit the potential to enhance human daily life in several domains. However, there is an unanswered question about how people interpret and interact with new forms of technology. According to ISO 9241-210:2019, those activities and tasks occur in, and are part of, a context of use. Thus, ISO standards advise deploying new artefacts in a context of use to evaluate them.

We introduce a notion of affording situations that specifies a context of use on the notion of constraints. We define an affording situation as a set of relational constraints that define user interaction with an artefact in an environment to achieve an outcome that fulfils a purpose. This is derived from Gibson's (1979) concept of affordance which describes how actions can be constrained by the purposeful relationship between an agent and its environment. For an affording situation, the primary sources of constraints are the artefact itself, the user, the environment, and the purpose. This complies with the definition of context of use in ISO 9241-210:2019. It should be noted that the affording situation term has been first used by Baber et al. (2017), and has been elaborated further in the Embodying Design book by Baber (2022).

In this paper, we apply the concept of affording situations to the evaluation of Tangible User Interfaces (TUI) which can change their shape in response to user activity or which allow users to manipulate digital information using physical representations. Previous evaluations of TUI (Kwak et al., 2014; Tiab & Hornbæk, 2016) can be criticised for limited consideration of context of use. Specifically, these papers seem to assume that an 'affordance' is a property of the designed artefact rather than the richer definition that Gibson proposed, characterised by our concept of affording situations. We demonstrate how responses to TUI can be affected by the affording situation.

Method

A within-subject design is conducted with two conditions representing different contexts of use:

- Condition 1: Artefact Only: participants were asked to interact with an artefact.
- Condition 2: Affording Situation: participants were asked to interact with an artefact in an environment to achieve an outcome that fulfils a purpose.

For this study, we designed, and 3D printed an artefact composed of three different parts that change its shape illustrated in Fig. 1. The designed artefact can act as a multifunctional controller. For example, rotating the whole artefact in (Fig.1,b1) could turn the controlled object on or off; rotating the upper casing (Fig.1,b2) could be used to switch modes of the controlled object; rotating Part A or the dial in (Fig.1,b3) could increase or decrease a specific parameter, e.g., volume, intensity etc. Thus, our tangible controller enables users to rotate, press, and flip elements.

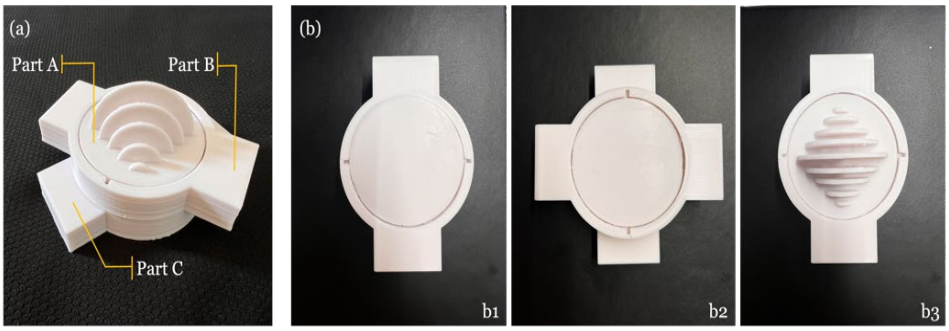

Figure 1: The designed artefact for the study: (a) The artefact's three main components: Part A, B, and C. (b) The artefact's three main forms

In the artifact-only condition, participants were asked to interact with the artefact without giving information on the purpose of the artefact nor where it is deployed. In the Affording Situation condition, participants were asked to interact with the artefact to control the light of a desk lamp in front of them. The experiment followed a within-subject design. To mitigate order effects, we started with the artifact-only condition for half of the participants and the other half started with the affording situation condition.

To understand the activities users performed with the artefact, this study conducted a microanalysis of user interactions in two parts:

1. Analysis of physical manipulation of the artefact

The occurrence of actions in both conditions was measured by analysing the video recordings of the participants' physical interactions with the controller using ELAN software (ELAN, 2023), a tool for transcribing multimodal activity. Any physical action had been analysed in terms of the action type (What), action location (Where), and the hand morphology for the action (How). First, each physical action has been annotated with the action type (What), and the location (Where). Table 1 demonstrates some examples of the action annotations. Secondly, the GRASP Taxonomy of Human Grasp Types proposed by Feix et al. (2016) was used to analyse and annotate the user's hand morphology during these physical actions (How). Table 1 provides examples of the classification of actions in terms of movement, e.g., flip, lift, rotate, grasp type, e.g., power or precision grasp, and force, e.g., press.

2. Analysis of user experience:

User experience of the controller was measured using the User Experience Questionnaire (UEQ) (Laugwitz et al., 2008). UEQ allow participants to evaluate the artefact in terms of attractiveness, and pragmatic and hedonic quality aspects by ranking 26 items using the seven-stage scale. In addition, participants were interviewed to allow them to describe their interpretation of the artefact and justify their actions.

Table 1: Annotation of the most common physical actions performed by participants.

Action annotation	Meaning	Example
Flip A to D	Flip part A from flat side to dome side	
Lift W	Lift the whole artefact from the table slightly	
Press Af	Press once or twice on the flat side of part A with one finger or more	
Rotate A	Rotate the dome in part A, using pinch grasp	
Rotate B CCW	Rotate part B in an anti-clockwise direction while Part C remained fixed	
Rotate B CW	Rotate part B clockwise while Part C remained fixed	

Subjects

Six participants aged between 22-34 years voluntarily agreed to participate in this study. They were recruited through the first author's personal social network. All participants are graduate students, and three are PhD students. They all had normal or corrected vision. All participants are right-handed and did not report any hand or arm injuries.

Apparatus

In both conditions, a triple-lens camera with 12 megapixels on an iPhone 13 Pro was used to record video of the participant's hands and their interaction with the artefact. The camera was positioned above the artefact using a mobile-phone tripod. The recording only captured the artefact and participants hands. Participants were made aware of the recording and its analysis was explained to them prior to them completing the informed consent form.

Task

In both conditions, participants were asked to interact with the three main different forms of the artefact. This is followed by a semi-structured interview to describe their interpretation of the artefact and justify their actions. After that, participants are asked to evaluate the artefact through completing the User Experience Questionnaire (UEQ), to gain insight into their perceived experiences.

Procedure

Ethical approval for the experiment was provided by University of Birmingham. After briefing the participants about the experiment, we asked them to sign the consent form. Participants then sat at a table which held the artefact with a camera installed above it. In both conditions, the artefact was presented to participants in three forms. In the first form, the artefact was in its closed state, with part A being on the flat side (Fig.1,b1). In the second form, the artefact was open, with part A being on the flat side (Fig.1,b2). In the third form, the artefact was closed with Part A on the dome side (Fig.1,b3).

In the Artifact-only condition, participants were asked to interact with the artefact in each of these three forms without knowing the artefact's purpose or environment. We asked them "How can you use it in this form? Could you please try using it?". In the Affording Situation condition, participants were told that the artefact was intended to be used for controlling light features on a table lamp. Then, we asked them to use the controller in the three different forms. The controller was not functioning at the time of the experiment and participants were aware of this.

In both conditions, participants had to fill out the User Experience Questionnaire (UEQ) after interacting with the artefact in its three different forms. At the end of the experiment, we conducted a short semi-structured interview and asked for comments about their choice of actions.

Data Preparation

The videos of the participants were analysed using ELAN to calculate the total number of actions as well as the total number of different actions. Annotating each action followed the approach outlined in Table 1. We classified the unique actions into six main categories: Assembling, Flipping, Pressing, Rotating, Positioning, and Others.

We calculated the ratio of each unique action to total actions in each condition. Statistical analysis was conducted in R Studio with $\alpha=0.05$. The ratio data are assumed to follow a normal distribution according to the Shapiro–Wilk test results ($p=0.3856$). Hence, a parametric statistical test was performed.

Participants' responses to the UEQ were used to evaluate the controller in terms of attractiveness, and pragmatic and hedonic quality aspects. Shapiro–Wilk test results ($p=0.2563$, $p=0.2506$, $p=0.9236$) for attractiveness, pragmatic, and hedonic quality data, respectively, revealed that these data could be assumed to follow a normal distribution. Thus, parametric statistics were performed.

Results

Physical Interaction with the artefact

Participants performed forty-two unique actions across both conditions. Of these, thirty-eight actions appeared in condition 1 and twenty-five actions in condition 2. Participants performed these actions repeatedly, so the ratio of unique actions to total actions was calculated. The results show the significant effect of the context of use on the ratio; $t(5)= -2.9588$, p-value = 0.03156.

Participants choice of actions differ between condition 1 and condition 2, Fig2. The average occurrence of pressing actions in the Affording Situation condition (2.37) was almost 3 times more than their occurrence in the Artifact-only condition (0.75). Conversely, assembling actions were used approximately 7 times more in the Artifact-only condition (0.572) than in the Affording Situation condition (0.083). The Disassemble B-AC action was the most frequent action in the assembling category and was performed a total of 14 times in the Artifact-only condition by half of the participants while no one performed it in the Affording Situation condition.

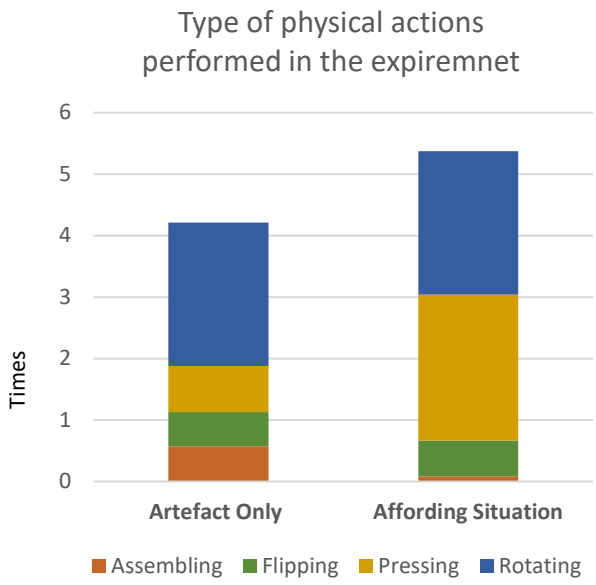

Figure 2: Distribution of commonly performed actions.

To confirm whether participants were more likely to perform a specific action in one condition than the other, we subtracted the occurrence of the action in the Artefact Only condition from its occurrence in the Affording Situation condition. The result of the six most common actions performed by participants showed that participants performed more of the Press Af, Rotate B CW, and Rotate A actions in the Affording Situation condition, while they performed more of the Rotate B CCW, Flip A to D, and Lift W actions in the Artefact Only condition, fig.3.

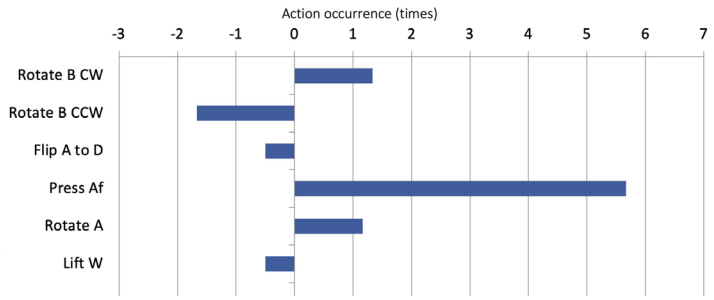

Figure 3: The difference between action occurrences in the two conditions shows the likelihood of performing a specific action in the Affording Situation condition (positive values) or the Artefact Only condition (negative values).

Statistical analysis of the user's hand morphology revealed that there are no significant differences between the opposition force direction or the users' grasp types used in the two conditions.

User perception and interpretation of the artefact

UEQ was used to evaluate the perceived user experience regarding the artefact's attractiveness, and pragmatic and hedonic quality aspects. We conducted paired t-tests for each scale to explore the effects of context of use on the participants' evaluation of the artefact. All significance levels were set to $\alpha = 0.05$.

The attractiveness scale is a pure valence dimension, and it measures participants' overall impression of the artefact. There was a significant difference between the attractiveness rating for the Artefact Only (M=0.89, SD=1.34) and the Affording Situation condition (M=1.42, SD= 1.19) conditions: t(5) = -2.9284, p-value = 0.03269. In addition, we found a significant main effect of context of use on the evaluations of the hedonic quality aspect of the artefact, which is represented by the Stimulation and Novelty scales: t(5) = -2.9957, p-value = 0.03025. In terms of the pragmatic quality aspects of the artefact, we did not find a significant main effect of context of use: t(5)= -1.3242, p-value = 0.2427. However, the rating of the pragmatic quality aspects in the Artefact Only condition (M=0.36, SD= 0.96) increased in the Affording Situation condition (M=0.89, SD= 1.44), Figure 4.

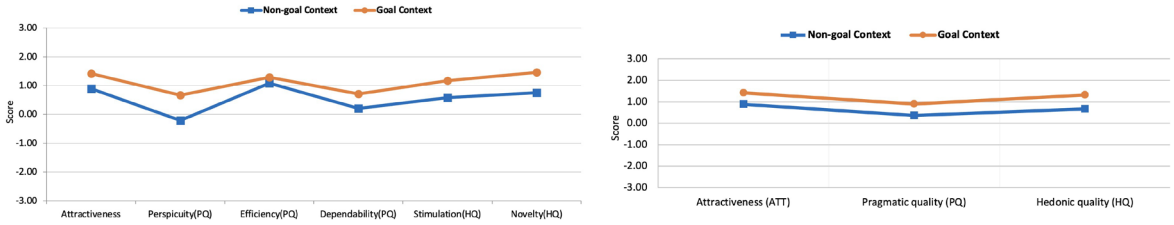

Figure 4: Diagrams from the UEQ revealing the mean values of (left) each of the UEQ scales and (right) the scales grouped into attractiveness, and pragmatic and hedonic quality aspects.

The qualitative results suggest differences in user's perception toward the artefact in the two contexts of use. One of the participants did not touch the dome in the Affording Situation condition because he associated it with a warning message about an increase in the lamp temperature "Do not touch it, it is hot". When we asked him whether he was associating the dome with a warning in the Artefact Only context, he responded in the negative. The dome made another participant perform a flipping action on Part A in the Artefact Only context, as he thought the half-circle shape would move in such a way as to complete the circular shape. However, the same participant slid the dome with a finger to change the illumination level in the Affording Situation condition because he associated it with sliding a circular controller on a lamp.

Discussion and limitation

The results show a significant difference in actions performed in the two conditions. Participants performed more unique actions when they are exposed to the artefact constraints only (condition 1) but tend to be more consistent in their interaction in the defined affording situation (Affording Situation, condition 2). The lower frequency of different actions in the Affording Situation condition suggests that people are more focused on their choice when they have a clear goal they want to achieve and have a mental model of how they would achieve it. In terms of the shape of the hand used in the physical actions people perform, the results indicate that the physical dimensions of the artefact (which was the same in both condition) seem to have a greater impact than purpose and environment. We conclude that the artefact structure allows types of grasps that allow types of actions that support the artefact's purpose.

The findings also reveal the significant effect of defining affording situations on evaluations of the attractiveness and hedonic quality aspects of the technology. Although participants evaluate the same artefact, they seem to rate it more highly in the affording situation. The result does not reveal a difference in the rating of the pragmatic quality aspects, although the explanation for this is not clear. This might relate to the physical structure of the artefact which, as we saw in the analysis of morphology, did not lead to appreciable differences between conditions. However, participants'

comments suggest that the affording situation affected the interpretation of the artefact, e.g., one participant perceived the dome shape as a warning message in the Affording Situation condition but not in the Artefact Only condition.

The findings demonstrate the importance of the context of use in evaluation. Applying the notion of affording situations and considering the four sources of constraints would result in consensus in user interpretations and interactions with that new technology. Thus, valuable insights can be derived to formulate design guidelines that help designers create less error-prone interfaces, resulting in increasing usability features and contributing to a better experience. Evaluating approaches that neglect the situation might lead to suggesting design practices that are true for some situations but not all. This can be seen in the work of (Fan & Coutrix, 2023) and (Provancher et al., 2005). Moreover, the results potentially reveal the reason behind the difficulties of exploring affordance in Tiab and Hornbæk (2016) as they concluded that participants interpreted shape-changing mechanisms differently and interacted differently. We suggest that their conclusion was limited by the lack of context of use in their experimental design, i.e., the absence of a defined affording situation.

One of the limitations of this study is the utilization of a controller which was not functioning, which may have made participants feel the controller was impractical, as they did not receive any feedback. This might explain the absence of differences in ratings of the pragmatic quality aspects in the different contexts.

Conclusion

This study conducted a within-subject experiment with six participants to explore the effect of a defined affording situation on interaction with, and evaluation of new technologies. The results show that people's physical interaction with new technologies is not only affected by the abstract form of the technology. The purpose of the technology and the environment that is being deployed in/ in which it is handled can constrain physical actions the person would perform on the technology. Defining an affording situation not only provokes different physical actions but also may change the users' perceived experiences. This highlights the importance of defining an Affording Situation when exploring the affordance of new technologies, which will assist designers in increasing usability features in subsequent technologies.

Conceptualising the context of use with the notion of affording situation provides a theoretical underpinning to the ISO requirement of the context of use in evaluating new technologies. The affording situation notion is built upon the affordance theory that explains how user interaction is shaped by affordances. It allows us to understand the reason behind users undertaking one action rather than the other in a context of use.

Future work might include utilizing a finished product, which can provide feedback on user actions, to study the effect of defining an affording situation on people's interaction. Further research might also investigate people's interaction and evaluation of new technologies in two different affording situations.

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