

Physical Handles at the Interactive Surface: Exploring Tangibility and its Benefits

Lucia Terrenghi¹, David Kirk², Hendrik Richter³, Sebastian Krämer³, Otmar Hilliges³, Andreas Butz³

¹Vodafone GRUOP R&D
Chiemgauerstrasse 116
D-81549 Munich

lucia.terrenghi@vodafone.com

²Microsoft Research
7 J J Thomson Ave, Cambridge
CB3 0FB, UK

dakirk@microsoft.com

³LMU University of Munich
Amalienstrasse 17,
D-80333 Munich

{hendrik.richter; sebastian.krämer;
otmar.hilliges;butz} @ifi.lmu.de

ABSTRACT

In this paper we investigate tangible interaction on interactive tabletops. These afford the support and integration of physical artefacts for the manipulation of digital media. To inform the design of interfaces for interactive surfaces we think it is necessary to deeply understand the benefits of employing such physical handles, i.e., the benefits of employing a third spatial dimension at the point of interaction.

To this end we conducted an experimental study by designing and comparing two versions of an interactive tool on a tabletop display, one with a physical 3D handle, and one purely graphical (but direct touch enabled). Whilst hypothesizing that the 3D version would provide a number of benefits, our observations revealed that users developed diverse interaction approaches and attitudes about hybrid and direct touch interaction.

Categories and Subject Descriptors

H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

Keywords

Tangible, Hybrid, GUI, Interfaces, Design.

1. INTRODUCTION AND MOTIVATION

Progress in the field of display technologies has enabled novel forms of interactive surfaces, which often accommodate co-located input and output [7], [25], [34], thus supporting direct touch and direct manipulation [28] of digital information. The detection of multiple fingers, hands, styli and objects widens the design space for novel interaction techniques and interfaces. Furthermore, such computationally enabled surfaces can be expected to become increasingly embedded into everyday life environments, such as walls or furniture. They will be accessible to a variety of user groups and will support activities which are not necessarily related to office work. This requires the design of novel solutions, which afford social and casual interaction with digital media, and support leisure and collaborative activities, for example, browsing and sharing digital photos.

As the designers of such interactions, we have to conceive of and construct interactive systems which are attuned to the require-

ments of these physical and social spaces in which users are situated, in such a way as to allow us to take advantage of the rich potential of digital technology. When considering how this might be achieved a plethora of forms of interaction have been proffered but two broad classes of interactive systems in particular have begun to capture popular imagination. There are systems that support direct touch control of a graphical user interface (GUI) (e.g., [30], [35]), and those that bring tangible physical objects (TUIs) to a computationally enhanced surface (e.g. [10], [12], [16], [22], [25], [32], [33]). In each case technology is designed such that it appropriates humans' manipulation skills and mental models gained from interactions with the physical world and integrates them with the extensive possibilities of digital media.

The two approaches, though, are different in aspects of physical interaction that are drawn upon in the design of hybrid, physical/digital systems. In the case of GUIs for direct touch, designers often rely, for example, on the metaphorical 2D representation of physical artefacts to suggest the hand gestures or marking strokes to be operated. In the case of TUIs, designers exploit the degrees of freedom, manipulation vocabulary and haptic feedback enabled by the 3rd spatial dimension of the physical transducer.

Thus, when designing such systems, designers have mostly created and exploited design principles from either WIMP-based interaction (i.e., GUI design) or physical interaction (i.e., product design). Most of these principles are derived either from the comparative observation of physically enhanced vs. WIMP-based interaction (e.g., [2], [23]), or from the dedicated analysis of one of the two (e.g., [13], [18]). Although this has produced valuable insights, which are also fostered by ergonomics, cognitive psychology, and sociology (e.g., [8], [14], [19]), the spatial combination of physical manipulation and display of digital output in direct touch interactive surfaces creates new design challenges and opportunities, indeed there is significant potential, given advances in technology, to construct 'Hybrid' interfaces which combine elements of *both* tangible interaction and the ability to perform direct touch style manipulations with digital/graphical representations. With this potential functionality then, the previous evaluative studies do not provide significant guidance as to the relative benefits of when and how to exploit the '3rd Dimension' in an interaction scenario. If the facility for essentially manipulable 2D graphical content is concomitant, why design into a 3rd dimension, and if one does, what impact might this have on the user's behaviour?

To investigate the effect of tangibility and physicality more closely, we built 3D and 2D versions of PhotoLens, a system for photo browsing on an interactive tabletop. Herein we present our design rationale for the 3D PhotoLens, discussing it in relation to what existing research literature suggests are potential benefits of tangible devices. We then present a comparative evaluation study

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.

AVT'08, May 28-30, 2008, Napoli, Italy.

Copyright 2008 ACM 1-978-60558-141-5...\$5.00.

wherein users explored both this interface and the 2D graphical alternative (direct touch enabled). This allowed us to evaluate how pushing the interaction into a tangible 3rd dimension influenced patterns of user behaviour. We discuss the observed design implications of doing this and highlight key questions which arise.

2. RELATED WORK

Integration of aspects of physicality in the design of interactive systems has followed different paths of “material embodiment” and “metaphorical representation” [9] as technology has matured.

The seminal work on Toolglasses and Magic Lenses by Bier et al. [3] introduced a see-through style of GUIs, which metaphorically evoked filters. These interfaces were operated with two hands, using touch-pads, track-balls or mice as input (i.e., the input region was detached from the output display). One of the main benefits was to afford two-handed interaction, thus overcoming mode changes and taking advantage of human bimanual skills (which in turn shows cognitive and manipulation benefits [20], especially when the hands do not perform simultaneously [4]).

Fitzmaurice et al.’s work on Bricks and the ActiveDesk [10] goes a step further in this direction: The materiality and “graspability” of the bricks as input devices (which have more degrees of freedom and a richer manipulation vocabulary than the mouse), together with the direct contact between input object and output surface, aimed at “facilitating two-handed interactions, spatial caching, and parallel position and orientation control” [10]. This work forms the basis for the Tangible User Interfaces paradigm. The main benefits claimed in this area of research are intuitiveness [15], motor memory [19], and learnability [26].

Because of the physical affordances of the table, such as horizontal support for physical artefacts, several instantiations of the TUI paradigm can be found in conjunction with tabletop displays: These are usually ad-hoc designed tools, whose formal shape can more (e.g., [32]) or less (e.g., [12], [25]) literally represent a metaphor. Furthermore, the integration of such physical artefacts in the design of applications for multi-user tabletop displays is often motivated by the goal of supporting casual co-located collaboration, as suggested for example in [16], [22], [33].

The use of tangible interaction is claimed to be beneficial for collaborative work and group awareness [8], [14], as it implies the mutual visibility of explicit actions among participants [27].

This work on the interweaving of physical and digital aspects in interface design for interactive surfaces suggests a variety of benefits: cognitive (e.g., intuitiveness and learnability), manipulative (e.g., motor memory), collaborative (e.g., group awareness), experiential, as well as in terms of efficiency. But the empirical work that supports such claims is actually limited and mostly focuses on one aspect in isolation from the others, thus taking for granted, to some extent, some of the benefits of integrating aspects of physical interaction in the design of hybrid ones. From our perspective, we think that the mutual influences of the different aspects cannot emerge if we do not start distinguishing what are the very aspects of physical interaction we integrate in the design of hybrid, physical-digital interactive systems, while considering, at the same time, their implications on different levels of the experience of use (e.g., discoverability of the interface, easiness, fun). These aspects become crucial when we expect interactive surfaces to support everyday life including causal and leisure interactions.

To address these issues we draw upon the aspects of physical interaction for the design of hybrid systems suggested by Terrenghi et al [31]. Such aspects are: metaphorical representation;

space-multiplex input; direct spatial mapping between input and output; continuity of action; 3D space of manipulation; rich multimodal feedback. Through the comparative analysis of design solutions that integrate (or not) some of these aspects, we can then start eliciting the effects and implications of such integrations more consciously.

3. DESIGNING THE PHOTOLENS

To unpack tangibility and its effects on interaction behaviours, we built the PhotoLens system, a hybrid tool for browsing and organization of photos on an interactive tabletop display. The choice of developing an interface for photo-browsing is particularly linked to this notion of evolving interaction paradigms being tethered to the support of digital interactions in more social and casual areas. The rapid shift of photography from analog to digital, together with the reduced cost of taking pictures, has caused a substantial growth of personal photo collections, and the technology that we use to capture, display and interact with them [4]. On the other hand, the size and orientation of the displays of Desktop PCs, together with their WIMP paradigm, neither provide social affordances suitable for co-located sharing and collaborative manipulation and organization of collections (an imperative feature of users’ interactions with photos [11]), nor the creation of temporal spatial structures, as our physical artefacts do [18].

In the envisioned scenario, the collections of different users (e.g., friends, family members) can be displayed on the tabletop. Photo collections are visualized in piles, in analogy to [21] and [1]. Piles can be freely translated on the tabletop (i.e., no automatic snapping to a grid) by touching and dragging the image on the top with a finger or with a stylus (see Figure 1, a). In order to save real estate and avoid clutter, we use PhotoLens to gain a localized, unfolded view of the pictures contained in one pile, without interfering with the information landscape of the shared display (see Figure 1, b and c). For a complete overview of how the PhotoLens works see figure 1 and the description below.

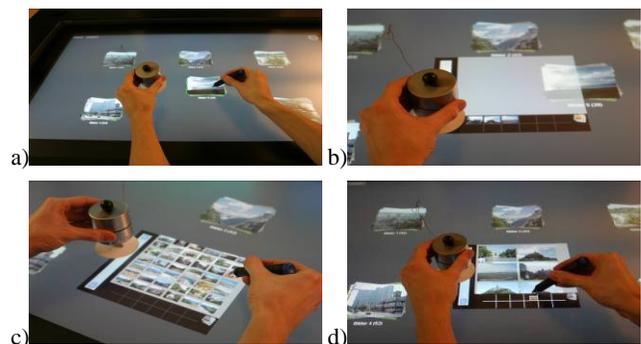


Figure 1: Interaction with the 3D PhotoLens:

The illustrations in figure 1, show how the PhotoLens works: a) Piles can be moved freely on the table using the stylus. b) The digital lens only appears when the physical tool is placed on the table. c) The pile unfolds in a thumbnail view and moving the handle up and down the scroll bar scrolls through the thumbnails. d) The view can be zoomed in and out by rotating the upper part of the tool and selected pictures can be copied to a temporary tray (retained independent of the pile viewed). Additionally, a new pile containing photos from different collections can be created by tipping on the icon in the right bottom corner of the lens.

3.1 Rationale and Expectations

Previously Terrenghi et al. [31] have observed that despite some interactive systems allowing for bimanual interaction on a display

(which is known to offer both physical and cognitive benefits [20]), people tend to use only one hand and preferably the dominant one when manipulating digital media, possibly due to their acquaintance with the WIMP paradigm. Therefore we expected the use of a physical tool, associated with a digital frame and a stylus for interaction, to more explicitly suggest two-hand cooperative work. Indeed, by providing both a tool and a stylus we wanted to suggest the use of the non-dominant hand for navigation tasks (i.e., grasping and rotating the tool) and of the dominant hand for fine-grained tasks (i.e., selecting and dragging pictures). The stylus is indeed typically held with the dominant hand, so that we expected users to use the non-dominant hand for interacting with the physical tool in order to use their hands cooperatively, such as in Guiards' kinematic chain [13]. To make this affordance even more explicit, and given predominant right-handedness, we designed the graphical lens so that it would extend on the right-up side of the physical tool (see Figure 1, b). We then mapped navigation functionalities, e.g. placing (appearing of the lens frame), scrolling and zooming to the physical tool.

Additionally, we expected that the physical affordances of the tool, like placement and rotation, would support the offload of cognitive effort thanks to the haptic feedback it provides. The tool, indeed, can be operated without looking at it, thus not hindering users' visual attention. The effect of its manipulation is mapped in real time and in the same area (e.g., zooming and scrolling of the pictures in the lens), thus providing an isomorphic visual feedback of action. In this sense we expected that the continuity of action it supports (rotation and translation) and the multimodal feedback (haptic and visual) would provide a higher sense of control. In this sense we refer to Buxton's work on the effect of continuity of action on chunking and phrasing [5], as well as on Balakrishnan and Hinckley' investigation on the value of proprioception in asymmetric bimanual tasks [2].

Since the graphical lens appears when the tool is placed on the table, and disappears when the tool is lifted, we expected this feature to support an efficient use of the real estate: users could indeed display the lens only when required. Furthermore, the fact that the lens can be physically picked up in the 3D space and moved to another pile, makes it unnecessary to drag it in 2D across the screen, stretching arms and sidling between other piles, thus providing motor benefits.

Although we are aware of the social benefits of tangibility claimed in the related literature, our current technical setup only recognizes two input points (i.e., interaction with only one PhotoLens at a time). Thus, interactions with the system are in this instance based on individual action, which makes the social affordances of such interfaces a consideration for future work.

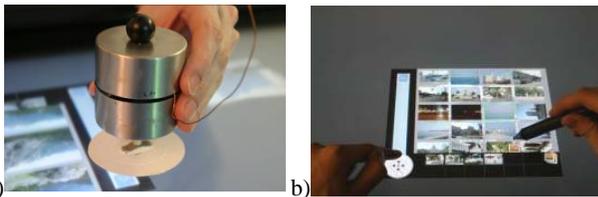


Figure 2: a) The physical component of the 3D PhotoLens. b) The purely graphical 2D PhotoLens.

3.2 Technical Implementation

The technical setup of PhotoLens consists of an interactive table and a modified wireless mouse for the implementation of the physical handle. The components of the mouse were rearranged in a metal cylinder with a diameter of 7 cm and height of 9 cm,

which we took from a disassembled kitchen timer (see Figure 2, a). The size of the tool is determined by the features of the mouse.

The interactive table consists of an LCD monitor with a resolution of 1366 x 768 pixels in 16:9 format and a diagonal size of 100 cm, embedded in a 15 cm wide wooden frame. Input is provided by a DVIT [29] overlay frame, which uses four cameras in the corners of the frame to track two input points simultaneously. An input point can either be a pen, a tool, or simply a users' finger. The frame we use has limitations when wide input points are on one of its diagonals, as this causes a mutual occlusion. The thinner the body of the input mediator, the lower the risk of occlusion, and the more accurate the tracking, for this reason we created a base for the physical tool (see Figure 2, a), so that its stem creates a smaller shadow and hence provides more accurate tracking.

3.3 Constructing a Comparative Graphical PhotoLens

For comparative purposes our 2D PhotoLens had inherently the same functionality as the 3D version, it was a direct touch enabled graphical interface, but did not extend into the 3rd dimension. Lacking a physical handle for picking it up, the 2D PhotoLens is permanently displayed on the tabletop and can metaphorically overlap photo piles when it is dragged onto them. The control for scrolling and zooming of the PhotoLens is represented by an interactive circle, as illustrated in Figure 3.



Figure 3: Screen shot of the 2D PhotoLens.

When a user touches the small circle on the graphical control wheel and slides her finger along the circular trajectory of the graphical control, clockwise rotation zooms in and counter-clockwise rotation zooms out. When the user touches the center of the same graphical wheel, four perpendicular arrows appear (see Figure 2, b): these resemble the symbol of movement used in the GUI of several desktop applications (e.g., Microsoft PowerPoint, Adobe Photoshop). Sliding the finger up and down along the line of the scrollbar, the thumbnails scroll up or down, as in a desktop GUI. When the control circle is touched and dragged away from the pile for more than 5 cm, the whole lens moves along, for example onto another photo pile or into an empty area of the table.

4. STUDY METHODOLOGY

4.1 Study Design

To engage users with the interface they were asked to bring a sample of 80 personal digital photos (from a trip or vacation) to the study session. During study trials participants completed two tasks with their photos using both interfaces (i.e. 3D and 2D, whose order of execution was counterbalanced across trials and participants), giving a total of 4 trials. In each trial participants were presented with 6 piles of 80 photos (80 random images from their own collection in one pile, with other piles being made up of images provided by the researchers, and used to simulate the presence of a companion's images). In one trial the participants were told to interact with only their pile, selecting 12 images suitable

for use as desktop wallpapers and in the other trial they interacted with all of the piles, searching for 12 images to accompany a proposed calendar. In both cases participants were told to store selected images in the PhotoLens temporary tray creating a new pile on the tabletop.

Before each task, the user had that current task explained and the interface demonstrated (including demonstration of the potential for using two handed interactions). After the trials, the participants completed an evaluation questionnaire and discussed their experiences with the experimenter in charge of the session.

Our participants were 12 right-handed adults (mostly university students, with different majors, in an age range from 20 to 30 years old), comprised of 6 men and 6 women, all with normal or corrected to normal vision, and all having normal arm mobility.

4.2 Analysis

To help ground our deeper analysis and to understand broader patterns of action at the interface, we calculated the extent of use of differing forms of interface manipulation (i.e. different forms of handed interaction) in the two conditions. And then to ground these actions in a more reflective consideration of subjective response to differing interface styles, we solicited feedback of users' perceptions of use from their experiences of the two interfaces, (using Likert scales from 1 to 5, negative to positive) to get general response on key characteristics such as ease of use and enjoyment, and certain specific manipulative actions such as *zooming*, *scrolling*, and *placing* the lens (see Figure 13).

All user trials were video recorded; our evaluation is mainly based on direct consideration of these video materials. The footage was studied by an interdisciplinary design team and subjected to an interaction analysis [17]. The focus of the analysis was to look for patterns of common interaction strategies and specific moments of novel interaction, or moments when the interaction faltered. Attention was also given to moments of initiation of interaction. This approach to the data was taken as it was felt more appropriate than traditional attempts to exclusively quantify behaviours at the interface. The paradigm of digital interaction that was being explored, i.e. leisure technology (photo browsing in this case) does not fit a traditional model of recording task completion times. It was felt that by taking a fine-grained, micro-analytic approach to recovering patterns of activity and breakdown during interface interaction a richer understanding could be derived of how, qualitatively, a third dimension in an interface was appropriated and understood by users. Consequently the ensuing results section seeks to articulate some vignettes of interaction, some moments of user activity, which we felt were of particular interest and were particularly illuminating in our attempts to understand the impact of tangibility on interactive behaviour.

5. RESULTS

Our results are split into two sections, the first highlights some patterns of handed interaction at the interface, the second providing a more detailed view of some of the common elements of interaction during tasks.

5.1 Forms of Handed Interactions across Modalities

As we can observe in Table 1, our participants demonstrated diverse approaches to interacting with the interface which might suggest that they were developing different mental models of system function or simply approaching the interface with different pre-conceived manipulation skills, habits and preferences for physical and digital media.

We observed 5 predominant forms of interaction with the interface as shown in Table 1, logically conforming to those actions immediately possible (NB, none of the participants, selected the photos with the non-dominant hand). These broader patterns of action framed our subsequent inquiry and, thus, our interaction analysis partially draws on such a classification of conditions to identify, analyze and describe snippets of interactions which we found relevant for what can be considered a 'catalogue of interaction experiences', which we articulate and present below.

Table 1. Average percentage of time spent in differing forms of handed interactions in both physical (3D) and purely graphical (2D) conditions (standard deviations in brackets).

Forms of handed interactions	3D	2D
 Two-handed interaction with PhotoLens.	9.0% (11.9)	19.4% (24.7)
 The non-dominant hand interacts with the control wheel for scrolling and zooming.	44.7% (15.6)	37.5% (24.8)
 The dominant hand interacts with the control wheel for scrolling and zooming.	2.1% (5.6)	17.4% (24.6)
 The dominant hand interacts with the photos for selection tasks.	31.3% (21.6)	17.0% (11.2)
 No hands are on the interactive area	12.9% (6.4)	8.8% (7.8)

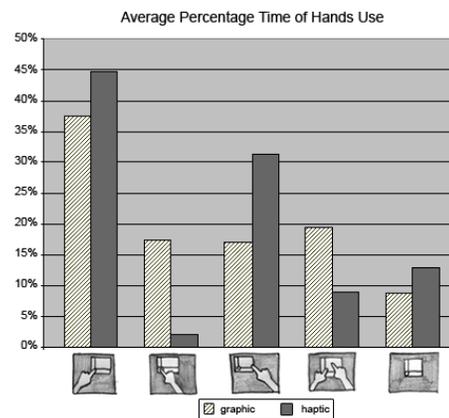


Fig. 4. Representation of average percentage of time spent in differing forms of handed interactions.

5.2 A Catalogue of Interaction Experiences

In this section we present vignettes of interaction following the common life-cycle of interface activities during elements of the photo-browsing task.

Approaching the Task

At the beginning of the task, in both modalities, the participants were asked to select 12 photos from their own pile, which was displayed in the bottom right corner of the table. Piles could be moved freely across the table, so as to enable epistemic actions, i.e., allow users to create spatial arrangements as they liked and found more comfortable for interaction. Despite such a feature, we noticed some interesting differences amongst subjects in the way they approached the task and the posture they adopted.

The participant in Fig. 5, for example, first moves the pile in front of her away using the stylus in her right hand, gaining space; then she moves her pile from the right to the center of the table. In this way she creates a focused interaction area, where she can easily

visualize and reach the photos of her collection/pile. She then grasps the physical handle from the border of the table with her left hand, and starts browsing through the photos.



Fig. 5. Moving the artifacts towards the body.

A different interaction style can be observed in Fig. 6, where the participant moves her body towards the pile to be sorted, rather than the alternate. In this case she first places the physical handle on the screen of the table with the dominant hand; she then drags it on the table towards the pile in the right bottom corner. Thus, in order to better reach the interaction area, she moves the chair to the right side of the table, in the proximity of the pile she wants to sort, and she then starts interacting with the PhotoLens.

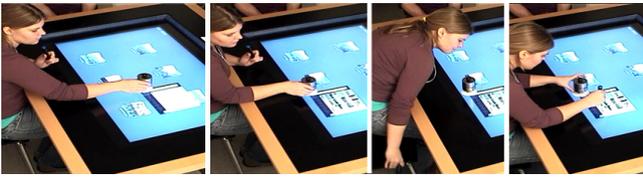


Fig. 6. Moving the body towards the artifacts.

Browsing the Photo Collection by Scrolling and Zooming.

By rotating and sliding the control wheel (either the 3D or the 2D one) users could browse through the photo collection, thus exploring the content of the pile. Our design choice of placing the control wheel at the left bottom corner of the lens was meant to afford two-handed manipulation of the PhotoLens, and manipulation of the control wheel with the non-dominant hand. This was not, however, always the approach taken by our participants.

In Fig. 7 the participant interacts with the control wheel with the pen, held in the dominant hand, while the non-dominant hand is rested on the border of the table. In this way the participant partially occludes her own view, which brings her to alternatively lift the pen and her hand from the table to better see the pictures in the thumbnail view (e.g., second frame of Fig. 7). Furthermore, as she explained in the post-test questionnaire, she found it more difficult to manipulate the small sensible area of the 2D wheel for zooming, in comparison to grasping the physical handle: We can speculate that this is why, as we could observe in the video analysis, in the 2D modality she mostly used the scrolling function of the wheel to browse through the photo collection, but hardly changed the zooming factor.

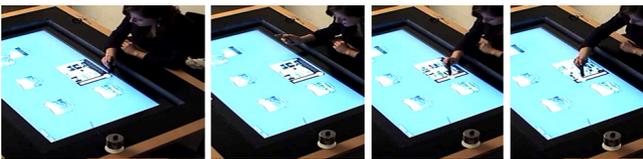


Fig. 7. One-handed interaction with the 2D PhotoLens.

Alternatively, when interacting with the 3D PhotoLens, she manipulated the physical control wheel with the non-dominant hand only, exploring the content of the collection both with scrolling and zooming (e.g., see the third frame in Fig. 8). In such an interaction pattern, both the hands were kept on the interactive area of the table during the whole interaction with one pile.

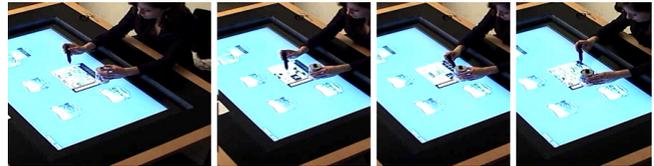


Fig. 8. Two-handed interaction with the 3D PhotoLens.

Selecting Photos in the Lens.

By providing our participants with a stylus we expected them to interact with the dominant hand for selection tasks: none of the participants (who were all right handed), indeed, performed selection tasks with the non-dominant hand. Additionally, because of the laterality of the control wheel and of the scrolling bar, we expected interaction patterns similar to drawing ones [13] to emerge. In these cases a tool (e.g., a ruler) is usually held with the non-dominant hand, while the dominant one performs micro-metric tasks in the proximity of the tool (e.g., draws a line). The type of patterns we assisted to were often rather different across modalities, though, in the way people alternatively or simultaneously used the non-dominant and dominant hand.



Fig. 9. Alternate use of the dominant and non-dominant hands with the 3D PhotoLens

As we can see in Fig. 9, as an example of interaction with the 3D PhotoLens, the participant first positions the physical tool on a photo pile with the non-dominant hand, and starts browsing through the photos by scrolling and zooming. In this phase she keeps the dominant hand in the proximity of the interactive area, holding the stylus. After she has set a preferred height in the scroll bar, and a desired zooming factor, she then releases the non-dominant hand (Fig. 9, second frame) and rests it at the border of the table (Fig. 9, third frame). She then proceeds in the task by selecting the photos with the dominant hand: Such a cycle of interactions unfolds again when the zooming and scrolling are newly set with the non-dominant hand (Fig. 9, fourth frame).

Surprisingly, in the 2D modality participants kept more continuously both hands simultaneously on the interactive area (see time percentage in Table 1). As shown in Fig. 10, for example, the participant keeps his left forefinger on the 2D control wheel during the whole interaction with a pile: I.e., both when the dominant hand is selecting photos (e.g., second and third frame) or it is just held in the proximity of the lens (e.g., frame 4).

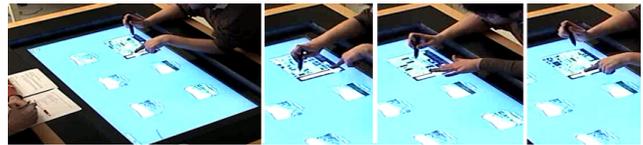


Fig. 10: Concomitant use of the dominant and non-dominant hands with the 2D PhotoLens.

Although the 2D graphic PhotoLens is permanently present on the interactive surface, and can be moved on the table only when it is dragged, several participants mentioned in the post-test questionnaire that they constantly kept their fingers on the wheel as they had the feeling that the lens would disappear otherwise.

Placing and Moving the PhotoLens.

When participants were asked to create a new collection by selecting photos across several piles on the table, different strategies of moving the lens and photos could be noticed, showing differences among both subjects and modalities in how people took the tool to the pile or vice versa.

In Fig. 11 we can observe how a user interacts with the 2D (Fig 11, a) and the 3D PhotoLens (Fig. 11, b). To reach the piles he stands up. In the 2D modality he drags the lens towards different piles with a finger of the non-dominant hand. When selecting photos from one collection (e.g., third frame Fig. 12, a) he rests his non-dominant hand on the border of the table: he than uses it again for moving the lens towards another pile (e.g., fourth and fifth frame Fig. 12, a), while resting the right hand to the border this time. All in all, he never moves the piles, and alternatively uses the non-dominant and dominant hand for respectively moving the lens on the table and selecting photos within the lens. In the 3D modality he adopts a very similar strategy. He first places the physical handle with the dominant hand on a pile: then he swaps hands for browsing, and again for selecting. In these cases one of the hands is always rested at the border of the table. In order to move the lens towards another pile he slides the physical tool on the table surface (e.g., fourth and fifth frame in Fig.11).

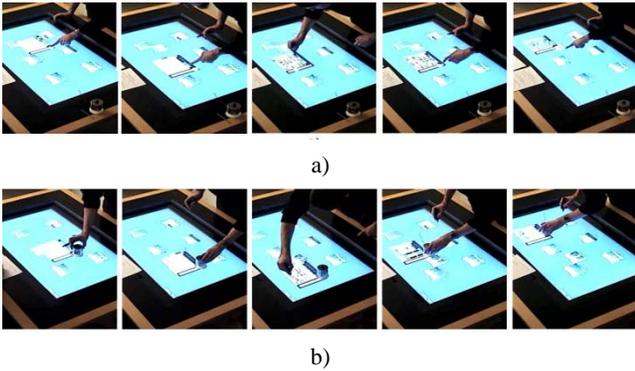


Figure 11: Moving the tool and the body towards the piles: a) 2D PhotoLens; b) 3D PhotoLens.

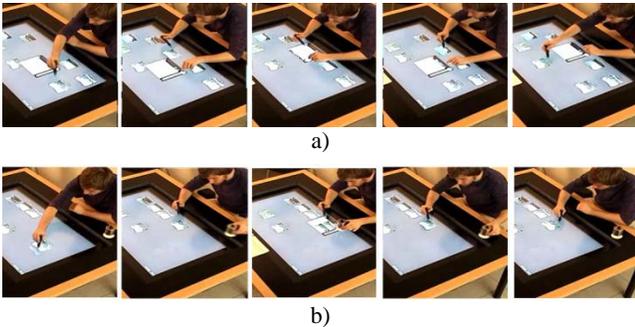


Figure 12: Moving the tool and the piles towards the body: a) 2D PhotoLens; b) 3D PhotoLens.

A different approach can be observed in Fig. 12. In this case the participant tends to move the piles and the lens towards his body. In the first frame of Fig. 12, a, he drags a pile towards himself with the dominant hand: with the non-dominant one (second and third frame) he then moves the 2D Photolens towards the pile to interact with it. In the fourth and fifth frame, he moves other piles towards himself with the dominant hand, while slightly moving the PhotoLens between one interaction cycle and another one with the non-dominant hand. The interaction takes place in the proximity of his body, and the dominant and non-dominant hands are alternatively used for moving respectively the piles and the lens.

When interacting with the 3D PhotoLens (Fig. 12, b) he adopts a similar allocation of tasks to dominant and non-dominant hand (i.e., moving the piles and the lens accordingly). In this case he takes advantage of the graspability and mobility of the physical handle in the 3D space to alternatively place it at the border of the table (e.g., second and fifth frame in Fig. 12, b).

5.3 Perceived Experience

Figure 13 reports the results of post-test questionnaires (average values on a Likert scale). Despite the physical control being easier to use on average (with a remarkable difference in ease of use between the two interfaces for the zooming function in particular), participants reported that overall it is more fun to use their hands on the screen than the tool. To explore this response a little more it is worth referring to participants' comments.

For some the 3D PhotoLens was easier to use, especially in the zooming function, as it does not require such precise interaction as with the graphical wheel. In this respect they told us: "With the physical tool you only have to rotate"; "With the physical tool you don't have to think about what you can do, you see it immediately"; "You don't need to look for the exact point where to put your finger to rotate"; "The rotation for zooming reminds the use of analogue cameras"; and finally "it is easy to place it and rest it in one position: with the digital lens I had the feeling I needed to hold it in place". When considering *why* the graphical interface is fun to use, participants cited such factors as: "It is more natural to interact *directly* with your hand than with a device"; "With your hand you are *directly* on the image, the tool is too far away from it"; "You need to get used to a device, sometimes the zooming with the tool is too fast, you have a better control with your hand directly"; "When you interact with the tool you don't have the feeling 'on the finger tips' of where the scrollbar ends". Such comments raise interesting questions about subjective perceptions of directness, control, haptic feedback, discoverability, easiness and enjoyment of interaction, especially when the interaction purposes are not merely linked to models of efficiency and performance. Aspects of easiness and enjoyment of interaction, for example, do not appear to be causally related.

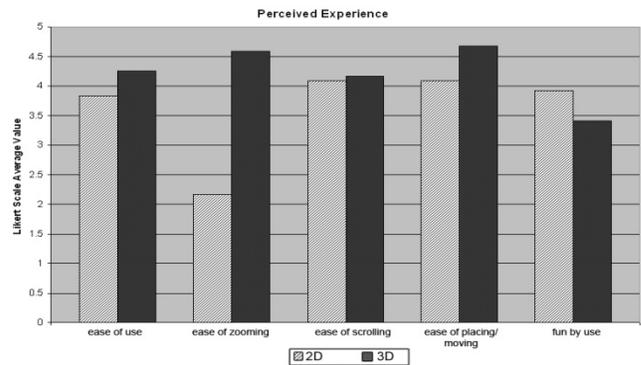


Figure 13: The results of perceived experience in terms of average of the Likert scale values.

6. DISCUSSION

Having presented vignettes of action and grounded them in details of common practice, it is germane to discuss implications of these observations for our discussion of tangibility. The appropriation of an experimental methodology allowed us to inform our critical enquiry of tangibility by forcing users into making comparative use of two functionally similar but fundamentally altered interfaces. By forcing this comparative evaluation with a direct-touch enabled GUI, we have been able, perhaps more explicitly than in past studies [23], to explore the effects of pushing an interface

into a 3rd dimension. Our analysis followed the common life-cycle of interactions at the interface during photo browsing and manipulation; flowing from the initiation of contact, through pile browsing, selecting images and then moving the ‘lens’ onto new piles and iterating. From observation of each of these common stages of interface use we feel that there are three key aspects of activity raised that we should discuss further, *Idiosyncrasy of action*, *Concomitant bimanualism* and *Sequential action and laterality*.

6.1 Idiosyncrasy of Action

Not all of our participants used the interface similarly: which means that individual actions were often highly idiosyncratic regardless of the interface that participants used, as shown by the standard deviations presented in Table 1. Even in our first stage of analysis, considering the initiation of interaction, participants clearly approached the task (bodily) in different ways. Some understood that piles of pictures could be dragged towards themselves and others relied on moving a tool to the digital objects of interest. This latter form of interaction potentially demonstrated an existing mental model, perhaps created from years of WIMP use, where the fundamental paradigm is to manipulate an interceding tool and take that to the objects of interest (e.g. tools mediated by mouse movement in a Photoshop environment). This is as opposed to bringing artefacts of interest to the tool of use, such as might happen in the real world (e.g. ‘examining’ or ‘framing’ tools like microscopes). None-the-less such patterns of interaction at the interface were not consistent across all subjects, although this is perhaps to be expected with such open interfaces and relatively open tasks.

This idiosyncratic action has two implications. Firstly it highlights the issue of ‘discoverability’ at the interface begging reflection on some of the claimed benefits of intuitiveness of the interface in some of the TUI literature [15], [19]. We had designed the 3D interface to suggest a style of use. However, during our study (which represents users’ initial explorations of such interfaces) many did not use the interface as intended. Some failed to discover for themselves our prompted scheme of interaction. This suggests that even if an interface is designed to incorporate a 3rd dimension, there is no guarantee that all users will appropriate it as the designer intends, so some of the performance benefits expected will not materialize. This strongly suggests that consideration be given to ensuring that 3D interface elements have an inherent level of discoverability. Especially if a specific style of interaction (e.g. bimanual) purportedly offers some kind of benefit.

Secondly, however, this observed idiosyncrasy potentially implies that one should perhaps design for conflicting user preferences. In this open scenario, with a less constrained study task than in some previous experiments [20], we saw that users adapted their use of the interface to suit factors such as comfort (hence the one handed interactions). If this is how users are going to act, perhaps we should in future be less concerned with the *a priori* shaping of the minutiae of interaction (such as appropriate handed interactions). Instead, we should actively consider designing tangible elements that can be appropriated by the user in personal ways.

6.2 Concomitant Bimanualism

This form of interaction refers to users using both hands simultaneously to operate the interface. Relatively speaking, this did not happen that much, however, when it did happen it was more likely to occur in interactions with the 2D interface than with the 3D interface. The reason given for this by the users appears to centre on mistaken mental models of the operation of the 2D interface. Some of the users really felt that if they took their left hand away from the surface the Lens would disappear (contrary to what they

were shown). Conversely, for these people the physical handle of the 3D interface held some form of object permanence: once placed, the physical handle was comfortably left alone.

Here then, our choice of a comparative analysis has been particularly beneficial. Had we not had the comparison with a 2D interface we would have had a poorer understanding of the effects of using a 3D handle, seeing sequential actions during its use and assuming that this was entirely user-comfort driven. From understanding the bimanual response to the 2D interface we see that an implication of building into the 3rd dimension, beyond apparent user comfort, is the inherent substantiality of a 3D interface control creates assurances of consistent action. A benefit of 3D elements is possibly therefore that they suggest a more consistent and accurate control than a comparable 2D interface.

6.3 Sequential Action and Laterality

Previous research [31] suggests users of such interfaces utilise one-handed interactions, and we also assumed that our interface design would promote a lateral division of handed interactions. For a large number of users this was often the pattern of behavior observed. Particularly those using the 3D interface rather than the 2D. So in this respect our design solution worked and we can confirm that the introduction of a tangible 3D element to the interface appeared to support the lateral division of handedness, promoting bimanualism (albeit sequential rather than concurrent). Given research [20] has suggesting performance benefits of bimanualism we have effectively observed a benefit from pushing the interface into a 3rd dimension.

However, there is a problem posed by the questionnaire data. Previous work discussing the benefits of tangibility has taken a more engineering led approach to the evaluation. They have considered metrics of performance such as speed and task completion, and in this respect some of our questionnaire results concur with their findings, subjective responses from our users suggest that there were performance benefits for the 3D interface. However, this critically conflicts with their perceived *preference* for the 2D interface, which they found more *fun to use*. And it is the reasoning behind this which is of particular interest here. It appears that certainly for some users there was a significant increase in the perception of direct engagement with the 2D interface. Contrary to regular expectations that tangibility and three-dimensionality enhance physical engagement with digital information, we would suggest that such a process can perhaps, unwittingly, create a perceptible barrier between user and data. In the TUI ideal, physical elements are both input and output. From testing our own design we would suggest that if the 3D elements of an interface are not deeply considered they can unfortunately all too easily traverse a hidden line into becoming just another tool for *mediating* action at the interface, another form of ‘mouse’. The level of direct engagement between user and digital artifact can be less than that found in direct touch enabled GUIs and consequently, it seems, this impacts user enjoyment., which is after all, the *critical metric* for evaluating interactions with leisure technologies.

7. CONCLUSION

While the field of interactive surfaces is still in its infancy, we think that through the design of interactive systems which consciously combine physical and digital affordances, and the systematic evaluation thereof, we can learn about people’s interaction schemas. To this end we need to investigate what the very differences, benefits and trade-offs of physical and digital qualities in the interaction actually are, and how they affect the user experience in different contexts. Which solutions provide the best mental model for bimanual cooperative work? Where shall we draw

the line between graphical metaphorical representation and embodiment of the functionalities in a physical tool? Agarawala et al.'s recent work [1] on physics enhanced desktop-metaphors makes an interesting case for this discussion: in this work, physics-based behaviors are simulated so that icons can "be dragged and tossed around with the feel of realistic characteristics such as friction and mass". Accordingly it is timely to explore the borders and influences between the *look* and the *feel*, the *visual* and the *haptic*. In this respect, our research agenda is to pursue comparative design and evaluation, contributing to a deeper understanding of human interaction behaviour through the design of comparable solutions which tackle specific aspects of the interaction (e.g., physicality and tangibility), and at the same time provide experiences which are open for people's expression of preferences and relate to realistic everyday life scenarios (e.g., photo browsing). The main focus then of our comparative evaluation is not the success of design solutions *per se*, but rather on the discovery and understanding of factors affecting user experience. By combining empirical and explorative approaches, we attempt to recognize patterns which shed light on relationships between design solutions and resulting experience, informing the design of hybrid systems.

8. ACKNOWLEDGMENTS

We kindly thank all the participants of our study.

9. REFERENCES

- [1] Agarawala, A., Balakrishnan, R. Keepin' it Real: Pushing the Desktop Metaphor with Physics, Piles and the Pen. In *Proc. of CHI'06*, 1283-1292.
- [2] Balakrishnan, R. and Hinckley, K. The role of kinesthetic reference frames in two-handed input performance. In *Proc. of UIST '99*, 171-178.
- [3] Bier, E.A., Stone, M.C., Pier, K., Buxton, W. and DeRose, T.D. Toolglass and magic lenses: The see-through interface. In *Proc. of SIGGRAPH '93*, 73-80.
- [4] Buxton, W., and Myers, B., A. A Study in TwoHanded Input. In *Proc. of CHI '86*, 32-326.
- [5] Buxton, W. Chunking and Phrasing and the Design of Human-Computer Dialogues. In *Proc. of the IFIP World Computer Congress*, Dublin, Ireland, 1986, 475-480.
- [6] Crabtree, A., Rodden, T., and Mariani, J. 2004. Collaborating Around Collections: Informing the Continued Development of Photoware. In *Proc. of CSCW '04*, 396-405.
- [7] Dietz, P., Leigh, D. DiamondTouch: A Multi-User Touch Technology. In *Proc. of UIST'01*, 219-226.
- [8] Dourish, P.: Where the Action is. The Foundations of Embodied Interaction. *Bradford Books*, 2001.
- [9] Fishkin, K. P. A Taxonomy for and Analysis of Tangible Interfaces. *Journal of Personal and Ubiquitous Computing*, 8 (5), September 2004, 347-358.
- [10] Fitzmaurice, G., Ishii, H., Buxton, W. Bricks: Laying the foundations for graspable user interfaces. In *Proc. of CHI'95*, 432-449.
- [11] Frohlich, D., Kuchinsky, A., Pering, C., Don, A., and Ariss, S. 2002. Requirements for photoware. In *Proc. of CSCW '02*, 166-175.
- [12] Gorbet M.G., Orth M., Ishii H., Triangles: Tangible Interface for Manipulation and Exploration of Digital Information Topography. In *Proc. of CHI ' 98*, 49-56.
- [13] Guiard, Y., "Asymmetric Division of Labor in Human Skilled Bimanual Action: The Kinematic Chain as a Model," *J. Motor Behaviour*, 19 (4), 1987, 486-517.
- [14] Hornecker, E., Buur, J.: Getting a Grip on Tangible Interaction: A Framework on Physical Space and Social Interaction. In *Proc. of CHI 2006*, 437-446
- [15] Ishii, H. and Ullmer, B. 1997. Tangible bits: towards seamless interfaces between people, bits and atoms. In *Proc. of CHI'97*, 234-241.
- [16] Jordà, S., Geiger, G., Alonso, A., Kaltbrunner, M. The re-acTable: Exploring the Synergy between Live Music Performance and Tabletop Tangible Interfaces. In *Proc. of TEF'07*.
- [17] Jordan and Henderson. Interaction Analysis: Foundations and practice. *Journal of the Learning Sciences*. 4 (1), 1995
- [18] Kirsh, D. The Intelligent Use of Space. In *Artificial Intelligence*, 73, 1995, 31-68.
- [19] Klemmer, S. R., Hartmann, B., and Takayama, L. How Bodies Matter: Five Themes for Interaction Design. In *Proc. of DIS '06*, 140-149.
- [20] Leganchuk, A., Zhai, S., Buxton, W. Manual and Cognitive Benefits of Two-Handed Input: An Experimental Study. In *Transactions on Computer-Human Interaction*, Vol5 (4), 1998, 326-359.
- [21] Mander, R., Salomon, G., and Wong, Y. Y. 1992. A "pile" metaphor for supporting casual organization of information. In *Proc. CHI'92*, 627-634.
- [22] Mazalek, A., Reynolds, M., Davenport, G. TViews: An Extensible Architecture for Multiuser Digital Media Tables. *IEEE Computer Graphics and Applications*, vol. 26, no. 5, pp. 47-55, Sept/Oct, 2006.
- [23] Patten, J. and Ishii, H. 2000. A comparison of spatial organization strategies in graphical and tangible user interfaces. In *Proc. of DARE'00*, 41-50.
- [24] Rekimoto, J. SmartSkin: An Infrastructure for Freehand Manipulation on Interactive Surfaces. In *Proc. of CHI '01*, 113-120.
- [25] Rekimoto J., Ullmer B., and Oba H., DataTiles: A Modular Platform for Mixed Physical and Graphical Interactions. In: *Proc. of CHI'01*.
- [26] Resnick, M., Martin, F., Berg, R., Borovoy, R., Colella, V., Kramer, K., and Silverman, B. 1998. Digital manipulatives: new toys to think with. In *Proc. CHI'98*, 281-287.
- [27] Scott, S.D., Grant, K., D., & Mandryk, R.: System Guidelines for Co-located, Collaborative Work on a Tabletop Display. In *Proc. of ECSCW '03*, 159-178.
- [28] Shneiderman, B., Direct manipulation: A step beyond programming languages, *IEEE Computer* 16, 8, August 1983, 57-69.
- [29] SmartTech DViT <http://www.smarttech.com/DViT/>
- [30] Terrenghi, L., Fritsche, T., Butz, A.: The EnLighTable: Design of Affordances to Support Collaborative Creativity. In *Proc. of Smart Graphics Symposium 2006*, 206-217.
- [31] Terrenghi, L., Kirk, D., Sellen, A., Izadi, S. Affordances for Manipulation of Physical versus Digital Media on Interactive Surfaces. In *Proc. of CHI'07*, 1157-1166.
- [32] Ullmer, B. and Ishii, H. The metaDESK: models and prototypes for tangible user interfaces. In *Proc. of UIST '97*, 86-96.
- [33] Underkoffler, J., Ishii, H., Urp: a luminous Tangible Workbench for Urban Planning and Design. In *Proc. of CHI'99*, 386-393.
- [34] Wilson, A. PlayAnywhere: a Compact Interactive Tabletop Projection-vision System. In *Proc. UIST '05*, 83-92.
- [35] Wu, M., Balakrishnan, R. Multi-finger and Whole Hand Gestural Interaction Techniques for Multi-User Tabletop Displays. In *Proc. of UIST '3*, 193-202