Pico-ing into the Future of Mobile Projection and Contexts

Max L. Wilson*, Dan Craggs, Simon Robinson, Matt Jones, Kristian Brimble

Future Interaction Technology Lab,
Department of Computer Science,
Swansea University,
Swansea, SA28PP, UK

Tel: +44 (0) 1792 295393
Fax: +44 (0) 1792 295708
{m.l.wilson, csdanc, s.n.w.robinson, matt.jones}@swansea.ac.uk

Abstract

Ten years ago we were on the verge of having cameras built into our mobile phones, but knew very little about what to expect or how they would be used. Now we are faced with the same unknowns with mobile projector phones. This research seeks to explore how people will want to use such technology, how they will feel when using it, and what social effects we can expect to see. This paper describes our two-phase field investigation that uses a combination of methods to investigate how, when, and why mobile projections may be used. The first study used an experience sampling method to investigate responses to a range of different media types, and, for example, the choice of surfaces used in each case. The second study asked users to create video diary entries showing when, where, and why they would have wanted to project information. Together these studies provide complementary insights into the future use of mobile projector phones. Our results cover detailed responses to a range of media types from the first study, while the second identified which of the known mobile information needs were commonly recorded by participants. Both studies provide insights that may help shape the hardware, software, and interaction design of mobile projector phones as they become increasingly available.

Keywords

Pico-projectors, diary study, experience sampling, mobile

1 Introduction

More than a decade ago we were anticipating the arrival of camera phones, and investigating how and when people might use them. Today we await the widespread arrival of mobile phones with built-in projectors, and are faced with the same kinds of research questions about their future use. Notably, however, while cameras were added as an input method to mobile phones, projectors will become a new style of output, and one that that will have a much more external social and public impact. This article reports on two complementary studies that evaluate both what people expect they might use future mobile phone projectors for, and their reactions to a working prototype.

Early academic expectations for camera phones were varied, with some researchers predicting elements of how photographs might be widely shared between people using mobile phones [1]. More modern sharing mechanisms, however, have meant that our use of camera phones has far outstripped original expectations [2], even after extensive and elaborate use case studies (such as that conducted by Frohlich and colleagues [3]). News channels now actively request images and videos from the public, and anybody can be the centre of attention (for good or bad reasons) when a photo is distributed automatically through a social network.

Now, with small mobile (pico) projectors becoming more readily available, and with their size shrinking to mere centimetres, the potential for their integration into mobile devices such as phones and PDAs is increasing dramatically. Indeed, manufacturers have already released prototypes of just such devices[1]. With research confirming that many people have their mobile device with them the vast majority of the time [4], it therefore makes sense that potential uses of personal projection technology should be an area of active examination.

Below, this paper first covers related work, both in how our community studied the imminent and early onset of camera phones, and other early work on pico-projection and mobile projector phones. In Section 3 we describe our two user studies. The first, in Section 3.1, uses an experience sampling method, with a working prototype as a probe, to see how people react to both their own and to other people's projections. Section 3.2 then describes a video diary study of when and why people might wish to use mobile projection in real-life circumstances. Section 4 concludes with the main findings and contributions of our research.

2 Related Work

Recent advances in personal pico-projector technology have made personal projectors viable for the consumer market, with models now commercially available. Improving upon early LED-based

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* Contact author

[1] http://www.pcmag.com/article2/0,2817,2356407,00.asp

devices, laser-based projectors have eliminated focus issues and further extended battery life[2], making the technology not only accessible to consumers but also practical for small hand-held devices. More recently, these have begun to be embedded directly into mobile phones, with the first – ChinaKing's Epoq – released online in August 2008. Since the Epoq, major mobile phone companies, including Samsung and LG, have demonstrated high-level prototype phones that are set to become available in the phone market.

Before the widespread availability of consumer devices, however, researchers have been keen to investigate their potential. In lieu of working with real phones, many researchers have created prototype devices. Greaves, Hang and colleagues, for example, conducted a series of studies to examine a possible use of projections for photo-sharing and map interactions [5,6], using a mobile phone strapped to a desktop projector. The projector was connected to a laptop to provide a higher projection resolution than that available from the phone, and Bluetooth was used to synchronize the displays.

Comparing screen, projector, and screen-plus-projector variations showed that the phone's screen was important for text entry, but having the higher resolution projection improved task performance and satisfaction. Using similar desktop-projector lab studies, Beardsley *et al.* investigated the possible use of mobile projections to augment physical environments using small desktop projectors controlled via a joystick [7], and Blaskó *et al.* explored an alternative touch-screen-based control system for wrist-mounted projection systems [8]. Both Karitsuka *et al.* and Sugimoto *et al.* experimented instead with the use of infrared tracking to both correctly display and track personal projections for both single [9] and multiple [10] users.

After creating an easily-controllable prototype mechanism for moving small desktop-projections freely by hand [11], Cao and colleagues examined co-located collaborative applications of handheld projections, allowing two users to combine or overlap their projected content [12]. Their shoulder-mounted hand-controlled projector system was used to study methods for tasks such as exchanging pictures or enhancing another person's projection with their own annotations.

Focusing more on the portable usability of mobile projector devices, rather than social interactions, McFarlane and colleagues discussed 'interactive dirt', exploring the potential for wearable shoulder-mounted projectors in the extreme conditions of the military to project vital tactical and support information [13]. Turning to a more commercial environment, work by Raskar *et al.* has augmented stockroom items with personal projections, based upon integration with RFID tracking systems [14]. Both systems allow, in different ways, environmentally-relevant information to be superimposed on surroundings.

[2] http://www.microvision.com/showwx

Aside from McFarlane and colleagues, many of these studies have been limited to lab environments due to technology constraints, but since handheld projection devices have become commercially available, more studies have moved into the field. For example, whereas Schöning, *et al.* evaluated a map augmentation system utilising a cameraphone and a projector in lab conditions [15], Greaves and colleagues projected maps in public spaces and enlisted the support of bystanders for directions [16]. Like early SMS and camera phone studies, participants were unsure how or when projector phones would be used. Further, unless directly addressed by the experimenters, the majority of bystanders did not react. Some participants, however, were concerned about accidentally projecting private data. Later, Greaves and colleagues also complimented the earlier lab work by Cao *et al.* (cf. [11,12]), by investigating sharing mechanisms and privacy issues with more portable phones and hand-held pico-projectors [17].

Small in-situ projections have been studied for use in creating ad-hoc user interfaces in the environment or even on the body. Both Mistry *et al.* [18] and Harrison *et al.* [19], for example, have utilised pico-sized projections for different skin-based gestures as inputs, allowing users to create pervasive interactive interfaces on the body. Automatically-reconfiguring systems such as that presented by Raskar, *et al.* [20] are beginning to allow relatively unhindered utilisation of such distorted surfaces, even with multiple projector-equipped users. Further, both Chan and colleagues [21], and Benko and colleagues [22] describe mechanisms to address the problems of non-tangible interaction with projected content in a range of complex environments.

One common theme of pervasive projection has been interaction in augmented reality scenarios, where projections can enhance environments with visual content. Molyneaux and colleagues, for example, examined a more general augmentation of 'smart objects' [23], augmented both by projection and the object's ability to convey information about itself. Similarly, studies by Gupta and colleagues have presented 3D tracking of items such as blank book pages to project perspective-corrected and warped content [24]. These studies have typically focused on technological challenges associated with tracking objects in the environment, and mapping perspective-corrected content into them.

The research covered above has focused on a range of scenarios, within four main categories: 1) projections in a range of environments, 2) sharing between users, 3) guiding one or more users, and 4) augmenting physical objects and surfaces. The investigations into different environments and surfaces consider that projections may have to adapt to different textures and shapes, and have focused on distortion and correction. Both the simple display and actual exchange for sharing different multimedia have been frequently considered, as has the displays of maps for in-context guidance and navigation. Further, researchers have considered how projections may augment physical objects, such as public displays and maps, and also collaboratively augment or work with other projections. After second-phase study below, we discuss the potential projection scenarios that were identified by our participants.

Our research continues with the theme of studying real potential uses of projections in the wild, like the studies performed by Greaves and colleagues, rather than in the lab. In lieu of acquiring consumer-level mobile projector phones, we have used a combination of methods to a) gauge responses to a range of media, and b) investigate real self-motivated needs for projected content.

3 Complementary User Studies

With the same exploratory aims as the early studies into the potential of camera phones (e.g. [3,1]), our focus has been to explore where and how people might use projector phones, and how they may feel while using them. However, while camera phone studies investigated the creation of new media, projection usually involves the display of existing media. We chose to perform our research in two phases to study both participant reactions to a range of pre-set media types, and their potential self-motivated uses of projections.

Our first-phase study used the Experience Sampling Method (ESM) [25] to elicit the reactions of participants to a range of media regardless of whether they would consider projecting them during undirected usage. In the second phase, we performed a diary study of potential mobile projection scenarios. Although consumer-level mobile projector phones were not available for use or study at the time, we believe that using prototype systems allowed participants to concentrate on the potential use of such devices, rather than the qualities of a finished product. The reactions in the first-phase study also helped to finalise the design of the materials in the second study, which in turn provided deeper insight into the reasoning behind the possible projections recorded in the second. Further, the more controlled nature of the first study provided insights into how people might react to a range of projection types that would not be observable by simply performing a diary study of self-motivated projector use.

3.1 Study 1: Experience Sampling Exposure to a Range of Media

The aim of our first study was to gain insight into people's reactions to both the projection of content, and to seeing projections of other people's content from mobile devices. A range of media types were chosen and delivered through a prototype probe, using an ESM study. The ESM allowed us to both control the timeliness and type of content being projected, and to investigate responses to multiple media types in different scenarios. Elements of this work have been previously reported in non-archival proceedings [26]; here, however, we re-present the study before describing and discussing our results and their implications in much more detail.

Fig. 1 Study 1 apparatus, where the projector and a pen video camera face the same direction

3.1.1 Materials

In lieu of a consumer-ready mobile projector phone we created the prototype shown in Fig. 1. The device consists of a standard mobile phone attached to a handheld pico-projector. Further, by pointing a pen video camera in the same direction as the projector, we are able to gather video recordings of projection events in context.

3.1.2 Method

After three single-user pilot studies, which allowed us to make the prototype more robust, 15 participants, aged between 18 and 65 (8 younger than 35 and 7 older) were provided with the prototype device for either one working day (7 males and 5 females) or a weekend (2 males and 1 female – see Participants 13-15 in the analysis). 12 of the 15 owned camera phones, with 11 using their phones, in general, at least a few times a day. All had at least a diploma, with 6 currently working towards a range of degree programs. One participant had once used, but did not own, a handheld projector. Participants were recruited, on a first-come first-served basis, by sending a mass email to staff (academic and non-academic) and students across the university.

Each participant received five ESM events each day, which presented one of 5 types of media: 1) a website, 2) a Google map, 3) a slideshow of photos, 4) a short TV clip, or 5) a text message. The examples chosen for each of these types of media were controlled as part of the study, rather than content created by users. Although this meant that the content was not personal and meaningful to the participant, the range of media and the times each was presented were designed to capture a range of responses to different content in both working and social spaces. Further, there were slight variations within each media type, such as a work message or a casual message, a comedy

video and a news clip, or a sports website and a social website, to elicit more nuanced responses to content. The involvement of weekend participants also provided a) an extended experience using the prototype, b) projection events in the home, and c) events outside of daylight hours. All participants signed consent forms, completed a demographics questionnaire, were led through a demo event, experienced their own demo event, and were provided with a help sheet and device chargers. To end the sessions, each participant received a short debrief and was given a bookstore voucher as a token of our appreciation.

Each ESM event, initiated by a beeping alarm, lasted around 2-5 minutes and comprised of 4 stages: 1) setup, 2) projection, 3) take down, and 4) questions. During setup, the user was guided by on-screen instructions to connect the phone to the projector and turn on both the projector and pen camera. When ready, the participant was asked to project the content onto any surface until the phone instructed them to stop. Take down involved disconnecting the phone and projector, and turning off both the projector and pen camera. Finally, nine on-screen, 7-point Likert scale, and two yes/no questions were asked about each event, regarding aspects such as projection clarity, emotional responses, and social responses. Users were able to immediately begin, delay, or cancel the event if particularly inconvenient. Cancellations were discussed during debriefing. For each event, the time, content-type, video footage, and answers to questions were automatically recorded.

3.1.3 Results

A total of 90 ESM events were triggered, and only 7 were cancelled, 4 of which were during the weekend. While being outdoors was the most cited reason for cancellation, the rest related to events such as meetings. 6 events were delayed, 5 of which were during the weekend, where the participant did not keep the prototype close to hand and did not hear the alarm. Although two participants found the combination of technologies confusing, most used the device confidently, with one even saying *"[It was] really pleasant to use."*

Social Responses. 51 events were triggered while participants were not alone, and participants reported choosing a socially visible projection space on 34 of these occasions. The average number of people present at these 51 events was 2.44. In line with previous anecdotal evidence [16], complete strangers only stopped to watch for 11 events. Further, no bystanders were reported as having commented or engaged during these few events. Participant P1 said: *"One person looked up, but then continued working."* P5 said: *"Other people were around, but no comments."* Participants felt that projection clarity had a significantly larger effect on surface choice when in the presence of colleagues, friends, or family ($t(80)=2.88$, $p<0.01$). In public spaces, and perhaps surprisingly, participants did not feel significantly less comfortable or safe, nor significantly more self-conscious. Participants did, however, report projections as being significantly more useful when in public ($t(80)=2.19$, $p<0.05$), whilst finding it significantly harder to locate a suitable surface ($t(80)=2.39$, $p<0.05$).

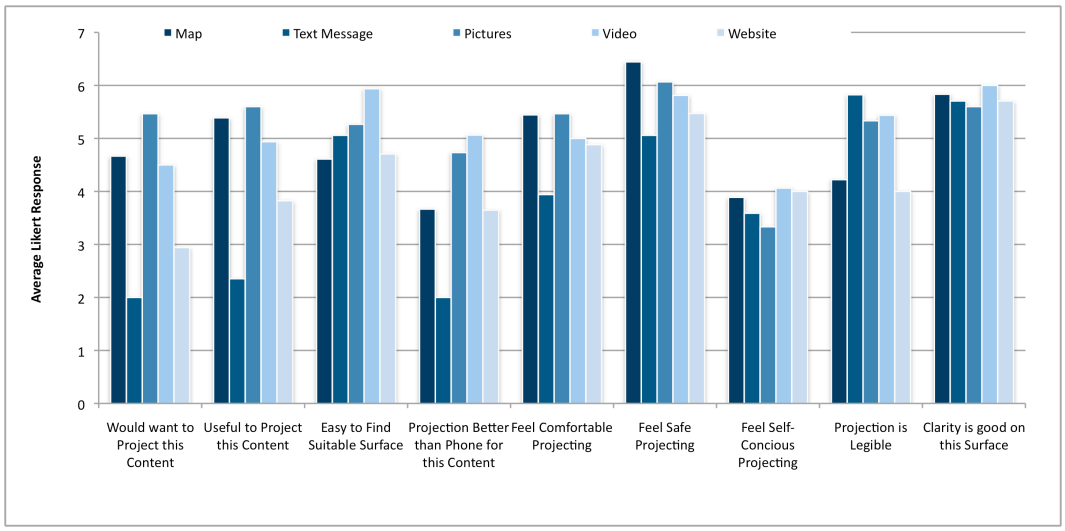


Fig. 2 The average subjective responses per media type

(a) (b) (c)

Fig. 3 Example surfaces captured by the pen cameras: (a) on the floor outside, (b) a PC monitor and (c) on another person's thigh

Friends and colleagues present during projections were reported as 'interested', but mainly in the novelty of the prototype rather than the content being projected. While participants in social groups often joked and commented about novelty uses and surfaces (such as people's foreheads), very few playful projections were recorded. P9 did project onto a colleague, and a friend of P9 used the prototype to project personal holiday photos from their own phone during a coffee break. Notably, this occurred before the participant had received a photo-based ESM event. P10 said that they would regularly use a projector phone *"for [pictures from] family events and things, instead of the TV. It's just easier."* Another participant said that it would provide an easy medium to share digital media with elderly people. Beyond social sharing, several additional use cases arose, including support for a travelling salesperson. Further, a participant suggested that it might be a useful way to quickly inject content during a meeting, without having to change the laptop plugged into a full-size projector. Another participant said it would be a useful tool for off-site teaching, where they could not be sure of the projection facilities available at their destination.

Personal Responses. The responses given by 1-day and weekend participants varied significantly for 2 of the 9 subjective questions. Weekend participants felt significantly less self-conscious

($t(81)=2.35$, $p<0.05$) and noted that clarity had less of an affect on surface choice ($t(81)=2.34$, $p<0.05$). Within the analysis by media type shown in Fig. 2, the differences were significant for: a) wanting to project that media from their own phones ($F(4)=5.87$, $p<0.0005$), b) being useful to project this content ($F(4)=6.43$, $p<0.0005$), and c) the projection being better than the phone screen ($F(4)=3.45$, $p<0.05$). Post-hoc Tukey tests revealed that this significance lay between the low scores given to text-messages compared to maps, pictures and videos ($p<0.01$ for all). P1 said: *"[The text message] made me feel self-conscious, even though I was alone."* and P8 said: *"I wouldn't project [a text message] though. Never."* While many participants noted concern over projecting private messages, a deeper analysis showed that statistically lower scores ($p<0.05$) were given to work-oriented text messages for being a) useful, b) better than when viewed on the phone, and c) causing them to feel self-conscious. P11 said that their work email often included confidential data that they wouldn't want to project.

No significant variances were found over other media types, although 4 participants said that the level of detail in web pages, and sometimes maps, was too high for the projector, and that they had to refer to the screen to clarify. This is reflected in the lower scores given to websites and sometimes maps in Fig. 2. Several participants suggested, in line with previous studies [5], that the projection should be of a different resolution to the phone. P10 said: *"Effectively, it's about getting a bigger screen, so showing the mobile web is not great."* Similarly P4 suggested that a different resolution could display long text-messages and emails without scrolling. Otherwise, as P10 put it, *"[A short message] doesn't need a big screen"*.

The data from weekend participants were further analysed for repetition effect, as these participants saw each media type twice. Although not significant across 30 events, the averages for each subjective question, except for comfort and safety, typically improved by 1 point on the 7-point Likert scale between the first and second experiences. When asked if the projection was better than the phone screen, for example, the average score rose from 2.93 (worse than) to 4.91 (better than) between the first and second times viewing each type of content. This result, and the improvement on a) wanting to project and b) finding it easier to find a suitable surface, suggests that experience led participants to see the projections as more valuable.

Surfaces. In addition to the 7 cancelled events, the camera was unable to capture the video footage of 4 others. During the 79 events captured on video a total of 195 surfaces were used. Of these, 75 were reflective surfaces and 120 were matte. Participants typically tried many surfaces. Table 1 shows all the surfaces tried, and the main (primary) surface used during each ESM event. Primary was defined as the surface that the participant settled on for the majority of time during the ESM event.

Although a wide range of surfaces were used, including bins, windows, and those shown in Fig. 3, the majority were walls, tables, floors, and ceilings. These, however, were biased to 1-day participants. 93% of the desk/table projections, for example, were by 1-day participants. 3 of the 5 door projections, however, were by weekend-trial participants. The most commonly used surface

by weekend participants was still the wall (24/51). Two potentially interesting surfaces, however, were paper and computer monitor. The former of these, according to comments during debrief, were in the quest to find a clean white surface. Participants may have thought the latter would provide a suitable surface, as it is built to display digital content. Notably, from

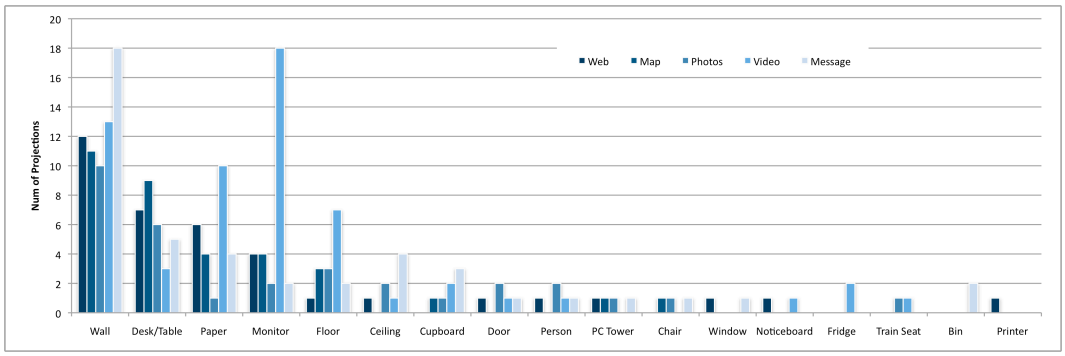


Fig. 4, computer monitors were mainly used for video projections.

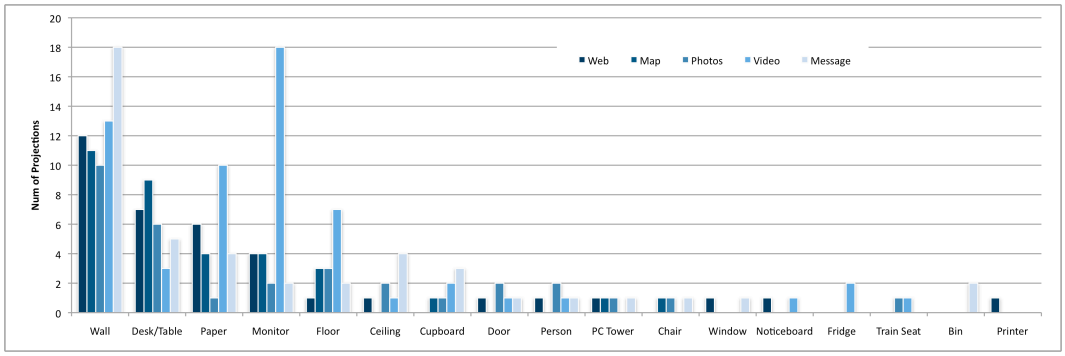


Fig. 4 also shows that text-based messages were nearly always projected onto walls. Three participants did note that dark surfaces were more suitable – P8, for example, said *"Dark is definitely better"*. P15 further noted that, for all media except the map, the back of a chair was best. The map, however, was particularly affected by distortion caused by the chair's curvature. Several participants also noted that surface colour had a large effect on projections, suggesting that black and white content was often clearer as surface colours did not affect the colour of the content.

Surfaces	Times Tried	Used as Primary	Surface	Times Tried	Used as Primary
Wall	76	47	Person	5	0
Desk/Table	30	7	PC tower	4	1
Paper	16	8	Chair	3	0
PC Monitor	14	5	Window	2	0
Floor	12	5	Pin board	2	0
Ceiling	11	2	Fridge	2	1
Cupboard	8	0	Train seat	2	2
Door	5	0	Total	195	79

Table 1 All 195 surfaces tried and 79 primary surfaces used during the 79 events captured by the pen video cameras. The primary surface was determined by the number of seconds spent on the surface during each ESM event.

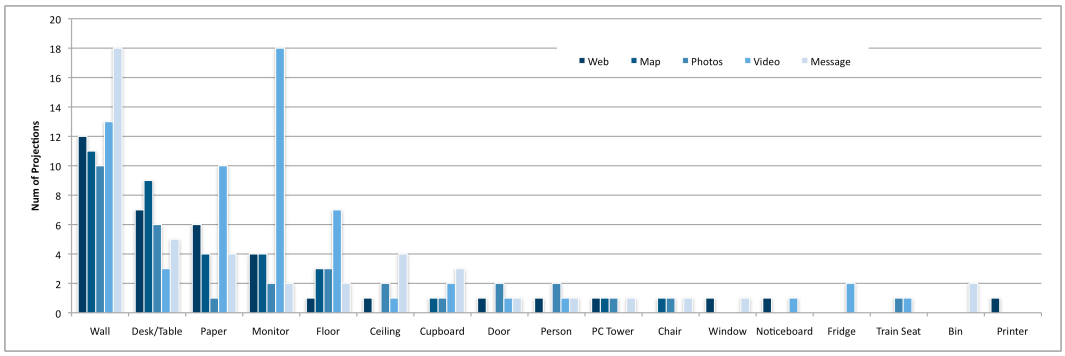


Fig. 4 Graph showing use of surface by media type

Finally, while many participants tried to enlarge projections by moving further away from a surface, the projector was often not bright enough to do so. Consequently, while maintaining a visible picture, some participants struggled to get a sufficiently large projection, with P1 saying: *"[I] tried the desk, but the wall was better. I had to stand up for the desk."* Another participant, after projecting on the back of a train seat, noted that it was difficult to get a sizeable projection in a confined space. Four participants further expected to go from small to large projections within an arm's length, with many using their arm position, rather than the projector's controls, to focus the content.

3.1.4 Discussion and Summary

Despite involving a slightly bulky, multi-part prototype device, this study generated high levels of participation, most notably in the in the large range of surfaces tried during the study. While many obvious surface types were tried, we discovered some features of surfaces that affected their suitability for different media types. Flat surfaces, for example, were important for media like maps, in order to avoid distortion. Further, we saw preference for surface types that were entirely black or white. Subjective responses indicated that participants found surface to be an important factor for projection clarity, but that good surfaces were sometimes harder to find in public spaces.

Most surprising amongst our results was the negative reaction to projecting text-based content such as text messages and emails. Despite being fictional study data, participants reported physiological and psycholigical reactions to seeing content, reasoning that private or confidential data might be accidentally seen by others. This reaction, conversely, was not present as people saw lots of potential in projecting pictures in public spaces. In analysing repetition effect, however, we saw a subjective responses increase positively in all cases, suggesting that participants became more comfortable with projection over time.

Limitations of the Study

Clearly it would have been more appropriate to perform this study using a consumer-level device rather than a multi-part prototype; however, the style of this study allowed us to control the types of content evaluated. We worked hard to minimise the complexity and size of the prototype, and consequently saw good participation levels. The length of the study and number of participants could also be increased, but we sought to minimise impact on participants' everyday lives while maximising results. Additional weekend participants, however, may have produced more significant findings.

3.2 Study 2: Diary Study of real pico-projection needs

The first study, although providing several insights into how people might react to several types of media in different contexts, was ultimately based on an arbitrary selection of content that was not personal to the participants. Although this is a limitation in ecological validity that is common in many task-oriented or controlled user studies, we wanted to extend the research to get a more user-led and personal sense of how mobile projector phones might be used. Consequently, we conducted an exploratory diary study, in which participants were recruited to record video entries about times when they would have liked to project personal content. While the first study explored reactions to a range of media that we, as experimenters, created, the second study aimed to investigate the contexts and desires for real-life projection needs. No actual projection device was provided, and so the study was simply a video diary of events where participants recognised that they would like to be able to project content from their mobiles phones.

This method of obtaining swift in-situ data, and allowing participants to elaborate on it upon later review, is similar to the 'snippet' method evaluated by Brandt and colleagues and was found to generate much more complete entries [27]. The use of a video diary as the 'snippet' mechanism has also has been *"clearly shown [to] help people recall activities in their working lives [and] is also useful in confirming and disconfirming what people think might have happened"* by Eldridge and colleagues [28].

The aims of this second study were threefold. First, we simply wished to discover which potential projection scenarios exist in participants' everyday lives. Second, we intended to examine the kinds of content that users expect or wish to be available at each location, both with regards to subject matter and media type. Third, we wished to look for correlations between potential projection choices and user traits, as determined by pre-study interviews.

3.2.1 Participants

13 participants were recruited for the study by means of e-mail to university staff and students. Eligible participants were chosen at random from the responders, where eligibility was determined as: not being from our own research group or department (and not be known to or be likely to have come across the authors work); they must own a mobile phone and use its camera; they must use social networking websites in some form to share media; and they must have access to the

recording device and the Internet (for logging purposes detailed below) throughout the study. Participants' affiliations from within the university were widespread, with a range from Engineering to Humanities, and from faculty, administration, and both graduate and undergraduate students. Mid-way through the experiment, one participant's external commitments led them to withdraw from the study, leaving data and observations from 12 participants (7 male and 5 female). After completing the study, each participant was given a £15 Amazon voucher as thanks for their time and effort.

3.2.2 Method

Pre-study Preparation

Each study participant took part independently for one week, including a weekend in order to capture casual use as well as work-oriented contexts. Participants were met in our research lab on a weekday afternoon at their convenience. After explaining the purpose of the study, a pre-study questionnaire was completed in order to capture demographics and subjective familiarity with related technologies: 1) mobile phone usage confidence; 2) frequency of media capture on their phone; 3) social networking usage frequency; 4) media sharing frequency via social media; 5) public speaking confidence; and 6) artistic work creation frequency. Ownership of different technologies, such as televisions and computers, was also recorded by means of a simple checklist.

After the pre-study questionnaire, participants were given the opportunity to examine and use a pico-projector to get an idea of how personal projections might work. Although they were not provided with a projector for the study, this exposure was aimed at helping them to understand what could be achieved with mobile phone projection in the near future. Participants were then given training with the Flip Video[3] camera that they were to use to record video diary entries for the duration of the study.

Diary Entries

Over the course of the week, whenever participants encountered an information need that they felt could be best satisfied by means of projected content, they were asked to briefly film the location, and state: 1) where the potential projection was, 2) what content they wished to project, 3) what surface they would have chosen, 4) roughly what time of day it was, and 5) how they might feel actually projecting in such a space. As a reminder of what information was required about the observation, each video camera had a tag attached to it that simply stated 'What? Where? Time? Content? Reaction?' – it was clear from transcriptions of the video footage that this prompt was used by many of the participants to structure their diary entry.

[3] http://www.theflip.com/en-gb/

At the end of each study day, participants were instructed to log on to an online data entry system with their unique ID, review all of that day's videos on their camera, and fill out a form that allowed them to both categorise and describe their observations. Specifically, users were asked to enter:

1. Date – "What day was the observation?"
2. Time – "Roughly what time of day was this at?"
3. Location – "Where were you? (e.g. Library)"
4. Surface – "What would you have projected onto? (e.g. Desk)
5. Content – "What would you have projected?
   (e.g. Book reviews)"
6. Content type – "What form would this have been in?"
7. Reaction – "What reaction did you get from those nearby?"

The selectable time was split into ranges of four hours, listed as: Wake up – 12pm, 12pm – 4pm, 4pm – 8pm, and 8pm onwards. These options were chosen so that participants did not have to worry about remembering the specific time, but would still provide useful categories for analysis. Content type was selectable from a list of image, video, text, web, document, and interactive. This was only specifically asked in the online system, giving participants time to reflect on this point. Onlooker reaction was selectable from a list that included: no reaction; positive; curious; negative; alone (not applicable).

During the study, a mid-week phone call gave participants the opportunity to ask any questions they had about the study or the technology, and to discuss any problems they were facing.

Debriefing

At the end of the study, participants were met to debrief. They returned the video camera (from which their videos were later downloaded), and were asked to both complete a post-study questionnaire and take part in an interview where they had an opportunity to elaborate on thoughts and questionnaire entries. Again, Likert scales were used to capture user reactions to various statements about their experiences, including: embarrassment during filming; anticipated embarrassment during actual projection; likelihood of projecting content if possible; perception of any content sharing advantage with personal projection. Finally, we asked participants to recall the diary entry that they felt contained a projection with the most potential benefit, and the one they felt most embarrassed to film in. Both were used to examine the general boundaries of comfort with the contexts discovered.

3.2.3 Results

In total, 74 diary entries were submitted during the study, with an average of 6.2 per person, or one a day. Example shots from the diary entries are shown in **Fig. 5**. One participant only submitted 2 entries, while another identified 23 occasions where they might wish to make a projection.

(a) (b)

(c) (d)

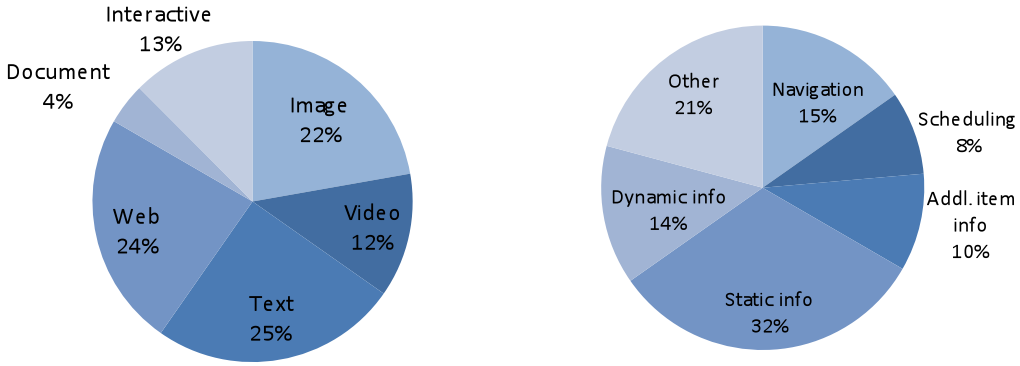
Fig. 5 Four examples of the focus of diary entries, some of which can be explicitly identified in **Table 2**; (a) shows products on a shelf, (b) shows a timetable, (c) shows a library bookshelf, and (d) shows a dental office sign. In each case, users wished to augment the surface with additional information

To assist in interpreting the responses beyond the broad categories selected by participants, two judges coded diary entries independently. The separate codes were then discussed and agreed by both coders, before being validated by a third independent judge. The analysis below, therefore, is based upon these codes and elaborated using qualitative statements from participants.

Types of content

The most commonly identified content types during the diary entries were: text, web and image (first, second and third respectively). Notably, even though mobile devices and projectors are capable of vibrant colours, animations and interactivity, the most frequently chosen category was informational text, as shown in **Fig. 6** (a).

Further, as shown in **Fig. 6** (b), we examined the type of information identified within these potential projections. We categorised responses as: navigational, scheduling, additional information, static information, dynamic information, and other (i.e. non-informational content). Dynamic information was differentiated as whether it was 'information that will be different each time it is viewed'. A recipe (P10) was an example of static content. We also considered observations such as the list of prices in a coffee shop (P1) in this category, as the information would not change dynamically. However, information such as the current song playing in a bar (P6) would evidently change. Notably, nearly one third of all identified projection needs included static informational content in our diary study.



(a) (b)

Fig. 6 Content identified in diary entries, categorized (a) by media type, and (b) by information type

As has been noted in prior work (e.g. [5]), navigation is evidently a very useful area to examine, with many participants wishing to create projections to help them find certain locations. Notably, the participants in our study identified in-situ directions more frequently than projected maps. Despite the work by Cao and colleagues [11,12], only 4 people identified the possibility of photo sharing, making up only a small proportion of the 'other' category.

Participants in our diary study identified 10 of the 15 general mobile information needs that were found by Sohn and colleagues [29]. These results, as shown in **Table 2**, indicate that the majority of the mobile information needs could be resolved in some way by using mobile projection. The top category discovered by Sohn and colleagues was 'Trivia', but this was not identified as something that would be projected by our participants. Additional categories not found in our study were 'Friend info' (finding the location of friends); 'Phone numbers' (this is likely not typically projectable content in most scenarios); 'Traffic'; and 'Weather'. The similarity between the findings of the two studies was calculated using a Pearson correlation, where a score of 0.65 was observed.

Categories by Sohn et al.	Example text	Our %	Sohn et al. %
Directions	*"Location of a [specific] text book within library."* *	10.8	13.3
Points of interest	*"[Location of] hairdressers nearby."*	5.4	12.4
Shopping	*"Online customer reviews of particular [DIY] tools."* *	9.5	7.1
Personal item	*"A reminder of when your [Dentist's] appointment is."* *	6.8	6.4
Schedule	*"Expected time of arrival of next bus."* *	9.5	5.7
Sports / stocks / news	*"News article and URL."*	2.7	3.8
E-mail	*"Search for e-mail on a portable Internet device … when you have forgotten a piece of information."*	1.4	2.6
Movie times	*"What is currently being shown in the cinema."*	2.7	2.4
Travel	*"Map, we were discussing travel plans."*	2.7	1.0
Recipes	*"Recipe from book."*	5.4	0.7

Table 2 Entry count correlation with Sohn, et al. [29] information needs categories, starred entries can be seen explicitly in **Fig. 5**

Content Availability

We also classified the identified projected content as to whether the information was already available in the environment. A shopping centre map (P10), for example, was already available at a nearby information stand, and so would be classified as 'available'. Contrastingly, the accurate and up-to-date arrival time of the next bus at a bus stop (P1) was not available nearby (the video provided context that the bus stop had no electronic display), and so is classed as 'unavailable'.

65% of observations provided content or information that could be accessed elsewhere. In some cases, this manifested itself as participants wanting information displayed inside a location such as a shop (P1) without having to enter the premises. In other cases it meant participants could access information without crossing a room to use a laptop (P7). Not all of this category's observations imply lack of motivation to move, however, with some wishing to share photos that could be otherwise seen on the mobile devices.

Location Sensitivity

53 observations (72%) had content related to either the participant's current location or the object being filmed. Of these 53, nine (17%, 12% overall) were related to an object, and, of those, only three (33%, 4% overall) observations discussed directly augmenting an object. The data here support the notion that projected content is frequently prompted by one's surroundings. However, at least in this study, it seems likely that there is little demand for directly augmentative projection, even though previous research has found this to be efficient and efficacious [30]. It is possible,

given the design of the study, that participants simply hadn't conceived that content could be augmented with a projection.

Time Sensitivity

Although we did not find any specific trends over the time of the day, we examined the timeliness of the information in projections, as shown in **Fig. 7**. We denoted four categories: immediate use, intermediate use, long-term use, and non-use.

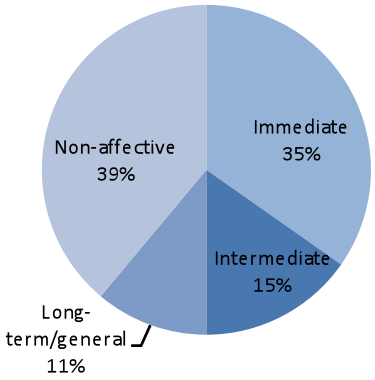


Fig. 7 Categorisation of the how immediately projected content was to be used

The location of a textbook within the library relative to one's current position (P1), for example, is for immediate use. Most navigational observations fell under this coding category. Conversely, the cooking possibilities for a particular ingredient (P9) are for use in the near future (intermediate) – it does not effect a decision being made at that point, but in the medium-term it has (or has potential to have) be used. A long-term example was the use of a map to examine a potential holiday country a few months ahead (P5). Non-use includes general information gathering such as identification of flowers (P9) and recent camera images (P10). Many of the categorisations are contextual in nature, and for this reason the video footage recorded by participants was examined in ambiguous cases, and validated by the independent third judge.

The majority (57%) of the projected content was for *immediate* use. Intermediate and long-term use combined was still less than that of immediate. *Non-use* content was marginally more frequent, however, which suggests that mobile projector phones should equally support mechanisms for delivering informational content for situational learning, as well as specific (possibly detailed) content to aid short-term decision-making (for immediately use).

3.2.4 Discussion

Although the diary study was aimed at identifying types of content that people wished to project during the study (and their reasons for doing so), we were also interested in many of the related

aspects to projection, such as choice of surface and individual variation. We discuss those now briefly, before drawing conclusions from both studies below.

Surfaces

As with our first study, the majority of surfaces sought for projection were flat. In the first study, 96% were flat, and here 91% were flat. The most deformed surface in the first study was the back of a chair, where here one participant noted using a car dashboard. Further, 29 observations (around 40%) were recorded as using 'wall' as their primary projection surface, where as in the first study of actual projection decisions, walls were used nearly 60% of the time. The difference here may well be between the desires of participants in this study, when compared to the actual limitations of projection technology from the first study.

Participant variation

The pre-study technology ownership checklist provided reasonably predictable results, with all participants owning a camera phone (a selection criterion), six of which were knowingly video-capable, and only one of the participants owning any form of projector. All participants owned either a laptop or netbook/tablet PC, but we saw the greatest correlation (Pearson 0.79) between the number of recorded observations with netbook ownership. The two participants that submitted the most observations both owned a netbook, and not a laptop. Further, both participants, and the participant with the next largest number of diary entries, owned a high-definition television. It could be surmised that those with a large high-resolution display were accustomed to the content size, potentially exacerbated by the relatively small screen size of a netbook.

Indeed, previous research has shown that those wishing to share videos, for example, often look for methods to display the video to a larger audience, of which personal projection is evidently one. For many, the most commonly used display medium is the largest screen at home, whilst away from home *"a lot [of videos are] left without showing"* due to the inability to share with many people [31].

As a minor validation point, there was minimal correlation (Pearson 0.09) between the number of entries and the ownership of video cameras. This, combined with the pre-study introduction to the camera, essentially rules out observation count skew due to technological unease. There were no other notable correlations between number of diary entries with other pre-study recordings, including social sharing.

Private content

One finding that potentially challenges the results of the first study was the *increase* in the amount of 'personal items' that were projected. While our first study discovered that participants had reservations (some strongly so) about projecting content such as text messages, we found in this study that privacy was flexible. Projection by its very nature is a public medium, and mobile

devices are very personal objects [32], yet we saw participants considering projecting this personally relevant content more whilst in public (54% of all observations) than in private surroundings (46% of all observations). Even items as basic as photos can be considered very personal, yet participants still felt happy to display them via a relatively open and public medium. Indeed, systems are being created to extend and enhance this medium's sharing potential for this content [16]. The study by design, however, notably attracted diary entries of where people *would* choose to project content, and may not have recorded clearly the occasions when users definitely would not choose to project.

Participant perspectives on future mobile projection

During their 2-week study of general mobile information needs, Sohn and colleagues found participants recording an average of around 10 needs per week [29]. Although we saw notable variation between participants, we received an average of 6.2 per participant. This potentially indicates that around two thirds of mobile information needs could be satisfied or facilitated by mobile projections. The post-study questionnaire and interview provided considerable insight into participants' motivations and feelings towards the study and the technology used, as shown in **Table 3**, noting that participants appeared to be excited about the potential of personal projection, without expecting to feel much embarrassment.

Statement	Avg.	Worst	Best
"I believe projecting content would make sharing content easier"	2.1	7	1
"I would be likely to project content from my mobile device if possible"	2.8	7	1
"When around others during the study, I found it embarrassing to film"	4.7	7	2
"I would be embarrassed to project content from my mobile device in public"	5.5	7	3

Table 3 Study/technology response Likert selections (1 = strongly agree, 7 = strongly disagree)

For locations that provided the most personal projection potential, four participants chose their home. Two of these commented specifically that they were more likely to have bare, plain walls at home. Two selected an academic scenario (lecture and lab) as their choice, and a bar, train station, and shops were all chosen by one participant. Two participants declined to comment. P7 envisaged many uses commercially, especially if the content was provided by the company themselves. They specifically mentioned being introduced to similar products in a supermarket when browsing, just as online shopping web sites often provide purchase recommendations based upon a user's shopping or browsing history.

From a number of participants, it became clear that there was a bias towards existing technologies simply because of the familiarity with them. Many also talked about screens being deemed satisfactory, with comments such as *"If I wanted to show you something, I'd just pass you the phone."* This discussion of current technologies even went as far as participants specifically

mentioning linking devices such as iPods to pico and mobile projectors. Notably, however, even those participants who had submitted few entries, or who had given poor Likert responses to ease of use or personal use, still stated they could see scenarios where the technology would be useful.

Participant 8, for example, hinted that projection size could be an important factor in them choosing to use projection where they would not otherwise. *"Personally I'd only project something if it was important. But if [the projection] was [much] bigger, people wouldn't have to crowd around."* Participant 5 also commented that resolution *"might be a turning point"* for them. Some participants commented on the environmental and non-consumable nature of projection: P8, for example, commented that they could see the technology saving *"money, paper and time."*

Personal Safety

Although much of the discussion of personal projection, including our first study, was focused on people feeling nervous about using such technology in public spaces, two participants in our second study noted that projections could enhance personal safety by creating transient personal spaces. Where streets do not have explicit bicycle lane, for example, one participant suggested that a cyclist could project an ad-hoc lane around their bicycle. Although this aspect has not been considered so frequently in prior work, projection for safety may also have multiple applications in many locations, including in care homes. The elderly may benefit from the technology, especially since they often fall under the reduced-visibility category, and may benefit from larger dynamically changing content.

In reviewing related work we highlighted some of the key scenarios that have been suggested in research to date, and some of these are evident in the results of this study. Participants showed interest in both contextual and non-contextual information, map display and augmentation, projection onto distorted surfaces and simple ephemeral projections. We did not see, within our study, any participants desiring collaborative projection, or tracking and augmentation of moving objects, although these could have been affected by the scope of the studies performed.

Limitations of Study

Diary studies always suffer the limitations of self-reporting and reflection on the past. To mitigate these effects, participants were provided with portable light-weight video recorders to capture rich multimedia diary entries at the time, which included prompts to maximise content. Again, this study could have benefited from real projector phones, but could then have been limited by what was actually possible, rather than what was desirable from mobile projectors in general. Like all diary studies we were unable to make sure participants recognised potential projection events, and recorded all that they considered; however, we kept semi-frequent contact with participants to remind and encourage them to participate. Another caveat for this second-phase study is that participants were not actually projecting, but keeping a diary of occasions for when and why they would like to project content. Although our findings can support the design considerations for future mobile projectors, these findings need validating in the future with actual projections.

4 Conclusions and Future Work

In lieu and in advance of studying the habitual use of mobile or cellular phones that have integrated pico-sized projectors, we have taken a two-fold approach to studying the potential uses and responses to mobile phone projectors. While our first study investigated the actual projection behaviour of participants using the ESM approach with a working prototype, our second diary study recorded a series of self-motivated scenarios where participants wanted to be able to project content. These two studies provided complementary results and useful insights.

Our first study focused on how people would respond to a range of media types, and in a range of different work and social environments, as controlled by the ESM. In particular, the study noted a surprisingly negative response to potentially personal content, such as text messages, with some reporting that they felt anxious being asked to project such content on the wall. Further, we saw that public observers showed very little interest in the projections being made by study participants. We did not see any significantly negative responses to projecting in social situations, although people were significantly less anxious about projecting and finding suitable surfaces when not at work. We were also able to identify some usability constraints, where participants expected to be able to control a reasonable amount of focus and projection size within one arm length. For the sake of augmentation, we also recommend that projection technology face the same way as the device's inbuilt camera.

Our second study revealed more direct insight into the types of content people actually wished they were able to project. Compared to a general study of mobile information needs [29], we speculate that participants might consider projecting information to solve around two thirds of the noted scenarios. While a large proportion was time, location and object sensitive, participants also recorded many cases of projecting static text that had no immediate or short-term benefit.

We expect, as many do, that mobile projection will become a widely available feature of mobile phones in the near future, and our results do indicate some notable design recommendations. First, we consider that privacy, and subsequent control over what is shown on the projection compared to the phone, should be carefully designed. Further, this control is increasingly important, as we expect phones to have different screens sizes and resolutions to projections. It may be challenging to design interactions for giving users careful control over what is projected and how. Our results indicate that we should not expect any significant projection anxiety for users, or any particular interest shown by bystanders, regardless of the potential popularity of mobile projector phones. Our second study in particular, however, notes that there may be many occasions where projection might be used to resolve a large proportion of previously identified mobile information needs.

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