Augmenting Space: Design approaches for making public interactive displays relevant in hyperconnected societies

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Augmenting Space: Design approaches for making public interactive displays relevant in hyper-connected societies

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I dedicate this thesis to my grandmothers, Enid Parker and Charmion Leyton-Grant.

Keywords

Public displays; pervasive displays; public interactive displays; ubiquitous computing; hyperconnected society; augmented space; augmented reality.

Abstract

Modern society is becoming increasingly driven by digital technologies that augment urban environments through digital information. A technology that has been increasingly permeating cities over the years is the Public Interactive Display (PID), a type of public display that accepts input. Consequently, large research communities have formed around this technology, exploring new ways it can be utilised, aside from being mediums for advertising.

With PIDs becoming commonplace, personal technologies, such as smartphones and wearables, have also proliferated and with that, society itself has shifted towards a new paradigm of hyperconnectedness, where people are constantly connected to the internet through their personal devices. Considering this, the role of a PID and its relevance to individuals in hyperconnected societies is questionable.

Therefore, the overarching aim of this research is to understand how PIDs can be designed so that they are relevant to individuals in hyperconnected societies. This thesis achieves this aim by first reporting on an observation of non-research, commercial public displays to gain a grounded understanding of the current *real-world* nature of these technologies and how they currently augment public space. This is followed by an evaluation of PID prototypes that were deployed both in the lab and the wild, to test methods for making PIDs relevant to individuals.

The key contributions of this research are:

- *Contemporary understanding of PIDs and their purpose in the wild* - gained through a field observation of non-research PIDs situated in different types of public spaces.
- A *device-free implicit personalisation framework* – describing how a PID can be made relevant to individual people without the reliance on intermediary devices for personal information.
- The *relevance triangle* – which proposes three factors that can influence the relevance of PIDs to individuals: User, Locale, and Time.
- *Design patterns* – after reviewing previous research, seven design patterns were defined for designing PIDs that are relevant to individuals. The purpose

of these patterns is to inform future deployments and research, while being continually built upon as technology and society progresses.

These contributions provide a structured approach for future researchers and industry practitioners to design PIDs that are relevant to individuals and have a purpose in hyperconnected societies.

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Statement of originality

This is to certify that to the best of my knowledge, the content of this thesis is my own work. This thesis has not been submitted for any degree or other purposes. I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged.

Signature:

Name: Callum Parker

Date: 29 June 2018

List of Publications

The following publications were achieved during my PhD candidature. Publications marked with an asterisk are included as chapters in this thesis.

Book Chapters

Callum Parker (2017). 'Augmenting Public Spaces with Virtual Content'. In: *Media Architecture Compendium: Digital Placemaking*. Ed. by Luke Hespanhol, M. Hank Haeusler, Martin Tomitsch, and Gernot Tscherteu. avedition, pp. 133–135

Journal Papers

Joel Fredericks, Luke Hespanhol, Callum Parker, Dawei Zhou, and Martin Tomitsch (2017a). 'Blending pop-up urbanism and participatory technologies: Challenges and opportunities for inclusive city making'. In: *City, Culture and Society*

* Callum Parker, Martin Tomitsch, and Judy Kay (2018d). 'Does the Public Still Look at Public Displays? A Field Observation of Public Displays in the Wild'. In: *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 2.2

* Callum Parker, Joel Fredericks, Judy Kay, and Martin Tomitsch (2018a). 'Design Patterns for Making Public Interactive Displays Relevant in Hyperconnected Societies'. *Under Review*

Conference Papers

Callum Parker and Martin Tomitsch (2014). 'Data visualisation trends in mobile augmented reality applications'. In: *Proceedings of the 7th International Symposium on Visual Information Communication and Interaction*. ACM, p. 228

Soojeong Yoo, Callum Parker, Judy Kay, and Martin Tomitsch (2015). 'To Dwell or Not to Dwell: An Evaluation of Mid-Air Gestures for Large Information Displays'. In: *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction*. ACM, pp. 187–191

* Callum Parker, Judy Kay, Matthias Baldauf, and Martin Tomitsch (2016). 'Design implications for interacting with personalised public displays through mobile augmented reality'. In: *Proceedings of the 5th ACM International Symposium on Pervasive Displays*. ACM, pp. 52–58

* Callum Parker and Martin Tomitsch (2017). 'Bridging the Interaction Gulf: Understanding the Factors that Drive Public Interactive Display Usage'. In: *OzCHI'17: Proceedings of the 29th Australian Conference on Human-Computer Interaction (OZCHI 2017)*. ACM

* Callum Parker, Judy Kay, and Martin Tomitsch (2018c). 'Device-free: An Implicit Personalisation Approach for Public Interactive Displays'. In: *ACSW'18: Proceedings of Australasian Computer Science Week 2018*. ACM

* Callum Parker, Marius Hoggenmueller, and Martin Tomitsch (2018b). 'Design Strategies for Overcoming Failures on Public Interactive Displays'. In: *Proceedings of the 7th ACM International Symposium on Pervasive Displays*. ACM

Workshop Proceedings

* Callum Parker, Martin Tomitsch, Judy Kay, and Matthias Baldauf (2015). 'Keeping it private: an augmented reality approach to citizen participation with public displays'. In: *Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers*. ACM, pp. 807–812

Soojeong Yoo, Callum Parker, and Judy Kay (2017). 'Designing a Personalized VR Exergame'. In: *Adjunct Publication of the 25th Conference on User Modeling, Adaptation and Personalization*. ACM, pp. 431–435

* Callum Parker, Joel Fredericks, Martin Tomitsch, and Soojeong Yoo (2017). 'Towards Adaptive Height-Aware Public Interactive Displays'. In: *Adjunct Publication of the 25th Conference on User Modeling, Adaptation and Personalization*. ACM, pp. 257–260

Posters

Soojeong Yoo and Callum Parker (2015). 'Controller-less interaction methods for Google cardboard'. In: *Proceedings of the 3rd ACM Symposium on Spatial User Interaction*. ACM, pp. 127–127

Authorship Attribution Statement

The publications listed below have been included in this thesis as separate chapters each presenting their own unique insights, related work, and synthesis of research findings and results. The following authorship attribution statements are included for each respective publication. Affiliations are based on the positions the co-authors held at the time of writing the papers.

Chapter 4

Callum Parker, Martin Tomitsch, and Judy Kay (2018d). 'Does the Public Still Look at Public Displays? A Field Observation of Public Displays in the Wild'. In: Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies 2.2

This chapter was co-authored as a journal article with Associate Professor Martin Tomitsch from the Design Lab, Sydney School of Architecture, Design and Planning, The University of Sydney; and, Professor Judy Kay from the Computer Human Adapted Interaction Lab, School of Information Technologies, The University of Sydney.

In this chapter, the results from a large field observation of public displays in the city of Sydney, Australia is discussed. I designed and developed the study, created the tools used to capture the data, and conducted the data collection myself. I wrote the sections within the article and created the figures. Martin and Judy were involved in the design and development of the overall study, contributed towards the analysis and synthesis of the data, and edited the article.

I will also present this article in October 2018 at the ACM International Joint Conference on Pervasive and Ubiquitous Computing (Ubicomp'18) in Singapore. The paper will be published as part of the proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT) in the ACM Digital Library.

Chapter 5

Callum Parker and Martin Tomitsch (2017). 'Bridging the Interaction Gulf: Understanding the Factors that Drive Public Interactive Display Usage'. In: OzCHI'17: Proceedings

of the 29th Australian Conference on Human-Computer Interaction (OZCHI 2017). ACM

This chapter was co-authored as a conference paper with Associate Professor Martin Tomitsch from the Design Lab, Sydney School of Architecture, Design and Planning, The University of Sydney.

This chapter discusses the results from two studies, field observation (introduced and discussed in Chapter 4) and field study, in relation to factors that contribute towards people noticing public interactive displays. The field study focused on the deployment of a prototype transit public interactive display which I designed and developed. An earlier version of this display appeared as a module for the digital pop-up called Pop-Spot, which formed part of a separate study conducted by Joel Fredericks and myself. Joel reported on the research findings from that study in his doctoral dissertation, titled: *Middle-Out Design: Enabling Collaborative City Making through Digitally Augmented Pop-Ups*.

I conducted the field study, analysed the collected data from the study, and contributed towards the main body of work for the whole paper. Martin was involved in the design of the two studies (field observation and field study) and supported the editing of the paper.

This paper was presented at the Annual Conference of the Australian Computer-Human Interaction Special Interest Group (OzCHI'17) in Brisbane, Australia, in November 2017. The paper was subsequently published as part of the conference proceedings in the ACM Digital Library.

Chapter 6

Callum Parker, Marius Hoggenmueller, and Martin Tomitsch (2018b). 'Design Strategies for Overcoming Failures on Public Interactive Displays'. In: Proceedings of the 7th ACM International Symposium on Pervasive Displays. ACM

This chapter was co-authored as a conference paper with Marius Hoggenmueller from LMU Munich; and, Associate Professor Martin Tomitsch from the Design Lab, Sydney School of Architecture, Design and Planning, The University of Sydney.

This chapter discusses a subset of the results from the field observation study (introduced and discussed in Chapter 4) in relation to the public displays that were observed with visible hardware and software failures.

I conducted the field observation, analysed the collected data from the study, and contributed towards the main body of work for the whole paper. Marius contributed towards the interpretation of the results and proof-reading. Martin was involved in

the design of the field observation study, contributed towards the conceptualisation of the failure matrix, and performed edits on the paper.

This paper was presented at the 7th ACM International Symposium on Pervasive Displays (PerDis'18) in Munich, Germany, in June 2018. The paper was subsequently published as part of the conference proceedings in the ACM Digital Library.

Chapter 7

Callum Parker, Martin Tomitsch, Judy Kay, and Matthias Baldauf (2015). 'Keeping it private: an augmented reality approach to citizen participation with public displays'. In: Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers. ACM, pp. 807–812

This chapter was a co-authored workshop paper with Associate Professor Martin Tomitsch from the Design Lab, Sydney School of Architecture, Design and Planning, The University of Sydney; Professor Judy Kay from the Computer Human Adapted Interaction Lab, School of Information Technologies, The University of Sydney; and, Dr. Matthias Baldauf from the Research Group for Industrial Software (INSO), Vienna University of Technology.

In this paper, I reviewed previous literature on interaction methods with public interactive displays and compared the level of privacy they offer. I contributed to the main body of work for the whole paper, including the analysis of the previous literature. Martin, Judy, and Matthias gave feedback on the paper structure in the early stages and supported editing the paper.

This paper was presented at the 2015 Pervasive Participation Workshop during the ACM International Joint Conference on Pervasive and Ubiquitous Computing (Ubicomp'15). The paper was subsequently published as part of the adjunct conference proceedings in the ACM Digital Library.

Chapter 8

Callum Parker, Judy Kay, Matthias Baldauf, and Martin Tomitsch (2016). 'Design implications for interacting with personalised public displays through mobile augmented reality'. In: Proceedings of the 5th ACM International Symposium on Pervasive Displays. ACM, pp. 52–58

This chapter was a co-authored conference paper with Professor Judy Kay from the Computer Human Adapted Interaction Lab, School of Information Technologies, The University of Sydney; Dr. Matthias Baldauf from from the Research Group for Industrial Software (INSO), Vienna University of Technology; and, Associate

Professor Martin Tomitsch from the Design Lab, Sydney School of Architecture, Design and Planning, The University of Sydney.

This chapter discusses the results from a field study I conducted with a prototype deployment of a public display with augmented reality assisted personalisation. The design of this prototype is based on the findings from the literature review in Chapter 7. In the paper, I analysed the results from the field study and contributed to the main body of work for the whole paper. Judy, Matthias, and Martin were involved in the design of the study and supported editing the paper.

This paper was presented at the 5th ACM International Symposium on Pervasive Displays (PerDis'16) in Oulu, Finland, in June 2016. The paper was subsequently published as part of the conference proceedings in the ACM Digital Library.

Chapter 9

Callum Parker, Joel Fredericks, Martin Tomitsch, and Soojeong Yoo (2017). 'Towards Adaptive Height-Aware Public Interactive Displays'. In: Adjunct Publication of the 25th Conference on User Modeling, Adaptation and Personalization. ACM, pp. 257–260

This chapter was co-authored as a workshop paper with Dr. Joel Fredericks from the Design Lab, Sydney School of Architecture, Design and Planning, The University of Sydney; Associate Professor Martin Tomitsch from the Design Lab, Sydney School of Architecture, Design and Planning, The University of Sydney; and, Soojeong Yoo from the Computer Human Adapted Interaction Lab, School of Information Technologies, The University of Sydney.

The paper details a lab study I conducted with a prototype public interactive display that could implicitly respond to the the height of users by adjusting its interface. I contributed towards the main body of work for the whole paper and developed the prototype for this study. Martin and Joel contributed ideas towards the design of the prototype and contributed towards the introduction and discussion sections, while also editing the paper. Soojeong contributed by providing some edits to the paper and presenting it at the 2nd International Workshop on Human Aspects in Adaptive and Personalized Interactive Environments (HAAPIE'17) that was held in conjunction with the 2017 User Modeling, Adaptation and Personalization conference (UMAP'17) held in Bratislava, Slovakia. The paper was subsequently published as part of the adjunct UMAP'17 conference proceedings in the ACM Digital Library.

Chapter 10

Callum Parker, Judy Kay, and Martin Tomitsch (2018c). 'Device-free: An Implicit Personalisation Approach for Public Interactive Displays'. In: ACSW'18: Proceedings of Australasian Computer Science Week 2018. ACM

This chapter was co-authored as a conference paper with Professor Judy Kay from the Computer Human Adapted Interaction Lab, School of Information Technologies, The University of Sydney; and, Associate Professor Martin Tomitsch from the Design Lab, Sydney School of Architecture, Design and Planning, The University of Sydney.

The paper details two studies that were first introduced in chapters 5 and 9 respectively. This paper specifically focuses on detailing the device-free approach taken in both studies. I developed the prototypes used in the studies, conducted the studies, and analysed their results. Additionally, I contributed towards the main body of work for the whole paper. Judy and Martin were involved in the design of the study and supported editing the paper.

This paper was presented at the 2018 Australasian Computer Science Week Multiconference (ACSW'18) in Brisbane, Australia, in February 2018. The paper was subsequently published as part of the conference proceedings in the ACM Digital Library.

Chapter 11

Callum Parker, Joel Fredericks, Judy Kay, and Martin Tomitsch (2018a). 'Design Patterns for Making Public Interactive Displays Relevant in Hyperconnected Societies'. Under Review.

This chapter was co-authored as a journal article with Dr. Joel Fredericks from the Design Lab, Sydney School of Architecture, Design and Planning, The University of Sydney; Professor Judy Kay from the Computer Human Adapted Interaction Lab, School of Information Technologies, The University of Sydney; and, Associate Professor Martin Tomitsch from the Design Lab, Sydney School of Architecture, Design and Planning, The University of Sydney.

This article details a set of design patterns for designing relevant public interactive displays. My contribution to this article was in the main body of the whole article, reviewing previous literature, and developing the design patterns. Joel wrote subsection 11.4.3 in the Background section and contributed advice for when I was writing the design patterns. Martin and Judy were involved in the design and deployment of the studies detailed in this article, and contributed towards the development of the design patterns. Additionally, Martin edited and reviewed the whole article.

This chapter was further developed and adapted for the 2019 Computer Human Interaction (CHI) conference. At the time of the thesis submission the paper is still under review. Should the paper not be accepted, it will then be improved based on the reviews and submitted to the International Journal of Human–Computer Interaction or ACM Transactions on Computer-Human Interaction (TOCHI) journal.

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Part I

Background

1 Introduction

> *The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.*
>
> — **Mark Weiser**
> (The Computer for the 21st Century, 1991)

1.1 Changing Times

Around the world, cities and the public spaces within them are changing due to advances in digital technologies and society's increasing dependence on them. This has led to the notion of "*smart cities*", that is, cities with embedded digital technologies for the purpose of improving the lives of urban dwellers within them (Tomitsch, 2018). Smart cities are commonly enabled through sensors to implicitly automate manual processes, such as turning on lights or walking up stairs. However, cities were not necessarily built from the ground up to be smart, rather they are gradually becoming smarter over time as technology becomes more extensible and embedded within them (Dourish, 2016). These digital technologies create information layers that exist over the physical space, resulting in the space being filled with dynamically changing information, thus augmenting the space (Manovich, 2006).

A common and often overlooked digital technology or 'augmentation' found in cities is digital signage, otherwise known as 'public displays'. This technology usually ranges from low-resolution pixel displays (Hoggenmueller et al., 2018; Offenhuber and Seitinger, 2014) to high definition LED screens, on both a small and large scale. Public displays contribute towards the notion of a smart city and augmented space as they embed digital information within urban spaces. Due to hardware advances and decreasing costs, public displays have become ubiquitous in modern cities in recent years (Colangelo, 2016; Hastings, 2018; Davies et al., 2017). This has largely been driven by advertisers, who see public displays as an opportunity to reach out

to the masses that pass through public spaces each day (Alt et al., 2012a), such as train stations, shopping centres, and airports. The advantage of public displays over traditional static posters is that the content can be made more eye-catching, with videos and animations, and allows providers to schedule content, keeping it fresh and reducing clutter.

While public displays are commonplace, they often lack connection to the local communities in which they are situated (Wouters et al., 2015a). Therefore, a growing amount of research has investigated the viability of public displays that accept input, referred to in this thesis as public interactive displays (PIDs), to engage communities on local issues that matter to them and provide urban dwellers within these communities a public platform they can use to voice their opinions on community matters (Schroeter and Foth, 2009; Hespanhol et al., 2015; Steinberger et al., 2014; Wouters et al., 2014; Du et al., 2017). This essentially enables public displays that can contribute to the 'smart' of smart cities by engaging urban dwellers with situated community centred content.

However, while situated community-centred content might be relevant to a community, it may not always be relevant to the needs of individual urban dwellers and their current context. Therefore, to make public displays relevant to individuals, research has investigated ways in which a public display could be personalised, similar to what is seen on the Web. Davies et al. (2014) state that "*the move towards personalised content in the signage industry precisely mirrors the shift towards personalised content that has occurred in the Web*". While personalisation on the Web is usually achieved through user profiles, personalising content on public displays is not as straightforward. People who use public displays are visible to other people passing through the space, meaning that simply signing in with a username and password, as one does on websites like Google and Facebook, could have serious privacy implications. To make personalisation work on a public display the user should be identified in a way that does not require their credentials to be exposed. This may require networked displays (Memarovic and Langheinrich, 2010) or a profile stored on a personal device, such as a smartphone, and sent via Bluetooth (Sharifi et al., 2006). However, even with a private authentication method, there is still the challenge of displaying content that is useful and does not identify the user (Davies et al., 2014). What is apparent from this research is that more understanding is needed of user preferences when it comes to viewing and interacting with content on public displays, particularly related to privacy and user needs.

With the rise of digital technologies in the public sphere, personal technologies have also risen. Digital technologies have essentially merged into the social fabric

of modern society due to personal devices, like smartphones and smartwatches, consequently making information access ubiquitous. These devices have enabled urban dwellers to become more connected than ever before, while relying on the information they provide. In this research, we describe such a society as being hyperconnected, which stems from the observation that society is generally becoming increasingly connected via the internet (Tragos et al., 2015; Choi, 2014; Passarelli and Angeluci, 2017). Personal devices allow us to become hyperconnected and to tap into information available via the internet and connect with each other from anywhere and at any time. Subsequently, hyperconnectedness and ubiquitous access of information from personal devices brings the role of public displays into question.

1.2 Research Aim and Questions

Building on from previous work, more understanding is needed of user preferences when it comes to viewing and interacting with content on PIDs. This is also linked to the rapid changes of technology and current trends, which raises new questions around the role PIDs have in society and the need for an updated understanding of how PIDs should be designed moving forward, despite there being a lot of research on PIDs already. Therefore, the overarching aim of this doctoral research is ***to understand how PIDs can be designed so that they are relevant to individuals in hyperconnected societies***. To help guide this research towards its aim, three research questions were posed. These research questions emerged from the literature review, where three gaps in the understanding of PIDs were identified: the current role of PIDs, the challenges with making PIDs relevant to individuals and how they can be overcome, and how PIDs can be designed so they are relevant to individuals.

Research Question 1 (RQ1)
What is the role of a public interactive display in a hyperconnected society?

Previous work has highlighted through deployments of PID prototypes that public displays can be much more than a medium for advertisements. Despite this, the public displays being tested in research are not always representative of non-research public displays. E. Huang et al. (2008) set out to overcome common assumptions made by researchers about non-research displays through an observation study. Since this work was published, society and public space has changed, with information access becoming ubiquitous; enabled through personal devices. This brings the current role of PIDs into question. Therefore, this research question is aimed at providing

grounding for the next two questions through a contemporary understanding of the role PIDs have in today's society.

Research Question 2 (RQ2)
What are the challenges with making public interactive displays relevant to individuals? And how can they be overcome?

Making PIDs relevant to individuals is not as straightforward as the individual relevance provided by some services on the internet, like Google and Facebook (Memarovic and Langheinrich, 2010). Due to the public nature of PIDs, a different set of constraints are faced, related to privacy (Davies et al., 2014) and logistics. Therefore, this question is focused on identifying current challenges with making PIDs relevant and how these can be overcome.

Research Question 3 (RQ3)
What factors influence the relevance of a public interactive display to individuals?

Unlike personal devices, PIDs are usually designed for a general audience, resulting in PIDs that are not always relevant to individuals and the communities in which they are situated. While much work has investigated methods to make PIDs relevant, more knowledge is needed with regard to what makes a PID relevant to individuals and the social aspects around it. Therefore, this question is posed with the intention of gaining further knowledge with regard to these aspects.

1.3 Significance

This research is significant in that it unveils the principles for the design of PIDs, so that they can enrich and augment experiences in public space. The specific contributions of this doctoral research provide a new way of thinking when it comes to making PIDs relevant and highlight the potential of PIDs and their role moving forward in hyperconnected societies.

While this work makes contributions towards the knowledge of PIDs, it has broader implications on four core intersecting areas of research: ***Human-computer interaction***, ***ubiquitous computing***, ***smart cities***, and ***pervasive displays***.

Human-Computer Interaction
In the field of human-computer interaction (HCI), we make the following contributions:

- Understanding how PIDs can be designed so the content displayed is relevant to individuals and communities.
- Understanding of the social challenges with making PIDs relevant and how these can be mitigated and addressed.
- Creation of methodological approaches to evaluate the relevance of PIDs both in the lab and wild.

Ubiquitous Computing

Throughout this thesis, we present and discuss our studies on different methods to make PIDs relevant towards individuals. The studies include our own prototype deployments as well as non-research public displays we observed in the wild. In the context of our own prototypes, relevance to individuals has been approached using personalisation, through sensors and personal devices. Specifically, this doctoral thesis makes the following contributions to ubiquitous computing:

- Insights into personalisation in public space and how technologies can implicitly respond to changing spatial conditions and the context of users.
- The intersection of personal and public technologies in a public setting.
- The hyperconnectivity of society and its implications on public technologies.

Smart Cities

Cities encompass the public spaces in which the studies in this thesis took place and are increasingly becoming smarter due to technologies like public displays. Ultimately the findings from the studies in this thesis lead towards an understanding of how PIDs fit into the larger scope of a smart city and meaningfully contribute towards urban experiences and quality of life.

Pervasive Displays

The research in this thesis makes contributions towards the pervasive displays community in the form of:

- Best practices for designing PIDs in a hyperconnected society.
- Understanding the current role of a PID and opportunities for future systems.

1.4 Thesis Scope

The purpose of this section is to clarify the scope of this research, which explores the relevance of PIDs to individuals. Throughout this doctoral thesis, the term '*relevance*' is frequently used. In the context of this thesis, relevance comes in two different types: intended and perceived. Intended relevance is based on what the PID provider believes is relevant to users, while perceived relevance is what the user believes is relevant to them. Relevance of a PID to individuals refers to the content shown on a PID or the physical structure of a PID. The studies detailed in this thesis focused around designing PIDs that are relevant to individuals all focus on intended relevance rather than perceived. This is because perceived relevance is highly subjective and difficult to measure, therefore outside the scope of this thesis.

Additionally, the definition of a PID in the context of this thesis refers to public displays that accept some form of input, such as touch and mid-air gestures. Furthermore, this term is only applied to interactive displays that are: (1) deployed in general public spaces and not specific contexts, like supermarkets, hospitals, etc; and (2) not a '*mundane*' technology (Henderson and Leong, 2017), such as parking metres and ATMs.

1.5 Thesis Structure

The core chapters that form the body of this thesis consist of published papers in accordance with The University of Sydney's regulations for a PhD thesis by publication[1]. In total, six conference papers and two journal articles are included as the core chapters, written during this PhD candidature. These papers have their own unique subsections of related work or background, methodology, findings, discussion, and conclusions. It should be noted that some aspects discussed in these papers, such as the related work or background, are repeated in the different publications. However, each publication is linked through a preamble and provides a distinct contribution to the overall thesis and its research questions. Additionally, the papers do not appear in chronological order, instead they have been arranged in an order that best fits the overall narrative of the thesis.

The core thesis is divided into five main parts described below.

[1] FAQs on Theses Including Publication - `http://sydney.edu.au/stuserv/learning_centre/thesis_pub.shtml`

Part I: Background
This thesis begins by discussing the literature relevant to this area of research. The methodology employed is then explained, followed by an account of the research progress linking the publications.

Part II: Understanding the Current Role of Public Interactive Displays
This part serves as a grounding for the rest of the thesis and focuses specifically on understanding the current role of PIDs. It is comprised of three chapters, each of which discuss existing literature and findings from a field observation study. The chapters contained in this part consist of the following papers:

- Callum Parker, Martin Tomitsch, and Judy Kay (2018d). 'Does the Public Still Look at Public Displays? A Field Observation of Public Displays in the Wild'. In: *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 2.2
- Callum Parker and Martin Tomitsch (2017). 'Bridging the Interaction Gulf: Understanding the Factors that Drive Public Interactive Display Usage'. In: *OzCHI'17: Proceedings of the 29th Australian Conference on Human-Computer Interaction (OZCHI 2017)*. ACM
- Callum Parker, Marius Hoggenmueller, and Martin Tomitsch (2018b). 'Design Strategies for Overcoming Failures on Public Interactive Displays'. In: *Proceedings of the 7th ACM International Symposium on Pervasive Displays*. ACM

Part III: Designing Relevant Public Interactive Displays
Leading on from the previous part, this part explores the aspects that can make a PID relevant to urban dwellers. Specifically, three prototypes were evaluated to gain an understanding of how relevant PIDs can be designed. The chapters contained in this part consist of the following papers:

- Callum Parker, Martin Tomitsch, Judy Kay, and Matthias Baldauf (2015). 'Keeping it private: an augmented reality approach to citizen participation with public displays'. In: *Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers*. ACM, pp. 807–812
- Callum Parker, Judy Kay, Matthias Baldauf, and Martin Tomitsch (2016). 'Design implications for interacting with personalised public displays through mobile augmented reality'. In: *Proceedings of the 5th ACM International Symposium on Pervasive Displays*. ACM, pp. 52–58

- Callum Parker, Joel Fredericks, Martin Tomitsch, and Soojeong Yoo (2017). 'Towards Adaptive Height-Aware Public Interactive Displays'. In: *Adjunct Publication of the 25th Conference on User Modeling, Adaptation and Personalization*. ACM, pp. 257–260

- Callum Parker, Judy Kay, and Martin Tomitsch (2018c). 'Device-free: An Implicit Personalisation Approach for Public Interactive Displays'. In: *ACSW'18: Proceedings of Australasian Computer Science Week 2018*. ACM

Part IV: New Opportunities for Public Interactive Displays
In this part the prototypes that were discussed in **Part III** are revisited along with a discussion of recent prototypes from the HCI community. The purpose of this part is to compile and synthesise the existing collective knowledge and findings for making PIDs relevant to individuals. This part consists of one chapter that will eventually be published as a journal article:

- Callum Parker, Joel Fredericks, Judy Kay, and Martin Tomitsch (2018a). 'Design Patterns for Making Public Interactive Displays Relevant in Hyperconnected Societies'. *Under Review*

Part V: Conclusion and Future Work
The final part reflects on the main findings and contributions of this thesis and describes opportunities for future work on PIDs.

Related Work

2

2.1 Preamble

This chapter presents an overview of the work in core areas underpinning this doctoral research. The work is specifically organised into three themes: (1) ***Purpose of PIDs***, (2) ***Making PIDs Relevant***, and (3) ***Augmented Space and the Hyperconnected Society***. These themes feed into and provide background for the research questions in this doctoral thesis. The purpose of this chapter is not to provide an exhaustive account of all the work in the field, but rather provide an initial overview of the related work. The chapters in later parts of this thesis build on from this section. Specifically, **parts II**, **III**, and **IV** contain chapters that are academic publications, each containing a subsection where related work aligned to the specific topic is presented and discussed within the theme and context of the respective chapter.

2.2 Purpose of Public Interactive Displays

PIDs situated in the wild are commonly utilised to deliver interactive advertisements (Figure 2.1A) and provide general information about an area in the form of touchscreen directories (Figure 2.1B). However, research has shown that PIDs also have a purpose outside of the commercial sphere. For instance, much work has focused on making public space more playful through mid-air gesture controlled PIDs (Müller et al., 2012; Wouters et al., 2015b; Carter et al., 2016; Cox et al., 2016; Tomitsch et al., 2014).

Other research has shown PIDs to be an effective medium when appropriated by regular people. For instance, work by Alt et al. (2011) has shown that PIDs can be effective when appropriated by the community. Their work explored a network of PIDs that were essentially a digital version of a community noticeboard. This system was setup in different public spaces around Oulu, Finland and displayed content posted by the general public, such as items for sale and events. Users could browse and create advertisements using the touchscreen. Alternatively, advertisements could be posted using a smartphone app. Each posting had a unique QR code that could

be scanned using a smartphone, enabling the user to take the content to read later. The findings from this research showed that people appreciated the locally relevant content, such as sales, events, and community-related information. Other work by Baldauf et al. (2012b) allowed users to drag and drop items stored on their smartphone to the public display through the smartphone's camera feed. Files could also be retrieved by dragging them from the public display to a specific location on the smartphone. This example highlights the potential of rich interactions that can be afforded by the mobile platform when paired with a digital public display.

Therefore, these examples show that PIDs can essentially be reappropriated as digital community noticeboards. This allows the content shown on PIDs to be specifically tailored to the local communities in which they are situated and gives citizens within the community greater control over the digital information displayed.

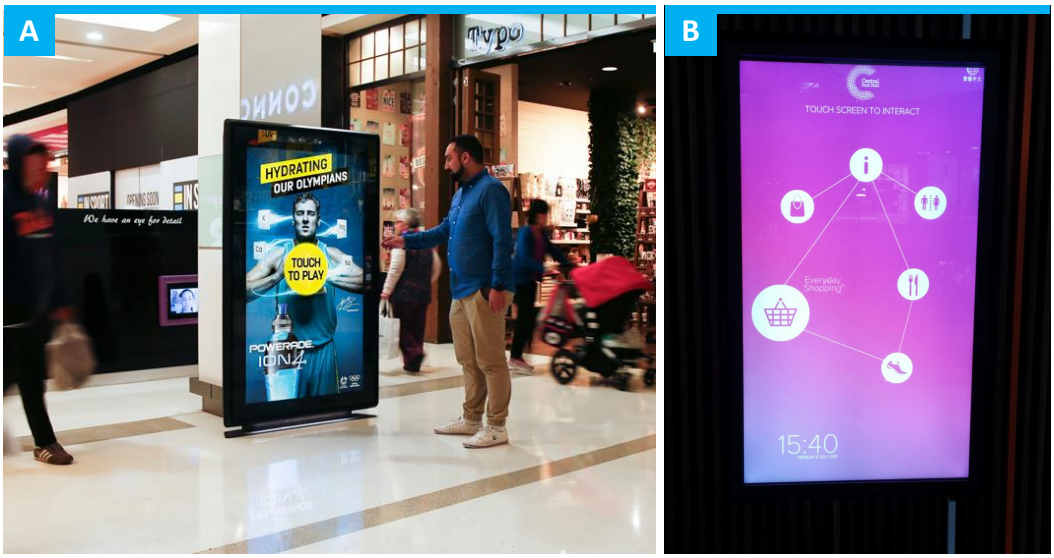

Fig. 2.1.: Touchscreen PIDs: (A) Interactive advertisement game in a shopping centre[1]; and (B) Shopping centre directory.

PIDs can also be an effective medium for enhancing civic engagement by providing a platform for urban dwellers to voice their opinions about locally relevant topics (Du et al., 2017; Foth et al., 2016; Hosio et al., 2014a). For instance, Baldauf et al. (2014) studied interactive opinion polls using a public display prototype setup in a local café to determine user privacy requirements and how these affected whether someone voted using the prototype PID or using their smartphone via an on-screen QR code. The content consisted of a question with the possible answers and the amount of votes visualised as a bar graph located directly below it. Their findings showed

[1]Image sourced from an article on the oOh! website: `https://www.oohmedia.com.au/news/interactive-ads-soar-during-first-year-of-oohs-excite-screens/`

that mobile interactions were mostly ignored, even though the mobile interaction technique provided more privacy than the touch interaction on the PID prototype. Additionally, the poll question did not seem to influence the voting interaction.

Steinberger et al. (2014) allowed people to use their feet to vote on questions displayed on a large screen. The benefit of this interaction is that it is more hygienic, as users do not need to use their hands. The system was deployed in a public place and people could step on tangible answer buttons, representing yes and no, to submit their vote on a particular question displayed on the screen. Questions could be suggested by sending an SMS or iMessage to the displayed phone number. Although this interaction allowed passers-by and bystanders to visibly see the opinion of the user, the majority of users had no issues with other people being able to see them vote. However, users did mention that the type of question, such as personal questions, would affect their use of the system.

Such systems have also been implemented and tested on a larger scale. Valkanova et al. (2014) presented a Kinect controlled polling system called "*MyPosition*" which allowed people to vote on certain topics by positioning themselves in front of their preferred answer and raising their hand to vote. It was found that such interactive visualizations can promote civic discussion on the topics.

Schroeter and Foth (2009) presented a large PID system that displayed messages from urban dwellers in the local community, usually in response to a particular topic. People could be send messages through SMS, Twitter, and email; enabling a broader cross-section of the community to access this system. The authors of this work later deployed and studied the system in public. The system was found to be effective as it encouraged urban dwellers to take part in civic engagement initiatives. In some cases people would use the system to have conversations or as a platform to reach out to others.

Hespanhol et al. (2015) investigated the use of gestures as an expression of full-body interaction, for engaging people on local issues that affect their community. Their study found that the interaction with a camera feed (Figure 3), which allowed passers-by to vote on issues by standing on a certain side of the screen depending on which way they wanted to vote, increased participation as the interaction offered a more playful interface compared to the control kiosk-style iPad setup. However, the iPad interface offered people some privacy and allowed users more time to consider their answer. Therefore, for people to notice the display and be motivated to interact, it is recommended that real-time feedback and tangible or full-body interaction be utilised with just enough playfulness. These results match outcomes previously mentioned in Tomitsch et al. (2014), where their research focused on

a large PID prototype called Media Wall, that was deployed in a busy area of a university campus. The Media Wall could be interacted with using mid-air hand gestures, enabled by the Microsoft Kinect, to give users control over the navigation of the interface. The gestures consisted of hand swiping (left or right) for navigating through the interface horizontally, and raising or lowering either hand for up and down vertical navigation. Aside from the interaction, the PID displayed content related to the university and a tracking skeleton that mimicked the movement of the person being tracked, which can capture the attention of passers-by. Additionally, a banner message would follow passers-by letting them know the screen is interactive. The findings from their work showed that having playful elements attracts users who have the potential to become active users after they have finished exploring the interface through play.

Therefore, previous work has shown that PIDs can be used for more than simply advertising or as information directories. Rather, they can be used to engage communities and empower the individual urban dwellers within them. Despite this however, it is unclear whether the techniques and findings from research are actually applied to non-research PIDs in the wild. Additionally, the research community's understanding of public displays and PIDs in the wild relies on literature that was published in 2008 (E. Huang et al., 2008). Since that time, both technology and society have changed, and more contemporary understanding is needed of the purpose public displays and PIDs have in today's society. In this doctoral research, the knowledge gap is addressed through the first research question (*What is the role of a public interactive display in a hyperconnected society?*), which is tackled through a field observation of public displays detailed in **part III** of this thesis.

2.3 Augmented Space and the Hyperconnected Society

As digital technology adoption is increasing, digitally augmented spaces are on the rise. In this section the concept of augmented space and the hyperconnected society is discussed; providing further background for research question 1 (*What is the role of a public interactive display in a hyperconnected society?*).

Manovich (2006) introduced the concept of augmented space, which describes how digital technologies, both personal and private, create digital layers that exist over the physical space, providing urban dwellers with dynamic information. These digital augmentations in public space commonly consist of technologies like PIDs, media façades, and augmented reality (AR). In the case of PIDs and media façades, the

digital content is brought into the physical space through a screen. The caveat to this is, however, that the content is constrained by the display's borders.

While PIDs have been shown to provide situated information either about the location or the community they are situated in, urban dwellers are now hyperconnected, and can tap into a fount of information from the internet and communicate with others through personal devices, such as smartphones. Public space has begun to cater for personal device usage. For example, QR codes and RFID are now widespread (Figure 2.2A) (Alt et al., 2013; Bauer et al., 2011; Parker et al., 2017), giving objects that exist in public space a form of meta information that can be accessed through a smartphone's camera. Furthermore, public space is starting to accommodate personal device usage through charging stations that can enable citizens to charge their smartphone's battery (Figure 2.2B). These charging stations are also starting to blend into public space with smart infrastructure, such as park benches, where citizens can sit while their phone wirelessly charges, as seen in some locations in South Korea (Figure 2.2C). The rise in smartphone usage has also led to more convenient methods of payments and identification, such as digital train tickets with smartphone RFID (Figure 2.2D) Triggs, 2015. Location-aware smartphone apps augment people's knowledge of public space with crowd sourced information.

Fig. 2.2.: Examples of smartphone interaction with public space: (A) Advertisement poster with QR code that will direct the user to more information about the product or service when scanned using the WeChat app; (B) Smartphone charging station in Newark Airport, New Jersey, USA; (C) Smart solar-powered bench in South Korea that wirelessly charges smartphones placed on it; (D) RFID-enabled smartphones used for transit payments in South Korea.

As both personal and public technologies pervade physical spaces, it brings back the question raised in earlier work by Manovich (2006) of how the physical and digital should relate to each other: "*Does the form become irrelevant, being reduced to functional and ultimately invisible support for information flows? Or do we end up with a new experience in which the spatial and information layers are equally important? In this case, do these layers add up to a single phenomenological gestalt or are they processed as separate layers?*". An approach taken in some research studies is to blend both the personal and public devices together, utilising personal devices as a

method of interaction with public displays. For instance, Schroeter and Foth (2009) developed a system for an existing large public display that enabled citizens to voice their opinions on certain topics related to the community, through SMS, Twitter, and Email. In other work by Alt et al. (2011), they studied a public interactive display (PID) network that displayed user generated content posted from a companion smartphone app. These studies demonstrate how personal and public devices can work in tandem, complementing each other.

However, as personal devices are improving technologically and becoming widely adopted, the challenge is to design PIDs that have a relevant purpose to urban dwellers in the future.

2.4 Making Public Interactive Displays Relevant to Individuals

In a public space, the target audience becomes hard to define as it can consist of a broad demographic, incorporating people with different beliefs, cultures, occupations, and physical abilities. Therefore, it is a challenge to make PIDs relevant to individuals. This section explores the current work tackling this challenge by discussing two main methods for creating PIDs that are relevant to individuals: Personalisation and Context-awareness. Specifically, this section provides background for research questions 2 (*What are the challenges with making public interactive displays relevant to individuals? And how can they be overcome?*) and 3 (*What factors influence the relevance of a public interactive display to individuals?*).

2.4.1 Personalisation

Making content on a PID relevant to individual urban dwellers is a logistical and social challenge. Unlike the Web where services like Facebook and Google have a profile of the user based on their history and interests, privacy could be impacted if people needed to sign in with a username and password on the screen (Figure 2.3). While this method of authentication works for public devices like ATMs, PIDs are normally of a larger scale and often utilise touchscreens for interaction, thus opening up the risk of shoulder surfing and smudge attacks. While work has investigated more secure authentication methods, making public displays more resistant to shoulder surfing (Brudy et al., 2014) and smudge attacks (Khamis et al., 2017), it is assumed that people would spend the time to sign into the display - which may not be feasible

for time-poor citizens. Therefore, a different approach to making PIDs relevant to individuals is needed.

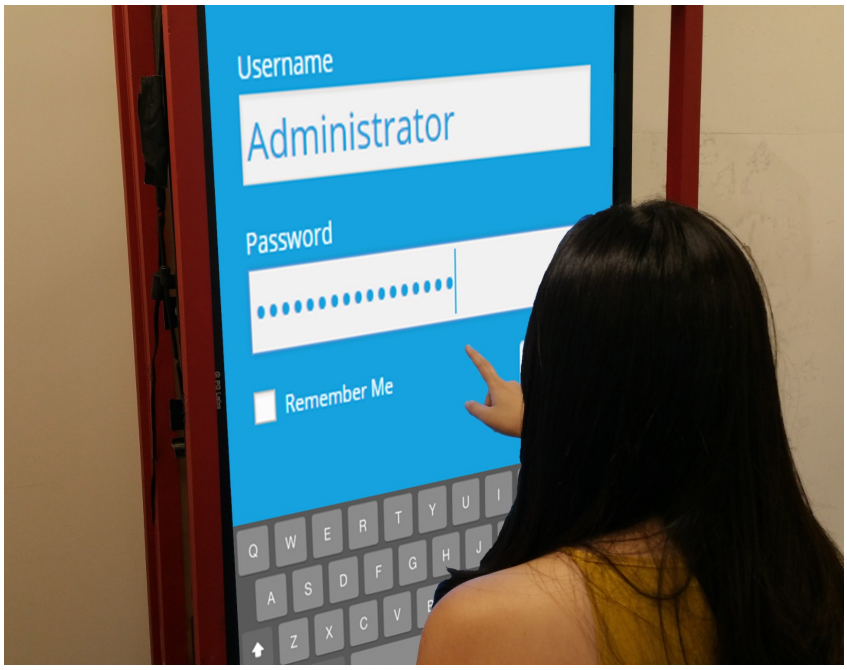

Fig. 2.3.: A mockup of a PID system where the user needs to login with a username and password on-screen.

As smartphone usage has increased over the years, research has investigated smartphones as a medium to enable personalised content on PIDs. The benefit of a smartphone is that it is personal and already contains profiles from common apps, like Facebook and Twitter, for user preferences. Work by Davies et al. (2014) explored using a custom smartphone app for users to share preference information with nearby public displays. The information was implicitly sent to public displays that were in close proximity to the user, triggering the displays to show content based on the user's preference, such as the weather. Earlier work by Hosio et al. (2010) demonstrated a similar direct approach where users needed to manually launch the public display applications from their smartphone.

Other work by Davies et al. (2009) explored using Bluetooth device names to eliminate the need of installing an app on a smartphone, instead users could change their device's Bluetooth name to perform interactions on a public display. For example, users could change their phone's Bluetooth name to certain keywords, such as "*youtube <search term>*" which would then make the public display play the first video from the search results.

Sending information via WiFi is an alternative approach that allows personal devices to transfer data to others over a longer range. Previous work has investigated the use of personalisation over WiFi through custom smartphone apps that store the user's preferences (Kubitza et al., 2013; Davies et al., 2014; Parker et al., 2016), which are collected when the app is first started and can be added to later. Once set up, this allows the personal devices to automatically send data to the PIDs, which then enables them to implicitly display relevant content, such as the weather forecast from a user's hometown (Kubitza et al., 2013).

Using smartphones to personalise PIDs should be approached carefully to ensure the information does not negatively harm users in any way, such as linking the content on the screen back to individuals (Munson et al., 2011). Another important consideration for display providers is to ensure users consent to their information being read by public devices like PIDs, to avoid potential legal and ethical issues. A prime example of such an occurrence was in London, where a display provider collected the MAC addresses from the smartphones of passers-by through a WiFi network without gaining permission (Passingham, 2013). This information was used to tailor advertisements on the displays at certain times. The company was later ordered by the government to shut down their display network.

2.4.2 Context-awareness

Making PIDs context-aware is an alternative approach to making PIDs relevant to individuals without the need of intermediary devices like smartphones. Context-aware computing is defined as systems that respond to the user's task based on their interactions or usage history (Dey, 2001). PIDs work differently as they adapt based on the changing context around them, such as environment, time, and behaviour of people (Tomitsch et al., 2014; Hosio et al., 2014b; Cardoso and José, 2009). Although the idea of PIDs being able to implicitly interpret what the user is doing and adapt accordingly seems like something out of science fiction films, such as Minority Report, Ghost in the Shell, and Blade Runner, with recent advances in IoT and sensor technology it is now more feasible.

The benefit of having a context-aware PID system over one that requires user profiles is that it is accessible to a broader range of people, as there is no need for a smartphone with a dedicated app installed. The idea is that a PID can respond based on what the user is currently doing, trying to do, or recently has done.

Most of the work on context-aware PIDs has made use of proxemics (Greenberg et al., 2011; Vogel and Balakrishnan, 2004). Early work by Prante et al., 2003 explored the

use of long and short-range RFID sensors to make an LED display change patterns based on a user's proximity. Work by Wang et al. (2012) presented a prototype that did not rely on personal devices as it could detect passers-by with a depth-camera and would beckon them to come and interact. Once a passer-by started interacting with the PID, it would then suggest items of interest according to the on-screen items selected, similar to the way Amazon and other online retailers recommend items based on customer interactions.

Other work (Ackad et al., 2016), presented a mid-air gesture controlled PID system called Media Wall, referred to earlier in this chapter. The system would react to passers-by by animating on-screen elements to catch their attention. When passers-by approached the PID, it would detect that they might be a new user and display a tutorial to introduce them to interacting with the PID.

2.5 Knowledge Gaps

The work discussed in this section shows the potential of PIDs to be more than simple information outputs, but rather enrich individual and community experiences within urban environments through games and civic engagement. However, the people that exist in these urban environments and communities have different needs and contexts, meaning that general approaches may not always be effective. This research provides a better understanding of the following research gaps:

- **A contemporary understanding of PIDs in the wild**
  Technology and physical public spaces have changed, thus having a potential effect on how PIDs are utilised. Little work has investigated how PID usage and purpose has changed over the years since (E. Huang et al., 2008). Therefore, to help guide the research toward filling this gap, RQ1 was posed: *What is the role of a public interactive display in a hyperconnected society?*.

- **Overcoming privacy concerns**
  The core challenges to making PIDs relevant to individuals relate to privacy, where the concern is to ensure that the user's privacy is protected. Previous work has tackled this challenge by developing PIDs that can adapt and block out parts of the screen that are not being used (Brudy et al., 2014). Other work has explored the use of smartphones as a method to transfer information to PIDs for personalisation (Davies et al., 2014; Davies et al., 2009). However, further work is needed to synthesise these solutions and gain a better understanding of the challenges with tailoring PIDs to individuals. This

work explores these challenges to resolve RQ2: *What are the challenges with making public interactive displays relevant to individuals? And how can they be overcome?*.

- **Creating PIDs that are relevant to individuals**
  While much work has explored the design of PIDs and how they can be tailored to individuals, little work has tested methods to make PIDs relevant to individuals in formal studies and in the wild. Insights into this gap were guided through RQ3: *What factors influence the relevance of a public interactive display to individuals?*.

These gaps and their associated research questions are addressed in the studies conducted for this doctoral thesis, detailed in **parts III**, **IV**, and **V**.

3 Methodology

3.1 Research Approach

The overarching aim of this doctoral research is ***to understand how PIDs can be designed so that they are relevant to individuals in hyperconnected societies***. To achieve this understanding, the core methodology for this research followed the Research through Design (RtD) approach by Zimmerman et al. (2007). The RtD approach is an active process, which involves creating ideas, critiquing potential solutions and reframing the problem through various iterations until the preferred state is achieved. To address the problem, a series of prototypes (artefacts) were created and tested. This approach allowed for different system designs to be iteratively explored and critiqued, leading to a more thorough understanding of how relevant PIDs can be designed.

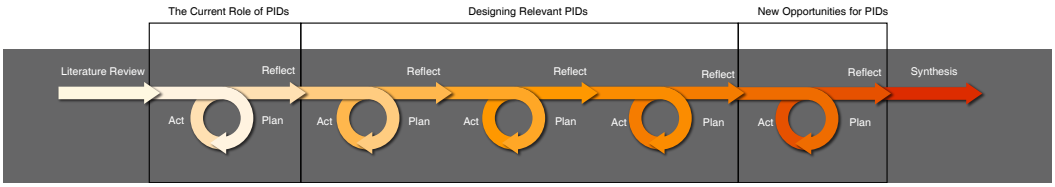

Fig. 3.1.: Overview of the iterative process this work went through.

The iterative cycles for the RtD approach followed the spiralled action research approach from Hayes (2011), allowing for the problem to be iteratively tackled until a solution or new knowledge is found. As shown in Figure 3.1, the core research went through five cycles across three stages: ***the current role of PIDs***, ***designing relevant PIDs***, and ***new opportunities for PIDs***.

In the synthesis, the research questions defined at the beginning of the research are revisited. The overall research is then evaluated using questions defined by Zimmerman et al. (2007):

- Process – How well were the methods utilised and was there enough detail to reproduce the process?

- Invention – How does the research contribute to the work already in the research community?
- Relevance – How is the work relevant and what is the motivation for it?
- Extensibility – How can this research be useful for future work in this field?

3.2 Research Questions

This research provides a theoretical and practical understanding of how PIDs can be designed to be relevant to individuals within a hyperconnected society. **Chapter 1** outlined the research questions and how they relate to the overall doctoral research. Table 12.1 builds on this further by describing the specific chapters that address these questions and the core contributions for each one.

Tab. 3.1.: The research questions, the chapters that address them, and their resulting contributions.

Research Questions (RQ)	Chapters	Contributions
RQ1 - What is the role of a public interactive display in a hyperconnected society?	4, 5, 6	• Contemporary knowledge of how non-research public interactive displays are used in the wild.
RQ2 - What are the challenges with making public interactive displays relevant to individuals? And how can they be overcome?	4, 5, 6, 7, 8, 9	• Insights into mitigating privacy concerns when making public interactive displays relevant to individuals. • The factors that drive people to use public interactive displays. • Understanding and overcoming common problems that occur on public interactive displays.
RQ3 - What factors influence the relevance of a public interactive display to individuals?	7, 8, 9, 10	• The relevance triangle and design patterns for creating relevant public interactive displays for individuals

3.3 Research Methods

For this research, a mixed methodology was followed, where both quantitative and qualitative data were collected, to enable the data to have both validity and context - thus strengthening the findings (Hussein, 2015; J. W. Creswell and J. D. Creswell, 2017). More specifically, the data was triangulated using the convergence model discussed by J. W. Creswell and J. D. Creswell (2017), where two different types of data were analysed separately, using native techniques for each type of data, to generate results which are then compared against each other to interpret the overall results. This process is illustrated in Figure 3.2.

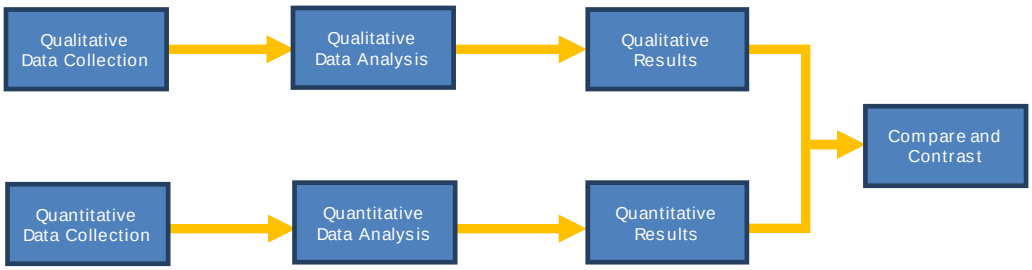

Fig. 3.2.: The convergence model - where we gathered data, performed analysis, and compared and contrasted the results.

Data was collected across three core methods: ***field studies***, ***field observations***, and ***lab studies***. These research methods allowed for a significant amount of data of different types to be collected, resulting in both qualitative and quantitative data. These study methods are described further below, along with the data collected.

Field Observations

This method is similar to the field study, but involved solely observing behaviours of the people and space around a PID. In the field observations, we wanted to observe naturally occurring behaviour around PIDs to better understand their usage. Therefore, the space under observation needed to be ecologically pure in the sense that the observer did not disturb the space by conducting interviews, recording video, or generally looking as though they are conducting a study. Specifically, data was collected consisted of:

- Observation notes made by the researchers regarding the space the PID was situated and the behaviour of people in the space and around the PID.
- Count of people's behaviour in the space.

- Photos and sketches of the PID and space.

Lab Studies

For more conceptual and focused studies around PID prototypes, we ran lab studies. These allowed us to have a certain degree of control compared to running a study in the field, where unexpected things can occur. This was useful when a specific aspect of a PID needed to be tested from a specific target audience. The data collected consisted of:

- Observation notes made by the researchers about participant behaviours.
- Audio recordings of the interviews with participants, which were later transcribed for grounded analysis.

Field Studies

The field studies conducted for the research in this thesis involved trialling PID prototypes in both indoor and outdoor settings in the city of Sydney, Australia. This method was utilised to address the need to understand aspects related to PIDs that could not be studied in a lab (Alt et al., 2012b), such as attention, social effects, audience behaviour, and privacy.

The field studies were carried out in two different ways, depending on the study. The first involved pre-recruiting participants before the study and asking them to trial the PID prototype in a public environment. The second involved allowing members of the general public to utilise the prototype PIDs freely. In both cases, to ensure as much ecological validity as possible, no formal structure was enforced and participants were allowed to freely explore the prototypes. No contact was made between the researchers and the participants until they had finished using the prototypes.

The data was collected in multiple ways:

- Observation notes made by the researchers of people's behaviour around the prototype PIDs deployed.
- Count of people's behaviour in the space, such as how many people walked past the prototype PID and whether anyone looked or interacted.
- Audio recordings of the interviews with participants, which were later transcribed for grounded analysis.
- System logs - with count of the interactions with the prototype PIDs.

- Questionnaires to gain qualitative feedback to specific questions.

3.4 Prototypes

This section presents a summary of the three prototypes that were designed and developed to help explore the design of potential solutions for personalising PIDs for the research in this thesis. Each prototype is briefly described below along with the chapters they appear in.

Prototype A: *Public Display with Augmented Reality Assisted Personalisation*
This prototype was created to evaluate the effectiveness of mobile augmented reality (MAR) at enabling personalised interactions with public displays while keeping the integrity of the user's privacy intact. The prototype system consisted of a public display application and a MAR app. The public display application ran on a PC connected to a 50 inch widescreen TV, where it displayed general information related to news in the local community and The University of Sydney, local buy and sell advertisements from Gumtree[1], and student accommodation for rent. The MAR app gave the user a personalised view of the public display through their smartphone's screen. Personalised content was displayed based on a manually generated user profile that was stored on the user's smartphone (Figure 3.3A). A non-personalised remote control mode for the MAR app was also developed for comparison with the personalised overlay mode (Figure 3.3B), allowing users to remotely interact with the public display. This prototype appears in the study detailed in **chapter 8**.

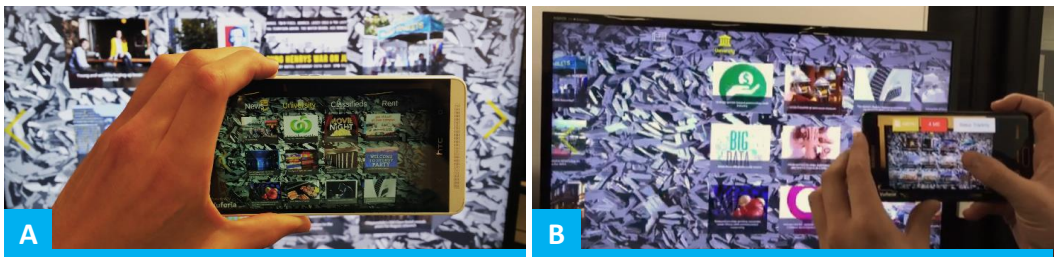

Fig. 3.3.: Prototype A featured a public display that could be interacted through smartphone augmented reality. The system had two viewing and interaction modes: (A) Private personalised overlay; and (B) Public non-personalised remote control.

Prototype B: *Transit Public Interactive Display*
To develop a better understanding of designing personalised public displays that subtly adapt their content based on the user's current context, we created a prototype

[1]Gumtree buy and sell website - `https://www.gumtree.com.au`

PID that was personalised using an implicit device-free approach. The prototype was created as an interactive transit timetable display that enabled users to select from 12 nearby suburbs (Figure 3.4A) which would trigger the prototype to implicitly recommend three bus times and places to visit (Figure 3.4B). This prototype appears in the study detailed in **chapters 5** and **10**.

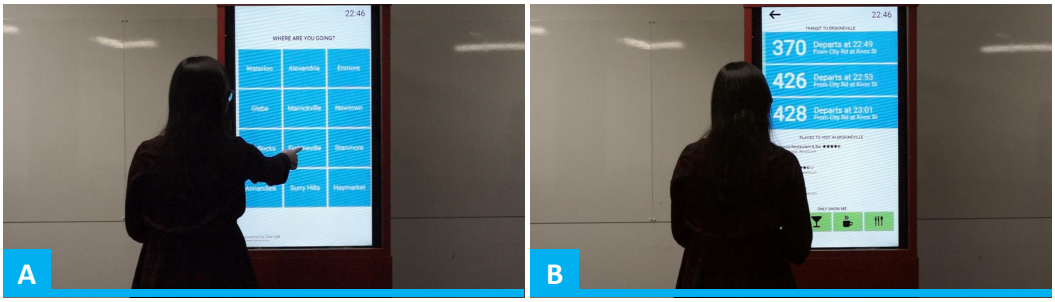

Fig. 3.4.: Prototype B, an interactive transit display, had two main screens: (A) Suburb select; and (B) Transit and places information for the selected suburb.

Prototype C: ***Height-aware Public Interactive Display***

This prototype was created in response to an observation that PIDs are often designed using a "*once size fits all*" approach using an average height specification. PIDs designed in this way potentially exclude a large range of users due to elements on screen being hard to reach. To address this challenge, we developed an experience prototype that allowed users to take self-portraits through its in-built webcam and could adjust its interface according to the user's height. To test different methods of height detection, we created the following semi-functional height-aware modes: touch interaction (Figure 11.3A), height-sensing through a NFC and Microsoft Kinect (Figure 11.3B), and reaching detection (Figure 11.3C). Some of these modes were simulated during the study using a keyboard to trigger the detection. This prototype appears in the study detailed in **chapters 9** and **10**.

3.5 Summary

In this section, the research approach, research questions, methods, and prototypes were discussed. To summarise this section and the way this doctoral research was carried out, Table 3.2 provides an overview; showing which chapters implemented each of the aforementioned research methods, along with the associated prototype if applicable.

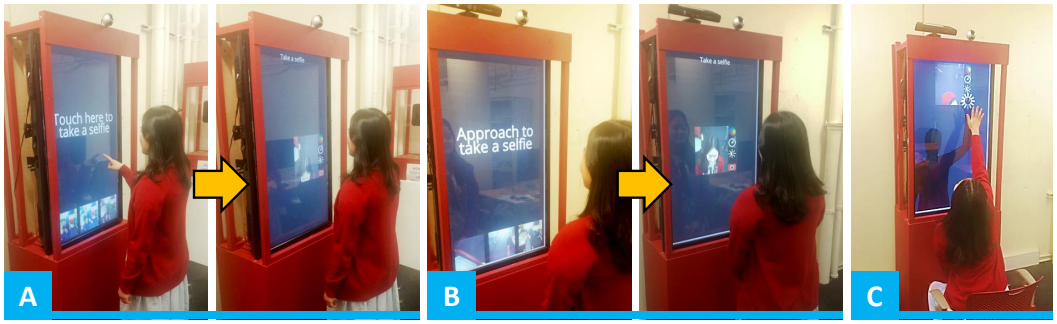

Fig. 3.5.: Prototype C, a height-aware public interactive display, had the following height adjustment modes: (A) Touch; (B) Proximity and height sensing; and (C) Reaching detection.

Tab. 3.2.: An overview of the methodology used in this research.

Research Method	Chapters	Prototype
Field Observations	4, 5, 6	N/A
Lab Studies	9, 10	Prototype A & B
Field Studies	5, 8, 10	Prototype C

In the next part of this thesis, the core chapters (publications) are organised into three parts, based on the three stages shown in Figure 3.1.

Part II

The current role of public interactive displays

4 Does the Public Still Look at Public Displays? A Field Observation of Public Displays in the Wild

4.1 Preamble

This chapter presents a field observation study of non-research public displays in the wild. This study was conducted so that a more grounded understanding of PIDs and public displays in general could be gained. While much of the literature on public displays has studied them from both a lab and field context, little work has looked at public displays that already exist in the wild. Work by E. Huang et al. (2008) studied a broad range of public displays in a number of cities. Since their study in 2008 however, technology, trends, public space, and society itself has changed. Therefore, this study was initiated in response to this identified gap. Specifically, this chapter addresses RQ1 (*What is the role of a public interactive display in a hyperconnected society?*), in presenting insights into the current role of a PID and how personal device usage affects the engagement with PIDs. The next two chapters are also related to this study, but branch out and discuss specific aspects. **Chapter 5** explores the factors that influence PID usage, presenting factors that can help bridge the gap between people and PIDs. While **Chapter 6** explores additional data that was collected and not reported on in this chapter, regarding PIDs we observed with certain types of failures. In relation to the thesis as a whole, the contributions of this chapter provide the foundations for other chapters exploring relevance to individuals and the design of PIDs, by providing a contemporary understanding of PIDs in the wild.

This chapter was accepted as a journal article for Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT) and will be published on ACM in June 2018. The paper will also be presented at the 2018 ACM International Joint Conference on Pervasive and Ubiquitous Computing in October 2018. The formatting and reference

style of this chapter differs from the original publication to fit the formatting of this thesis.

4.2 Abstract

Public displays are widely used for displaying information in public space, such as shopping centres. They are typically programmed to display advertisements or general information about the space in which they are situated. Due to recent advances in technology, public displays are becoming ubiquitous in space around cities and can potentially enable new interactions with public space.

Despite these advances, research reports that public displays are often found to be: (1) generally irrelevant to the space in which they are situated; and (2) ignored by passers-by. Although much research has focused on tackling these issues, a gap remains regarding knowledge about how public displays in the wild are currently being used at a time when people are increasingly relying on their smartphones as a main source for accessing information and for connecting with others.

The study reported in this article aims to address this gap by presenting new insights about the current practices of non-research public displays and their role in a hyperconnected society. To achieve this, we provide results from a field observation study of non-research public displays and contextualise our findings within an analysis of related work.

This article makes three main contributions: (1) identifying how user engagement with public displays has changed over the past 10 years; (2) understanding how the pervasiveness of smartphones and other connected devices has modified whether users notice public displays and their interactions with public displays; and (3) outlining design recommendations and opportunities towards making public displays more relevant in a hyperconnected society.

4.3 Introduction

A public display is a medium that brings digital content into the real world and into the eyes of the general public. With smaller hardware form factors and lower costs in display technology there is a growing investment into public displays, spawning large commercial public display networks, such as the Media Poles in Gangnam, Seoul (J.-H. Lee and W.-J. Lee, 2013) and Live Touch Screens in Sydney, Australia (Release,

2016). There has also been significant investment into digital out of home (DOOH) advertising due to a strong growth of this format over analogue advertisements and this investment is predicted to increase until the year 2020 (PwC, 2017). In research, there is a growing body of work studying public displays for purposes other than simply advertising. For instance, previous work has demonstrated that public displays can help engage local communities, allowing people to submit and publicly display their opinions on civic topics (Hespanhol et al., 2015; Schroeter and Foth, 2009; Wouters et al., 2014). Other work showed that public displays can be used to augment existing services, such as bus timetables (Parker et al., 2018c), community noticeboards (Alt et al., 2011), and wayfinding signage (Colley et al., 2015).

Despite this growth and potential of public displays as a ubiquitous media platform, a remaining challenge is getting people to notice and interact with the content on these displays (Memarovic et al., 2015; N. S. Dalton et al., 2015; Parker and Tomitsch, 2017; Alt et al., 2012b). Research has focused on addressing this challenge by designing public displays to grab users' attention through implicit responsiveness to passers-by (Wang et al., 2012; Müller et al., 2012; Ackad et al., 2016) and playful interactions (Tomitsch et al., 2014), allowing for the Honeypot effect to occur (Brignull and Rogers, 2003; Wouters et al., 2016; Michelis and Müller, 2011). While capturing attention is an important factor for engagement with public displays, the relevance of the content shown on a public display is also important. Content that is relevant to the space or community in which the public display is situated (Hespanhol et al., 2015; Alt et al., 2011; Davies et al., 2014) and to an individual's activities (Parker et al., 2016) can be effective at successfully engaging users.

Although there is much value in testing public displays in research, they are not always representative of non-research public displays deployed in the wild (Alt et al., 2012b). To overcome common assumptions made about non-research displays, Huang et al. (E. Huang et al., 2008) carried out an observation study in 2008 which led to a better understanding of non-research public displays in the wild. Their findings suggested that to increase attention, public displays should be positioned at eye-level and the content should be designed with the setting and audience taken into account. Since this work was published however, society and public space has changed. The changes in society have occurred largely in part due to new technological trends since the release of Apple's first-generation iPhone in 2007 (Vogelstein, 2017), leading to a rise of connected personal devices, such as smartphones, tablets, and smart watches. The adoption of smart personal devices and their integration into people's lives allows people to be hyperconnected at all times (Passarelli and Angeluci, 2017), where information is readily available

from personal devices. This ubiquitous information access raises new contemporary questions about the role of public displays.

In this paper, our aim is to offer researchers and designers concrete, ecologically valid knowledge about the use of non-research public displays in the wild by revisiting E. Huang et al. (2008) study conducted 10 years ago. To achieve this, we report findings from a field observation study of 18 non-research public displays carried out across 8 different locations in Sydney, Australia to understand current trends and observe people's behaviour around public displays.

The study itself was driven by four research questions in relation to public displays. More specifically, we were interested in the effect of four aspects on users' engagement with public displays, that is, whether users noticed and looked at the public display and (for interactive public displays) whether users interacted with the display. The research questions, therefore, are as follows:

- (RQ1) What design elements attract attention/convey interactivity?
- (RQ2) What is the effect of position and location?
- (RQ3) What type of content is relevant?
- (RQ4) What is the effect of smartphones?

Our study contributes to knowledge of public displays and ubiquitous computing research in three ways. First, the findings from our study contribute to an understanding of how current technological trends, such as smartphone usage, have modified user engagement with public displays. Second, we identify how public displays and user engagement with them has changed since the study conducted by Huang et al. (E. Huang et al., 2008) 10 years ago by contrasting the findings from our study with theirs. Finally, we outline design recommendations towards improving user engagement with public displays.

4.4 Background

To support and ground our study we first review literature that has investigated the role of size, positioning, and responsiveness of public displays for attracting attention and conveying interactivity (RQ1 and RQ2). We then discuss methods to make public displays relevant (RQ3), such as changing content based on context, related to people and the environment in which the public display is situated. Next we discuss the increase of personal device usage in society, which we refer to as

hyperconnectedness, and how this has affected the way we use a public space and public technologies within it. This feeds into RQ4 as it can have a potential effect on public display usage. Finally, we summarise this work and discuss how it influenced our study.

4.4.1 Gaining Attention and Conveying Interactivity

The problem of public displays gaining attention is referred to in public display literature as "*display blindness*" (Memarovic et al., 2015; Müller et al., 2009; E. Huang et al., 2008). Display blindness is similar to the concept of banner blindness on the web. It is characterised as either passers-by ignoring the existence of public displays as they assume the content is not of relevance or public displays becoming lost in the background of other things in the space vying for attention.

To tackle this, much research has aimed at understanding display blindness and how it can be overcome. Huang et al.'s (E. Huang et al., 2008) study of non-research public displays in the wild found that attention to public displays can be affected by the following factors:

- **Brevity of glances.** People only pay brief attention to public displays.
- **Position.** Public displays positioned at eye-level attract more attention than those that are not.
- **Content format.** Dynamic content, like videos, tend to attract more attention than static content.
- **Catching the eye.** Permeability and items within the space positioned nearby a public display can help draw attention and bring the public display into the peripheral vision of passers-by.
- **The "captive" audience.** Describes people held captive nearby a public display, such as on an escalator or waiting in line.
- **Small displays vs. large displays.** Smaller displays are generally better at sustaining longer amounts of attention than larger displays, as the smaller displays are designed for more intimate use, whereas large displays are more exposed.

While their study highlighted the effect positioning has on user engagement, Dalton et al. (N. S. Dalton et al., 2015) found that people may notice public displays regardless of where they are positioned. In their study, participants' eyes were

tracked using Tobii Mobile Eye Tracking Glasses to determine what they were gazing at while they moved through a shopping centre. Findings from this study suggest that display blindness may not always occur, as participants gave short glances to most of the public displays. As acknowledged by the authors, however, the study focused on one shopping centre only. The requirement for participants to wear a head-tracking device may have had a further effect on the results and their ecological validity. Our study adds to this work by including public displays positioned in multiple contexts and observing people without requiring them to wear any measurement instruments.

Research studies of public interactive displays report that adding interactivity is an effective method for garnering and retaining attention (Veenstra et al., 2015). Interactivity on large screens can be eye-catching when the public display responds to passers-by, for example, through screen elements that react to people's presence and proximity (Hespanhol and Tomitsch, 2015; Müller et al., 2012). In some cases, someone interacting with a public display can trigger a social phenomenon known as the Honeypot effect (Brignull and Rogers, 2003; Wouters et al., 2016; Michelis and Müller, 2011). This effect can occur when a passer-by notices someone interacting with a public display, potentially leading them to approach the public display and interact themselves.

Making public displays interactive leads to the challenge of conveying that the public display is interactive (Grace et al., 2013). To overcome this challenge, previous research has investigated the effectiveness of public display interfaces that react to the presence of passers-by. Ackad et al. (Ackad et al., 2016) reported on a study of a large interactive information display that used a Microsoft Kinect sensor with Mid-air gestures as a form of input. Their findings showed that interface elements are more likely to gain attention if they follow passers-by. In similar work, Beyer et al. (Beyer et al., 2014) deployed a long display in a public space and observed passer-by behaviour. Their study concluded that visual stimuli that follow the passers-by, such as frames and ellipses, are effective at grabbing the attention of the passers-by and directing them into position for interaction.

This previous work shows that making public displays interactive and responsive can increase the chance of a public display being noticed and used. In this study, we observe how effective public displays are at gaining attention and in the case of PIDs, convey to passers-by that they are interactive. Importantly, our study focuses on non-research public displays, whereas most of the previous work in this area has investigated public displays within the context of a research deployment study, that is, public displays that were designed and deployed by the researchers for the

purpose of conducting a user evaluation study. As such, our work is closer aligned with and adds to the studies conducted by Huang et al. (E. Huang et al., 2008) and Dalton et al. (N. S. Dalton et al., 2015).

4.4.2 Making Content Relevant

While making public displays eye-catching is important, the actual or perceived relevance of the display's content can be another factor that influences user engagement. Research identified that one of the reasons people do not interact or look at a public display is due to their perception that content on a public display is irrelevant (**Cardoso2009**; Davies et al., 2014; Parker et al., 2016). This problem can potentially be overcome when the content is related to the context of the space or community. For instance, Alt et al. (Alt et al., 2011) showed that content related to events and local information was highly relevant when they studied a digital noticeboard display that allowed citizens to post and view user-generated content, such as classified advertisements from citizens trying to sell second hand goods or promote community events. Other work used public displays to engage citizens on local issues for members of the community to voice their concerns and see aggregated data about what the other people in the community think about particular issues (Hespanhol et al., 2015; Schroeter and Foth, 2009; Steinberger et al., 2014; Baldauf et al., 2014).

Content on a public display can be tailored further through user profiles, similar to the ones commonly found on the web (Memarovic and Langheinrich, 2010). However, logging into a public display the same way as one would log into a web service on a personal computer is not very practical and could raise privacy implications. As a potential solution, research has suggested a device-based approach where personal devices are used as a private method of identification (Parker et al., 2015). Early work (Davies et al., 2009) utilised Bluetooth device names, where users could change their device's name to a search query triggering public displays they walked past to display certain content. Other work (Parker et al., 2016; Davies et al., 2014) tested custom apps that allowed the user to set their own preferences for the type of content they would like to see and would send this information over WiFi to personalise nearby public displays. At the same time, personalisation of public displays needs to be carefully tailored to ensure users perceive the information as useful (Parker et al., 2016), such as making the content relevant to what users are currently doing, like displaying traffic conditions or weather when the user is travelling home from work. However, a device-based approach assumes that everyone has a personal device and that they would spend the time to install the app

or connect to a dedicated network. Therefore, research has investigated device-free approaches for making content on a public display relevant. Wang et al. (Wang et al., 2012) presented the peddler framework for public displays which utilises proxemic interaction to deliver an experience similar to what is found on websites like Amazon, where the interface adjusts as the user comes closer, drawing them in with content that it determines is of most relevance. A similar system is realised by Elhart et al. (Elhart et al., 2017), where they present an approach which enables public displays to detect audience mobility in front of them and automatically schedule content based on the type of activity detected. While a device-free approach can enable public displays to become smarter by implicitly responding to people and predicting what they might be interested in, a current challenge is ensuring the content provided by public displays complements smartphone usage (Parker et al., 2018c).

In summary, the relevance of content displayed on a public display involves two perspectives: (1) whether the content is intended to be relevant; and (2) whether people perceive the content as relevant. Previous work in this area has mostly focused on how to make content relevant on a public display - in our work we observe how non-research public displays present their content and in what ways the content displayed is related to the context of the space and those passing through it.

4.4.3 Hyperconnectivity

The hyperconnected society stems from the observation that society is generally becoming increasingly connected via the internet (Tragos et al., 2015; Choi, 2014; Passarelli and Angeluci, 2017) enabled through personal connected devices, such as smartphones, smartwatches, and tablets. Personal devices allow us to become hyper-connected and to tap into information available via the internet and connect with each other from anywhere and at any time. As predicted by Manovich (Manovich, 2006), these technological advances have resulted in an augmentation of public space, creating digital layers that exist over the physical space, causing it to become an intersection of personal and public information (Hatuka and Toch, 2017).

Personal devices have enabled citizens to have new experiences with public space. For instance, QR codes and RFID have seen a revival in recent years, giving objects that exist in public space a form of meta information that can be accessed through a smartphone's camera. For example, a recent successful application of QR codes and RFID in public space has been their use in bicycle sharing schemes, where people

can use their smartphones to register bicycles to their account and unlock them for a determined period. QR codes also commonly appear on physical advertisement posters, allowing people to find out more information via their personal device. In regard to public displays, QR codes and RFID are well-established interaction techniques (Alt et al., 2013; Bauer et al., 2011; Parker et al., 2017; Prante et al., 2003).

The rise of personal devices raises questions about the role of public displays in a hyperconnected society. An approach taken in some research studies utilises personal devices for enabling interaction with public displays. Schroeter et al. (Schroeter and Foth, 2009) developed a system for an existing large public display that enabled citizens to voice their opinions on certain topics related to the community, through SMS, Twitter, and Email. Alt et al. (Alt et al., 2011) studied a public interactive display (PID) network that displayed user generated content posted from a companion smartphone app. These studies demonstrate how a public display can serve as a public broadcast medium, whereby citizens can send messages from their personal devices to public ones, enabling community discourse.

Despite these examples showing promise, more work is needed to understand how non-research public displays have changed in the wild and to understand the effects of personal device usage in relation to user engagement with public displays. This work sets out to gain insights into this and identify ways to enhance public displays through smartphone usage.

4.4.4 Research Gap

There is a considerable body of work investigating user engagement with public displays. Much work has also focused on how content on public displays can be designed so that it is relevant to users or those that look. However, since Huang et al.'s (E. Huang et al., 2008) study, which was conducted 10 years ago, there has not been any research focusing on user engagement with public displays in the wild across a variety of contexts and display types. Motivated by technological advancements and the potential effect of smartphone usage, our work aims to address this gap through a field observation of non-research public displays. Specifically, this research sets out to understand the effect of design elements (RQ1), position and location (RQ2), relevance of content (RQ3), and smartphone usage (RQ4) on user engagement.

4.5 Study Design

Our starting point was to replicate Huang et al.'s (E. Huang et al., 2008) study by adapting their study design to take into account the subsequent changes in technology, observed during our pilot study. The changes relate to public displays being generally larger than previously reported by Huang et al. (E. Huang et al., 2008). We also noticed a lot of smartphone usage from people within public space, which was not reported at the time of Huang et al's study as smartphones were still in their infancy. These changes could have an effect on display blindness, which remains a key challenge for public displays (Memarovic et al., 2015; K. Lee et al., 2014; Müller et al., 2009; Ojala et al., 2012; Houben and Weichel, 2013). Therefore, to gain further understanding and to readily support comparisons of display blindness (or attention) across the different displays observed, we decided to depart from the methodology used by E. Huang et al. (2008) to a mixed methods approach, with emphasis on collecting quantitative data.

This section explains how we selected the public displays to include in our study, the data we collected, the methods used to collect the data, and how the data was analysed.

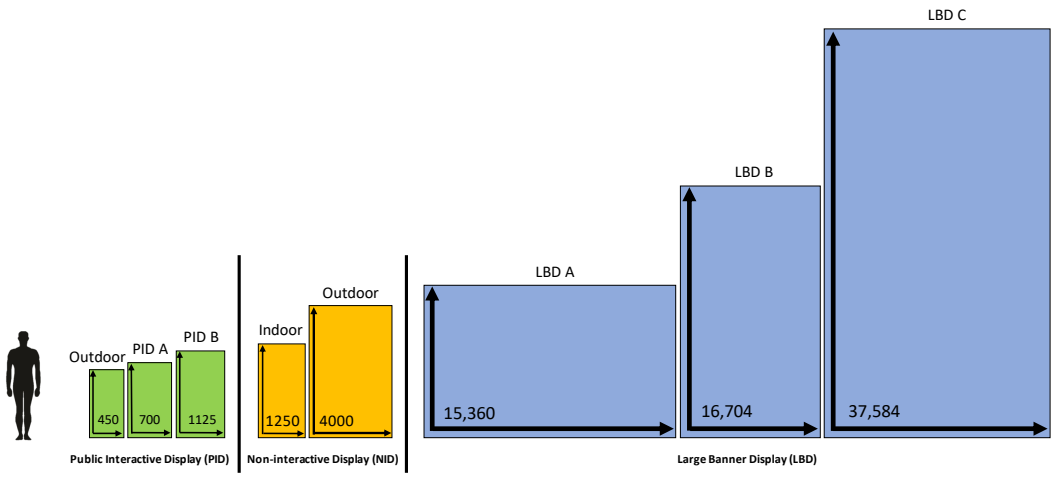

Fig. 4.1.: The three types of public displays observed: Public interactive displays (green), non-interactive displays (orange), and large banner displays (blue). Within each type of public display, the size in square inches (in^2) and orientation is illustrated.

4.5.1 Public Display Selection

We selected 18 public displays across 8 sites around the city of Sydney. This enabled us to have a broad representation of public displays, ranging from small to large displays, indoor and outdoor locations, non-interactive and interactive, and content related to advertisement and information. While aiming to have a broad representation of public displays and contexts, our selection process was also constrained by access to sites, the necessity to obtain relevant permissions (e.g. to conduct observations in shopping centres), and geographic location as we only studied public displays in one city.

We observed public displays in both indoor and outdoor spaces within the city of Sydney, Australia. Locations were chosen to give contrast to others and gain a broad representation of public display types from different areas. Figure 4.1 gives an overview of the different public displays observed, detailing the type, orientation, and size. We categorised the findings from our observations based on the type of public display observed. In total, we observed three different types: public interactive displays (PIDs), public non-interactive displays (NIDs), and large banner displays (LBDs).

To give an indication of how spread out around Sydney the public displays were, we outline them in Table 4.1 with the region of Sydney they were located in, their specific location, and their distance to the City Wharf - which we chose to be an anchor point as it is a central landmark in Sydney.

4.5.2 Data Collection

The context of a public space can change over time (Moere and Wouters, 2012), influencing the environment and people that pass through it. Therefore, observations of each public display were carried out over two sessions, once in the morning and once in the afternoon. The morning sessions were conducted between 9:00am and 11:00am, after the peak morning rush. The afternoon sessions were held between 4:00pm and 6:00pm, around the time people typically finish work. Each observation session lasted for 30 minutes, where we observed the behaviour of passers-by around each public display, recording glances, interactions, and any other interesting behaviour. Observations both indoor and outdoor were only carried out on days

Tab. 4.1.: The regions of Sydney the observation was conducted in with the locations and public displays found in each location. The table also includes the distance between each location and the City Wharf, which is a central landmark in Sydney.

Region	Locations	Public Displays	Distance to City Wharf
City	City Wharf	Outdoor PID & NID	0 km
	Chinatown	Outdoor PID & NID	2.2 km
	Business District	Outdoor PID & NID	0.8 km
	Public Square	LBD A	1.9 km
Inner West	Shopping Centre 1	Indoor PID A	3 km
		LBD B	
	Shopping Centre 2	Indoor PID B	2.8 km
	University	Indoor NID	3.7 km
Eastern Suburbs	Shopping Centre 3	LBD C	4.8 km

with good weather, avoiding rain and strong winds as they might have affected how people used each space.

The observation data for our study was collected manually by the researchers rather than using an automated approach through videos (Alt et al., 2012b) or instruments attached to passers-by (N. S. Dalton et al., 2015), as we considered this to be the least disruptive to the space while avoiding privacy and ethical issues associated with recording videos within a public space. We also opted to not conduct any interviews with passers-by to keep user behaviour and the space pure, in order to avoid discouraging people from looking at and interacting with the observed public displays (J. R. Williamson and J. Williamson, 2017).

We used a mixed methods approach, where we collected both quantitative and qualitative data. This data consisted of:

1. A count of passer-by engagement, using a custom developed smartphone app.
2. Descriptive notes about the space, the set-up of the public display, and behaviours of people in the area.
3. Photos of the space and the public display. In one case, we were not able to receive approval for taking photos and therefore sketched the area using a pen and paper.

The count of passers-by enabled us to clearly compare attention and display blindness for each public display. Specifically, we counted the people passing by, looking, interacting, and using a smartphone. The notes, photos, and sketches then added more context to the count of behaviours and helped explain why some public displays were more successful at gaining attention than others.

Throughout the findings section we will at times mention the exact dimensions of the screen. We only provide this information for public displays where it was possible to gain a measurement, such as public displays within arms reach like touch PIDs. To record the measurement we used a credit card sized marker and placed it in one of the corners. We then took a photo of the screen and used an image processing application to digitally clone the marker over the entire screen to determine the display's dimension. We used this approach over measuring tape as some screens were too large for us to be able to reach. For displays that were out of reach altogether (e.g. the large banner displays), we sourced the dimensions from the display provider's website or provided an estimate.

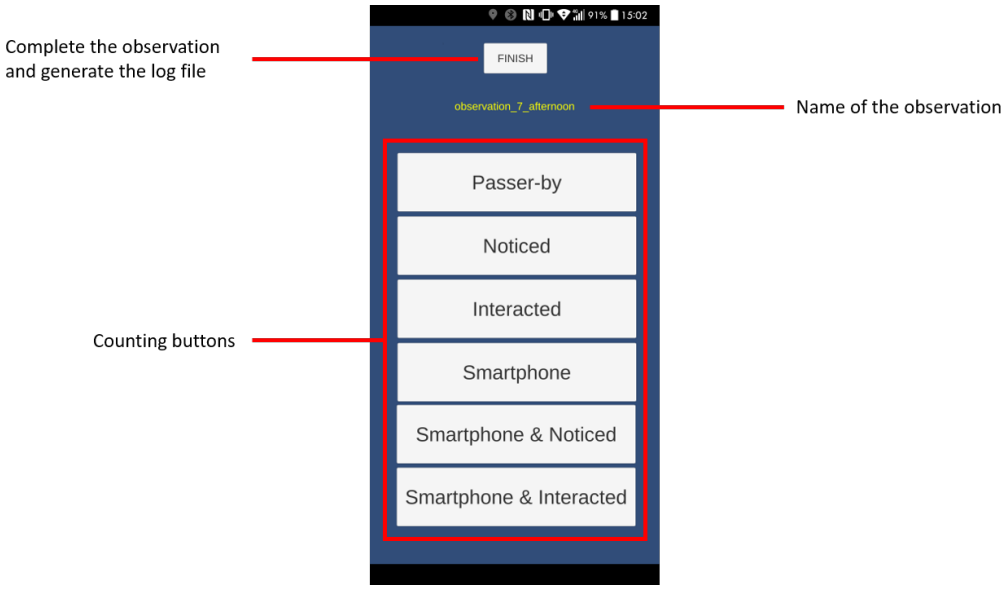

Fig. 4.2.: The counting app used for our observations. It contained six buttons for counting passer-by behaviours with the observed public display.

4.5.3 Observation Techniques

We applied different techniques for recording data depending on how crowded the space was. In spaces that were not crowded, we utilised the shadow observer technique (E. Huang et al., 2008) to focus on individual passers-by and record

their behaviour. In busier and more crowded spaces, we used a technique which we introduce as *selective path focus*, where the observer would first observe the permeability of the space and focus only on certain paths passers-by take. This made the observations more manageable, particularly when counting behaviours.

While manually recording the count of passers-by and their behaviours, we noticed in our pilot observations that counting different behaviours required the researcher to look down for a time to record, which reduced their recording accuracy as they would miss passers-by. Recording with pen and paper can also make the researcher stand out in space, affecting people passing through.

Therefore, we created a custom-made smartphone app[1] (Figure 4.2) to ease the counting of passers-by and to allow recording passer-by data without having to look down. The app contained six large buttons for counting particular behaviours of passers-by in relation to the public displayed observed:

1. passed by without looking or using their phone
2. looked at the public display
3. interacted
4. used a smartphone
5. used a smartphone and looked
6. used a smartphone and interacted

The "FINISH" button displayed at the top of the screen completes each session and saves a log file with the name of the observation to the device.

However, even with the app increasing the efficiency of counting passers-by, there were difficulties at times discerning whether passers-by were looking at the public displays. We counted a "look" when someone visibly turned their head towards the public display. Due to the sheer volume of people moving through most of the spaces, we did not record the duration of glances. Interactions were counted when a passer-by explicitly walked up and interacted with the public display, such as touching the screen.

[1]The source for our counting app is available on Github - `https://github.com/callumparker/observation-behaviour-counter`

4.5.4 Analysis

Our analysis began by aggregating all the collected data, which consisted of photos, sketches, notes, and observation logs generated by our smartphone counting app. We performed our data analysis by looking for common themes emerging from the different sets of data. The photos and sketches were used to help our descriptions of each public display observed, giving us a sense of each space and the spatial arrangement of the observed public displays. We placed the observation logs into a spreadsheet and looked for interesting links between each behaviour observed. We used a colour scale to help identify which behaviour was highest occurring for particular public displays. Our inferences from the observation logs were contextualised with the notes we made during each observation session, further describing the behaviours that were counted and explaining the factors that might be linked to a certain result, such as the environment layout.

4.6 Observation Findings

In this section our findings are categorised by the three different public display types observed during our study: public interactive displays, public non-interactive displays, and large banner displays.

4.6.1 Public Interactive Displays (PIDs)

The PIDs we encountered in our study enabled people to search for information about the space in which the PID is located. In this section we discuss our observations of three different PID networks that were observed during our study, with one of those networks located outdoors and two located indoors, within two different shopping centres.

Outdoor PIDs

The outdoor PIDs are built into a permanent booth structure, containing a payphone and the PID on one side, which is replaced by a static map in some locations, and a large advertisement display on the other (discussed in section 4.6.2). These booths form part of a network managed by an outdoor advertising company. To gain a broader representation of different spatial contexts around the city, we focused on

Tab. 4.2.: The count of passers-by and their different behaviours from the morning and afternoon observation sessions with the public interactive displays (PIDs). Total column refers to the absolute total number of passers-by, while the columns to the right of it refer to the passer-by behaviours as a percentage of the total.

>5% >10% >20% >40%

Public display	Total	Passers-by %	Looked %	Interacted %	Smartphone user %	Smartphone & looked %	Smartphone & interacted %
Outdoor PID (City Wharf)	186	87.6	3.8	0	8.6	0	0
Outdoor PID (Chinatown)	73	75.3	12.3	0	12.3	0	0
Outdoor PID (Business District)	408	90.2	2.9	0	6.9	0	0
Indoor PID A (Level 1)	261	88.1	2.7	0	8.8	0.4	0
Indoor PID A (Level 3)	145	86.2	4.8	0	8.3	0.7	0
Indoor PID B (Level 2)	110	83.6	1.8	0	14.5	0	0
Indoor PID B (Level 4)	120	85.8	8.3	0	5.8	0	0

(a) *Morning sessions*

Public display	Total	Passers-by %	Looked %	Interacted %	Smartphone user %	Smartphone & looked %	Smartphone & interacted
Outdoor PID (City Wharf)	539	84.2	3.9	0.6	10.6	0.7	0
Outdoor PID (Chinatown)	376	80.9	11.2	0.5	6.6	0.8	0
Outdoor PID (Business District)	428	83.6	4.4	0	11.7	0.2	0
Indoor PID A (Level 1)	393	87	3.6	2.3	7.1	0	0
Indoor PID A (Level 3)	164	80.5	9.8	1.2	7.9	0.6	0
Indoor PID B (Level 2)	219	90	2.7	0	7.3	0	0
Indoor PID B (Level 4)	67	79.1	6	0	14.9	0	0

(b) *Afternoon sessions*

three of these outdoor booths in the following locations: city wharf, Chinatown, and business district. The chosen locations provided a range of contexts, from tourist to business-centric areas.

These PIDs, at first, display an idle screen with the text "*Touch to activate*" and an animated hand performing a touching motion (Figure 4.3A). Upon touching the screen users are presented with a menu displaying the current time and date in the top left corner of the screen and four options to choose from displayed as tiles in the centre. The first option, "*Photos*", allowed users to swipe through photos of landmarks around the city. In the second option, users could browse a map of the city and search for a point of interest by typing with the on-screen keyboard. The third option displayed the current and future weather of Sydney City. While the fourth option was similar to the third, as it displayed a map and represented points of interest (such as tourist attractions and train stations) as icons that could be touched to view more information.

The outdoor PIDs were also affected by their positioning and the way they conveyed interactivity. Table 2 shows that despite being the least busiest outdoor space, the Chinatown PID received the most looks, with 12.3% looking at it in the morning and

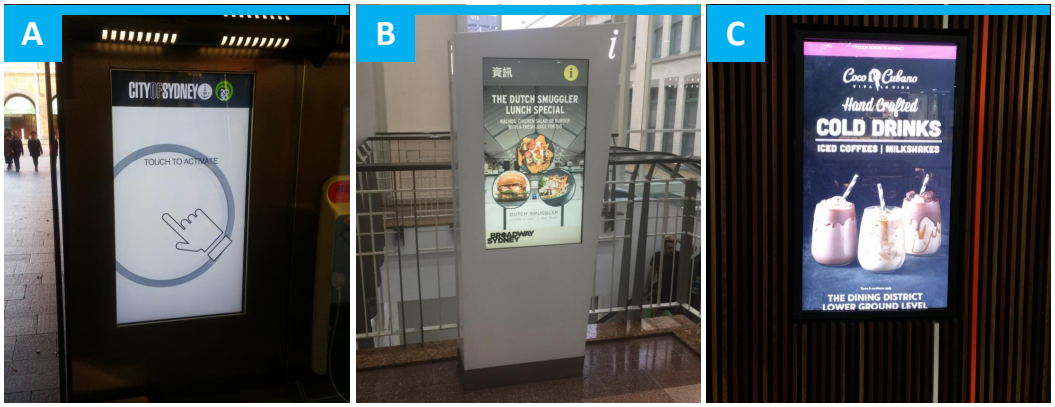

Fig. 4.3.: The different PIDs observed: (A) Outdoor PID; (B) Indoor PID A; (C) Indoor PID B.

11.2% looking in the afternoon. This could be explained by the Chinatown PID being situated in a smaller area and therefore the PID was in line of sight for passers-by. The area was also darker due to the tall buildings and trees, which meant the PID's brightness made it stand out more than the others that were positioned in more open spaces.

The city wharf PID was positioned outside the main path people took when walking through the space, which may have contributed to the low number of people noticing the display, 3.8% and 3.9% in the morning and afternoon respectively. We observed that the PID was facing away from the large crowds of people walking towards nearby tourist attractions. The glare from the sun was also strong in the afternoon, which made the content on this PID's glossy screen hard to see from a distance. The city wharf PID was also competing with static signage. We observed on two different occasions people referring to a static map that was positioned closer to the main path, making it in line of sight for people passing by. Like the city wharf location, the business district PID also received a low proportion of people looking at it, despite being positioned next to one of the busiest paths in that space. Therefore, it might be that the business district PID simply was not eye-catching enough or that it was not in the line of sight for people passing by. We also noticed that many passers-by walked through the space in groups, often talking with one another, which may have further decreased the amount of people looking.

In terms of interactions, all of the outdoor PIDs had low usage. This may have been due to the positioning of the PID as the advertisement side of the booth always faced the direction where majority of the pedestrian traffic was coming from. Another factor may have been that the outdoor PIDs do not necessarily convey interactivity or purpose. While the PIDs were idle they would display a splash screen with the

text "*Touch to activate*" and an animated hand performing a touch. The top part of the screen displayed a City of Sydney banner with a logo. However, nothing on the screen or booth itself gave indication about the purpose of the PID. Every location also had a significant proportion of smartphone users walking past, with few actually looking up from their smartphones while passing the PIDs.

Indoor PIDs

The indoor PIDs A (Figure 4.3B) and B (Figure 4.3C) were situated in shopping centres 1 and 2 respectively. The PIDs allowed users to view information about their respective shopping centres, such as where certain shops were located on a map. While there were many of these PIDs on each floor, we focused on two PIDs on different levels for each of the shopping centres to gain a sense of how a PID's location within a shopping centre could affect usage.

PID A (level 1) was situated near to the main entrance to the shopping centre, while PID A (level 3) was situated near to cafés, shops, and the carpark entrance. The PIDs cycled through advertisement content related to the shopping centre when not being used. A whole cycle through the content took 15 seconds, with four pieces of advertisement content. The screen would also switch between Chinese and English while idle, translating the top interface ribbon text "*Information*". The Chinese and English translations lasted for 5 and 8 seconds respectively and did not affect the language of the advertisement. The menu interface allowed users to search for businesses and services within the shopping centre using an on-screen keyboard or by selecting a category. Upon selection, the search query's location would be shown on a map of the shopping centre.

PID B was built into the wall next to the elevator on each of the five floors in shopping centre 2. While idle, the PIDs in this location would display full-screen advertisements, cycling through 10 pieces of content at a rate of one every 35 seconds. These directories contained wayfinding information relating to the general stores, clothing shops, restaurants, and restrooms. The language of the interface could be changed by pressing the language button in the top right corner of the screen, which would then bring up 12 different languages to choose from. In this location, we focused on two PIDs on different floors, the second and the fourth. The second floor accommodated cafés and shops, and could be accessed from the street through the main entrance. Unlike the other levels, the wall containing the PID on this level featured a large non-interactive media façade that displayed artistic animations and advertisements, which people were often observed to touch rather

than the PID. The fourth floor had a food court with space for dining and did not feature a media façade. Instead, the wall surrounding the PID and elevator was a mirror, which we observed to grab the attention of people waiting for the elevator.

The indoor PIDs, PID A and PID B, both had similar functionality but differences in utilisation. As shown in Table 2, PID A was interacted with in the afternoon, 2.3% on level 1 and 1.2% on level 3, while PID B received no interactions. Our field notes suggest that the differences could be linked to the PIDs' positioning and the way they conveyed interactivity. PID A was positioned in close proximity to one of the main entrances. Its position and orientation meant that PID A was in line of sight when people entered the space. Additionally, PID A was contained in a brightly coloured stand with a large glowing "*i*" on top, which may have helped it stand out in the space and indicate that it provided information. We noticed on one occasion the Honeypot effect, where a couple interacted with the PID, causing another person to approach and queue for the PID until the couple had finished. On the other hand, PID B was positioned outside of the main path people usually took while in the shopping centre, limiting the audience of these PIDs to those that passed by or waited for the elevator.

Summary

In summary, we found three emerging factors that contributed to certain PIDs receiving interactions. The first relates to placement of the PIDs, our observations show that PIDs positioned in line of sight and nearby the entrance to a space, received more interactions. Therefore, it is important to position PIDs in main paths so they are easier to see and enable opportunistic interactions. The second factor is the way that PIDs convey interactivity; PIDs should clearly convey their purpose both on-screen and physically, with signage attached to the PID booth or positioned around the PID. Finally, PIDs should be quick and easy to use. We observed in both the outdoor and indoor locations that people would often refer to static signage rather than use the PIDs. The PIDs we observed generally hid their information behind advertisements or in separate apps that can potentially serve as a barrier to time-concious passers-by.

4.6.2 Public Non-Interactive Displays (NIDs)

During our field observations we identified two types of non-interactive public displays that were primarily used for advertising. We observed four of these public

displays: one was located indoors in a university food court and the others were located outdoors in a booth.

Tab. 4.3.: The count of passers-by and their different behaviours from the morning and afternoon observation sessions with the public non-interactive displays (NIDs). Total column refers to the absolute total number of passers-by, while the columns to the right of it refer to the passer-by behaviours as a percentage of the total.

>5% >10% >20% >40%

Public display	Total	Passers-by %	Looked %	Smartphone user %	Smartphone & looked %
Outdoor NID (City Wharf)	189	79.4	13.2	7.4	0
Outdoor NID (Chinatown)	171	79.5	12.3	7.6	0.6
Outdoor NID (Business District)	431	80.7	7.9	11.1	0.2
Indoor NID	80	87.5	7.5	5	0

(a) *Morning sessions*

Public display	Total	Passers-by %	Looked %	Smartphone user %	Smartphone & noticed %
Outdoor NID (City Wharf)	655	86.7	5.5	7.6	0.2
Outdoor NID (Chinatown)	329	69.3	20.1	9.4	1.2
Outdoor NID (Business District)	578	71.1	5.4	23	0.5
Indoor NID	58	96.6	3.4	0	0

(b) *Afternoon sessions*

Outdoor NIDs

Each outdoor NID (Figure 4.4A) was contained in a large booth (introduced in section 4.6.1) installed around the city of Sydney. We observed the NIDs in three different locations: city wharf, Chinatown, and business district. The NIDs cycle sequentially through 8 general advertisements that change every 10 seconds. We noticed that the content displayed on the NIDs was exactly the same in all of the outdoor locations we observed and there was no change in the content from the morning to afternoon.

As shown in Table 3, the most popular NIDs were in the city wharf and Chinatown locations, with the city wharf NID receiving a larger number of people looking in the morning 13.2%, while a higher proportion of people in Chinatown looked in the afternoon, at 20.1%. The proportion of people looking in the city wharf location drastically drops in the afternoon, down to 5.5%. This could be attributed to the large crowds of people walking through city wharf, which may have been distracting. The other possibility could be the strong sun glare observed in the afternoon caused people to look away.

In the case of Chinatown, the high number of people noticing the NID is probably due to: (1) the positioning of the display - it was positioned near the entrance of

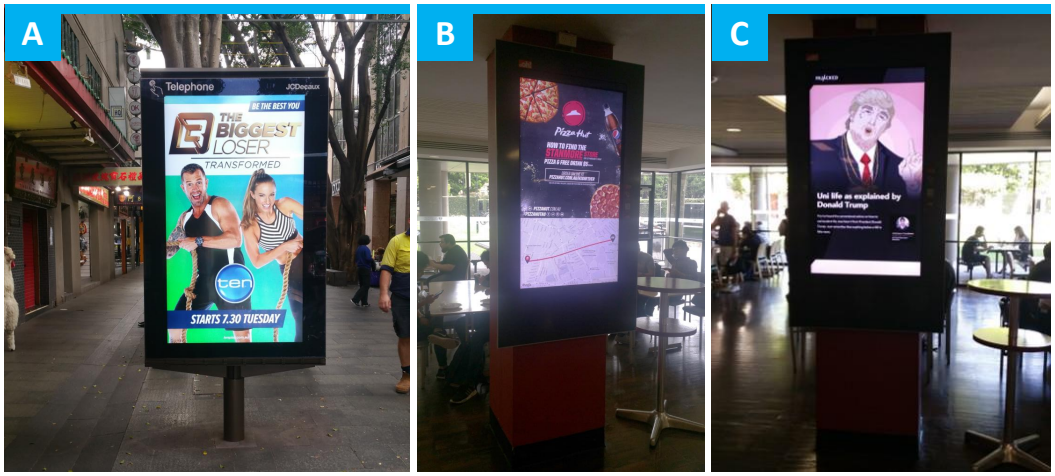

Fig. 4.4.: The different NIDs observed: (A) Outdoor NID displaying general advertisements (same in each location observed); (B) Indoor NID displaying advertising content relevant to the location; and (C) Indoor NID displaying student created news articles (sourced from Universities across Australia).

Chinatown, facing people that came in; (2) The space was closed with not as many paths to take, as there were buildings and trees on either side; and (3) The space was quite shaded as Chinatown is essentially a large alley, which meant the display's brightness made it stand out. Additionally, Chinatown also had the highest number of smartphone users noticing it, 0.6% (morning) and 1.2% (afternoon). Interestingly, the business district had the lowest percentage of people noticing but the highest number of smartphone users, with a low number of people looking away from their smartphones to observe the display.

Indoor NID

This NID was located within a food court at our university campus. It is a busy space with students gathering together at the tables and purchasing food from one of the food stalls. The NID was situated in the middle of the food court, near one of the main paths to the tables, entrance, and food stalls. The NID we observed contained general advertising content targeted at students (Figure 4.4B) and news about student life, written as short articles by journalist and student writers (Figure 4.4C). Students are able to submit their articles on the NID provider's website, where the articles are moderated by the NID provider before appearing on the NID. The content on the NID cycles every 5 to 12 seconds, although articles are displayed for a longer period. We noticed that one of the advertisements for Pizza Hut displayed a map with the location of the closest store to where the public display was located,

indicating that some of the content is tailored for specific locations given that this public display is deployed in universities across Australia. The display also featured NFC and QR code functionality to access the display provider's webpage. However, from our tests with multiple smartphones this feature appeared to not be working.

The location was not busy compared to other spaces we observed. While the NID was positioned in a main thoroughfare, of the 80 people that walked past the NID in the morning, only 7.5% looked at it. In the afternoon the space was quieter with 58 people walking past and 3.4% of people looking at the NID. This may have been due to the content generally consisting of a lot of text, such as the student articles, requiring a person to stop and read. This type of content may not suit the context of this space as people generally focused on purchasing food.

Summary

The NIDs seemed to be well positioned in their respective spaces as a significant proportion of people looked at them. However, the content on these NIDs seemed, in general, irrelevant to the space. Out of all the NIDs, the only one that displayed location-specific information was the indoor NID placed inside a university food court.

4.6.3 Large Banner Displays (LBDs)

We observed the LBDs in three different locations, with one mounted on an entrance to a shopping centre and the others hung from the ceiling within two different shopping centres. All of these displays were non-interactive and cycled through a series of advertisements related to either the businesses within their respective shopping centre or general product and service advertisements.

LBD A

This display (Figure 4.5A) was situated in a public square, which is a semi-outdoor public space with small boutique shops, restaurants, cafés, and public seating. Underneath this space was a large shopping centre which could be accessed by an escalator. In this location, we focused on a banner display that was mounted above the escalator. The content on this display consisted of property investment advertisements in Chinese and advertisements for Chinese and Korean films. Each

Tab. 4.4.: The count of passers-by and their different behaviours from the morning and afternoon observation sessions with the large banner displays (LBDs). Total column refers to the absolute total number of passers-by, while the columns to the right of it refer to the passer-by behaviours as a percentage of the total.

>5% >10% >20% >40%

Public display	Total	Passers-by %	Looked %	Smartphone user %	Smartphone & looked %
LBD A (going down)	95	67.5	14.5	17.5	0.4
LBD B (going up)	78	72.1	10.7	16.6	0.7
LBD B (going down)	234	50.6	26.4	20.1	3
LBD C (going up)	290	38.9	43.2	13.7	4.2
LBD C (going down)	269	35.9	42.3	19.2	2.6

(a) *Morning sessions*

Public Display	Total	Passers-by %	Looked %	Smartphone user %	Smartphone & looked %
LBD A (going down)	84	58.8	20.2	19.4	1.5
LBD B (going up)	82	77.3	9.1	13.1	0.5
LBD B (going down)	391	61.1	20.2	17	1.7
LBD C (going up)	427	65.5	20.2	14.3	0
LBD C (going down)	406	61	20.7	17.1	1.2

(b) *Afternoon sessions*

advertisement stayed on the screen for 13 seconds. People going down the escalator could see the display for 15 seconds before passing under it.

Our observations focused only on people going down the escalator, as the display was facing in their direction. Due to LBD A's placement, a fairly large proportion of people noticed it. In the morning session, we observed that of the people that went down, 14.5% noticed the display and 17.5% used their smartphones. The afternoon session saw 20.2% noticing the display and 19.4% using smartphones (as shown in Table 4).

LBD B

This display (Figure 4.5B) was located in shopping centre 1, which is a five-level shopping centre containing large supermarket chains, shops, and restaurants. Travelators were used to traverse these different levels. The display itself was a large dual-sided LED display that was hung from the ceiling and situated between two travelators, and could be seen by people going up and down. Therefore, we ran four 30-minute observation sessions for this display so as to observe people going up as well as down the travelators. There were two sessions in the morning (up and down) and another two in the afternoon (up and down).

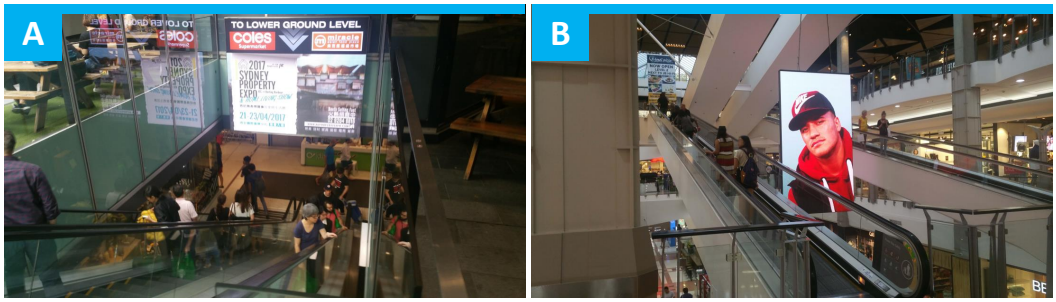

Fig. 4.5.: The different LBDs observed: (A) LBD A mounted above the entrance to an underground shopping centre; (B) LBD B hung from the ceiling between two travelators. No photo for LBD C is included as we did not receive permission to take photos within the shopping centre in which it was located.

In the morning session 10.7% of people looked while going up and 26.4% looked while going down. However, the afternoon session showed a decrease in the proportion of people noticing the display, with 9.1% noticing while going up and 20.2% noticing while going down. This may have been due to the travelator becoming more crowded in the afternoon, distracting people's attention away from the screen.

In general, we noticed that most of the glances to the display occurred when something, such as an animation or video, changed on the screen. There were also times when the screen was clearly noticed by people outside the elevator. We observed people staring at the screen while walking around level 2 or waiting in line at the juice bar opposite the level 2 travelator entrance/exit.

LBD C

This display was located at shopping centre 3 which features a large variety of boutique shops, cinemas, food courts, and major retailers. In this location, we focused on observing a banner display hung from the ceiling near the food court and escalators. The display could be seen from multiple angles and levels as the space was quite open. The display could be viewed from either side as it consisted of two LED screens in one enclosure. As one side of the display was next to escalators, there was a clear view from the side while going up and down. The display could also be seen clearly from a nearby café seating area. We were not able to include a photo of this display as we did not receive permission from the shopping centre.

Similar to the process adopted for LBD B, we conducted four observation sessions of people going up and down the escalators; twice in the morning and twice in the afternoon. We observed that the banner display cycled through four pieces

of content, changing every 10 to 20 seconds. The content on the banner display remained the same during the morning and afternoon sessions, displaying a car advertisement, information about a cinema's advance screening, a shopping centre brand advertisement, and an advertisement about free WiFi at the centre. It took approximately 20 seconds to reach the top or bottom when riding the escalator and the display could be seen the entire time as it is large and in an open space.

During the morning session there were many people having breakfast in the café seating area close to the display. We observed people looking up and glancing at the display, with one person facing towards the display and watching it while they had coffee. Table 4 shows that in the morning session this display had the highest proportion of people noticing it out of all the LBDs observed, with 43.2% (going up) and 42.3% (going down). However, the proportion of people noticing decreased in the afternoon session for people travelling in each direction of the escalator, with 20.2% (going up) and 20.7% (going down).

Summary

The observations from these displays revealed some surprising patterns. Despite smartphone usage being high, large proportions of passers-by actually noticed the displays. Our data shows that compared to the public displays from the previous two categories, the LBDs were able to attract attention from smartphone users.

While observing the LBDs we noticed common aspects of people's behaviour across all three locations that may affect whether a public display is noticed. People in groups, such as couples, would often turn around and face each other after stepping on the escalator or travelator, engaging each other in conversation, or collaboratively looking at a smartphone. For some people it was also a time where they could sort items in their bags or look at other people or nearby shop fronts.

4.7 Discussion

In this section, we first revisit the four research questions we outlined in the introduction section and discuss each of the questions in relation to the findings from our field observations. We then discuss our interpretation of the findings and how these relate to the design suggestions identified by E. Huang et al. (2008), while also providing new recommendations. Finally, we discuss the limitations of our study.

4.7.1 Research Questions Revisited

(RQ1) What design elements attract attention/convey interactivity?

From our observations, we found that the following three elements helped attract attention: size, structure holding the display, and screen brightness. These are discussed below.

Size matters. Our findings showed that the large banner displays were able to attract the most attention from people passing by when compared to public interactive displays and non-interactive displays. This may have been due to the size of these displays and their positioning near captive audiences, such as those on escalators. In some cases the large banner displays were able to draw attention even from smartphone users. For ubiquitous computing applications, including smartwatches and other wearable devices, this suggests that interactions with such applications might be affected by other interactive features in the environment.

The design of the structure holding the public display is important. An often overlooked and less covered factor in previous research is the stand or structure holding the public display, which can be utilised to make a public display more eye-catching. For instance, indoor public interactive display A was eye-catching due to the design of its stand, which was painted in a bright colour and featured a glowing information "*i*" on the top which helped advertise the purpose of the public interactive display and contrasted well with the content on the screen. Further we found that animated content and the use of videos, particularly on large banner displays, caught people's attention. On public interactive displays the idle screen should describe clearly what the purpose of the display is in a way that can be seen from a distance. For other ubiquitous computing applications, this points to an opportunity to consider the design of the surrounding structure and environment in conjunction with designing the application itself.

Screen brightness as an element to attract attention. Screen brightness is important as it seemed to have an impact on whether people noticed the display. For outdoor public displays screen brightness can be impacted by the time of day and weather conditions, and these should be accounted for in the design of the display, for example by automatically adjusting the brightness of the screen. While this finding may seem obvious, we did not observe this to be taken into account in any

of the outdoor public displays we observed. This suggests that screen brightness and visibility also remains an important design consideration in other ubiquitous computing applications. The relevance of context for ubiquitous computing has been studied in previous work (e.g. Abowd et al. (1999)). Our finding highlights the consideration of contextual factors such as time of the day and weather conditions as well as the concious design of screen brightness as a mechanism for drawing attention.

(RQ2) What is the effect of position and location?

Our findings show a clear correlation between user engagement and the proximity of a public displays to the main path within a public space. We further found that displays in darker spaces tended to stand out more due to the brightness of their screens, and consequently attracted more user engagement. For the outdoor public displays, the effect of sunlight is linked to the position and location of the display, and further dependent on the time of the day. Therefore, it is important to consider the environment in which the public display is situated and how it changes over time as this can affect its visibility and therefore its effectiveness at attracting user engagement.

We found the large banner displays to be an effective means at engaging people that were as E. Huang et al. (2008) describes, a "*captive audience*" while they were travelling up and down the escalators and travelators. We observed these displays to also engage people around the space as well, with people sitting nearby noticing them. This creates interesting implications for ubiquitous computing research focusing on large media displays, not only in terms of content and purpose of such media displays but also regarding opportunities for engaging a captive audience in short interactions. To that end, previous research on the use of proxemics in ubiquitous computing applications (Wang et al., 2012; Ballendat et al., 2010; Greenberg et al., 2011) could be employed to offer different experiences and means of interaction for people depending on their position in relation to the location of the display.

(RQ3) What type of content is relevant?

In the case of the public interactive displays, it appears that smartphones have not made them completely irrelevant. We observed occasions where people would queue to gain information about a shopping centre. Outdoors, some people would refer to static signage rather than their smartphones to find a location. Therefore,

a need for information about a space remains, but public interactive displays need to better advertise their capabilities and purpose. Previous ubiquitous computing research on location-aware systems (Blackwell et al., 2015; Alletto et al., 2016; Schilit et al., 2003) could be applied to translate some of the functionality of public interactive displays and static signage to smartphones, making it seamless for people to access relevant information on the go. Our observations highlight the role of contextually relevant and physically embedded digital information, which is in line with Weiser's original description of ubiquitous computing systems that "*vanish into the background*" (Weiser, 1991).

(RQ4) What is the effect of smartphones?

Our findings showed that during most observation sessions, a fairly large proportion of the people passing by used their smartphones. It seems that while the public interactive displays and non-interactive displays were not particularly effective at drawing people's attention away from their smartphones, the large banner displays managed to gain the most attention. This could be attributed to the large size of the banner displays, their position - near or in the main path of people passing by, and the brightness of their screens. We found that in the case of large banner display C, the combination of the large size, videos, screen brightness, and colour of the content helped it stand out and receive the highest proportion of people looking and people looking up from their smartphones. While we did not observe any occurrences of smartwatch interactions, we expect that smartwatches and other smart, wearable devices will become more popular over the next 10 years. Our findings highlight opportunities for designing the interactions with such devices under consideration of the wider media ecology surrounding the user at different times, such as public interactive displays and large banner displays. From our observations, we found that currently different devices and displays are competing for people's attention. An interesting future avenue could be to design interactions in a way that supports the fluid transition from one platform to another.

4.7.2 Interpretation - What Has Changed?

Since we concluded that we needed to design our study in ways that are significantly different from E. Huang et al. (2008), there is no simple and strict comparison of detailed results. However, the very fact that we needed to alter the method reflects important changes and we can make meaningful comparisons at a high

level. We do this in terms of the five design recommendations from E. Huang et al. (2008), where for each recommendation we first summarise the original recommendation and then discuss it based on our own findings and that of previous research. To this set of recommendations, we also add three more that emerged from this work.

Brevity of glances - ***People only pay brief attention to public displays.*** We did not measure how long people were glancing at public displays as to do so would cause us to miss counting passers-by and can be logistically challenging in busy environments. An emerging method to more accurately determine the length of glances is through eye-tracking (N. S. Dalton et al., 2015). However, this should be approached carefully in order to prevent disturbing the ecology of the space.

Positioning of the displays - ***Public displays positioned at eye-level attract more attention than those that are not.*** E. Huang et al. (2008) recommended that public displays should be positioned close to eye-height to encourage glances. However, the public displays we observed were all generally larger than the public displays observed in Huang et al's study. We noticed that the larger displays, particularly the large banner displays, received more attention. This means that the requirement for eye-level positioning disappears with large displays as they cover a range of eye-heights. In the case of public interactive displays with touchscreen interaction, careful consideration needs to be paid to the height of the screen as such displays are ultimately limited by the user's arm length. This problem could potentially be resolved through adaptive solutions, with the screen adjusting its content based on the height of the user (Parker et al., 2017). Such a solution could allow for a display that is large enough to gain attention, being accessible to everyone.

Content format and dynamics - ***Dynamic content, like videos, attract more attention than static content.*** The content we observed on the public displays ranged from static to dynamic, such as playing videos or sliding through static poster images. The advertising displays showed a broad range of content that was not always related, meaning they were designed for short time viewing rather than keeping someone continually engaged. For instance, people going up or down the escalator near the large banner displays would typically see 1 to 2 pieces of content by the time they reached the other end. While we noticed in our observations that the scale of the displays has become larger, research suggests that public displays can also come in a wide array of formats, from low-resolution lighting displays (Hoggenmueller et al., 2018) that are typically used in media façades, to LED displays that are bright and low power. Other work has shown that public displays could be smarter by changing content based on the time of day (Parker et al., 2018c; Davies et al., 2014)

or conserving power usage by powering off during off-peak times (Davies et al., 2017).

Catching the eye - ***Permeability and items within the space positioned nearby a public display can help draw attention and bring the public display into the peripheral vision of passers-by.*** While using objects to draw people's attention towards public displays can be effective (Houben and Weichel, 2013; E. Huang et al., 2008), we found in our study that public displays are more successful at drawing attention when they are: (1) a large size, pervading the peripheral of passers-by; (2) have a bright screen with dynamic content like videos or animations; and (3) the stand or object on which the public display is mounted can help it stand out.

Small displays vs. large displays - ***Smaller displays are generally better at sustaining longer amounts of attention than larger displays, as the smaller displays are designed for more intimate use, whereas large displays are more exposed.*** In our study, only the public interactive displays were of a similar size to the displays studied by E. Huang et al. (2008). The public interactive displays we observed provided facilities that are relevant and useful for a small proportion of the people in a space - with many of these people likely to be looking out for them or be repeat visitors who already know about the display. Compared with the large banner displays observed however, public interactive displays did not receive as much attention. We found that the most successful public interactive display was the indoor public interactive display A, as it had physical signage to help it stand out and convey its purpose. Therefore, it is important to balance the size of the display, ensuring the height is suitable for all users while being large enough to be seen.

Aside from brevity of glances, which our study did not test, our observations confirm that the key findings and recommendations from E. Huang et al. (2008) study are for the most part already embodied in the public displays we observed. However, based on the findings from our observation study, we suggest three new recommendations to complement Huang et al.'s original recommendations.

Complement smartphone usage. With smartphones and public displays becoming ubiquitous, the availability of both the personal carried device and the embedded public device seems to offer opportunities to create links between the place and the person. This has been investigated in previous research, where a smartphone could enable personalised content on a public display (Davies et al., 2014; Parker et al., 2016). Other work has explored allowing the user to post content to a public display, thereby enabling situated community discourse (Schroeter and Foth, 2009).

A smartphone can also be used to take content from a display (Baldauf et al., 2012b; Alt et al., 2011), consequently turning the public display into a digital community noticeboard. These potential solutions to create a link between private and public technologies however, carry the risk of compromising an individual's privacy. Therefore the privacy implications should be explored further.

Communicating purpose. While the design of the content on public interactive displays is important, designers should also focus on ensuring the structure that holds the public interactive display contrasts with the content, helping it stand out and convey the purpose of the display. This could be achieved through signage on the ground or around the display. For instance, the indoor PID A from our study utilised a glowing white "*i*" to indicate it holds information, which seemed to contribute towards it gaining the most attention when compared to the other public interactive displays. An alternative is to design a display which could implicitly respond to passers-by, conveying they are interactive (Grace et al., 2013).

Large banner displays and captive audiences. Our field observation study confirmed that captive audiences are more likely to look at a nearby large banner display. Beyond that, our findings also show that this was true even for smartphone users, albeit at a lower rate. We found that the large banner displays appeared to have been placed to take advantage of captive audiences nearby, such as people on escalators and travelators, waiting in line at a shop, or sitting down. For large banner displays, our results appear to refute the often stated claims regarding display blindness (Müller et al., 2009; Memarovic et al., 2015; Houben and Weichel, 2013; E. Huang et al., 2008), as we found that a large proportion of people would look at the display. Furthermore, we found that the large banner displays were even successful at gaining a significant amount of attention from smartphone users.

4.7.3 Limitations

We began this work with the goal of performing a replication of the study by Huang et al. (E. Huang et al., 2008), with changes to the study methods that take account of the changes since its publication and with the goal of gaining more detailed quantitative results than their methodology supported. The design of our study therefore makes it possible for such studies to be combined to conduct meta-analyses. These could serve to gain insights into temporal trends and richer design insights. The quantitative data could also serve as a baseline for further replications in future work.

We now discuss limitations of our work in terms of each of the key elements of our study design: the selection of displays to study, the data collection, and observation methods. While we tried to observe public displays over a diverse range of indoor and outdoor contexts, such as shopping centres and outdoor thoroughfares; our study was not inclusive of all possible contexts, such as public displays located at bus stops, train stations, and museums. Additionally, as this study was only conducted in one city, it may not be completely generalisable to other cities, such as cities with denser populations or different cultures. Despite this, due to our approach, the results from our study can be readily compared by future work replicating this study in different contexts.

As with the approach taken in E. Huang et al. (2008), we manually collected data to ensure the study was ecologically valid. While the smartphone app greatly helped the speed and accuracy with which we recorded passer-by behaviours, it was still difficult at times to discern whether someone was truly looking at a public display or at something nearby or behind the public display. The manual approach of collecting data also took time and effort to get right. Pilot studies helped immensely with this as they enabled us to determine the best vantage points to observe from so that we had a clear view that did not obstruct other people using the space.

4.8 Conclusion

This article presented findings from a field observation study aimed at offering researchers and designers concrete, ecologically valid knowledge about the use of non-research public displays in the wild by revisiting Huang et al.'s study that was conducted 10 years ago.

Our study shows that over the past 10 years, public displays have become more diversified and ubiquitous, which is likely to increase. We found that the different types of displays exposed different design requirements and had different effects on user engagement. For example, we found that for public interactive displays to successfully engage passers-by they need to be positioned near an entrance to a space and clearly communicate their purpose. Out of the public displays we observed however, the large banner displays were the most successful at engaging captive audiences, and beyond that, attracted people's attention even when they were using smartphones or engaged in conversations with others. Therefore, large banner displays clearly have the potential to provide some forms of information at a more usable scale and presentation than a smartphone.

Overall, the analysis of our findings suggests that the effectiveness of public displays at attracting user engagement is linked to a complex set of factors, including elements around the display, its position and location, relevance of the content displayed, and smartphone usage. These factors clearly involve compromises in design and the goals of various stakeholders with roles in defining the content. Our work indicates that it remains a challenge to address these factors. The findings from our study also point to new opportunities for integrating public displays into today's hyperconnected society by considering their purpose in relation to other personal devices, like smartwatches and smartphones. As the adoption of personal devices increases, the competition for attention will also increase.

The key contribution of this work lies in the methodology, where we presented an ecologically valid mixed methods observation approach. We hope the methodology will be taken up by others and that future studies will contribute to a growing and more comprehensive picture of the current and changing state of the attention people give to public displays.

5 Bridging the Interaction Gulf: Understanding the Factors that Drive Public Interactive Display Usage

5.1 Preamble

The purpose of this chapter is to provide further insights into the purpose of a PID and understand what drives people to engage with them. This is explored through an analysis of the results from the field observation presented in the previous chapter (**Chapter 4**) and the results from a field study evaluating prototype B (Figure 3.4), which appears later in this thesis in **Chapter 10**. The results from both the studies are brought together to better understand the factors that drive people to interact with PIDs, crossing over from a passer-by to an active participant.

Specifically, this chapter gives further grounding towards RQ1 (*What is the role of a public interactive display in a hyperconnected society?*) in that it provides insights into current PID trends and usage from the observations and interviews conducted across the two studies. This chapter also addresses RQ2 (*What are the challenges with making public interactive displays relevant to individuals? And how can they be overcome?*) specifically in relation to gaining understanding towards overcoming the challenges of display blindness and conveying interactivity, where it presents three key factors for bridging the interaction gulf between urban dwellers and PIDs.

This chapter was originally presented as a paper in the OzCHI 2017 conference in Brisbane, Australia. Subsequently, the paper was also published in the proceedings of the 29th Australian Conference on Computer-Human Interaction. The formatting and reference style differs from the original publication to fit this thesis.

5.2 Abstract

Previous HCI studies have identified challenges when designing public displays that often result in users ignoring them. In this paper, we explore the factors that drive passers-by to become active users and provide suggestions to guide the design of public interactive displays (PIDs). We contrast the findings from two different studies: (1) an observation of existing non-research PIDs to understand the issues currently facing displays in the wild; and (2) a field study of a PID research prototype. Based on the findings from both studies, the paper concludes with a discussion of three factors that have an effect on the utilisation of PIDs: position, content and function.

5.3 Introduction

Public interactive displays (PIDs) are becoming commonplace in public spaces around the world, often found in train stations, shopping centres, and airports. They offer opportunities to make information known to the broad public within a specific location. However, research suggests that the efficacy of PIDs is affected by a phenomenon referred to as display blindness (Memarovic et al., 2015; Müller et al., 2009; E. Huang et al., 2008) and their ability to convey interactivity (Ojala et al., 2012; Grace et al., 2013). Display blindness is characterised as either passers-by ignoring the existence of public displays as they assume the content is not of relevance or public displays becoming lost in the background of other things in the space vying for attention.

A recent study on display blindness using a head-mounted eye tracking device suggested that more people actually look at displays than previously recorded in earlier studies (N. S. Dalton et al., 2015), suggesting that display blindness might not always occur, particularly in environments such as shopping centres. Our study further contributes to this area of research by specifically investigating people's behaviour around PIDs.

Previous research has also focused on the issue of conveying interactivity. Typically this involves making the display grab attention through responsive screen elements (such as the interface) that react to the presence of passers-by using computer vision (Grace et al., 2013), audio cues (Kukka et al., 2016), and leveraging social behaviour, such as the Honeypot effect, to attract passers-by to the display (Wouters et al., 2016).

Our study more specifically set out to investigate some of the factors that affect whether people interact with a public display and suggest design strategies for addressing these factors. The research was carried out by reporting on two studies: (1) A field observation of non-research PIDs in four locations to understand current trends and to observe people's behaviour around PIDs in the wild; and (2) an evaluation study of a PID research prototype.

5.4 Non-research PID Field Observation

The goal of the field observation study was to understand the current issues faced by non-research PIDs in the wild. We chose to perform a field observation as a method of research as we were interested in whether people engaged in an interaction. We also recorded the properties of each PID, such as position, appearance, orientation, content, inputs, and the physical space.

Fig. 5.1.: Public interactive displays studied in this paper: (A) Free standing indoor PID; (B) Fixed indoor PID (built into a wall); (C) Outdoor PIDs in two locations (The city wharf and Chinatown); (D) Prototype transit PID used in our evaluation study.

5.4.1 Study Setup

We observed two indoor and two outdoor non-research touch directory PIDs across four locations within the city of Sydney, Australia. Touch directories were chosen as they are the most common type of PID found in the wild (Parker et al., 2015).

The two indoor displays were situated in two different shopping centres, where one was free standing (Figure 5.1A) and the other fixed inside a wall (Figure 5.1B). They allowed people to search for shops and services within their respective shopping centres. While idle, they also displayed advertisements related to products and shops that could be found in the building. Although each shopping centre contained PIDs on every floor, we focused on two specific PIDs only as they were situated in the

main entrance area of the respective shopping centres with many people passing through.

The outdoor PIDs (Figure 5.1C) were situated in two different locations, each with their own specific urban characteristic. The PIDs contained four "apps" that related to the city: (1) photos of landmarks around the city; (2) an interactive map of the city that could be searched using the on screen keyboard; (3) the current weather in the city; and (4) points of interest on an interactive map, such as landmarks and train stations.

Each PID observation consisted of two 30-minute sessions, one conducted in the morning and one in the afternoon, on weekdays. The morning sessions (am) took place between 9:00am and 11:00am, while the afternoon sessions (pm) were performed between 4:00pm to 6:00pm. The two blocks of times allowed us to gain an understanding of how the space and behaviour around the PIDs changed over time. These timespans for each session were chosen as they capture the peak times in the specific locations.

During the study, we took photos of the PIDs and recorded notes about the behaviour of people passing through the space. To gain a sense of how busy the space was and how successful each PID was at attracting interactions, we used a custom-developed smartphone counting app which contained three on-screen buttons to record three pieces of information: (1) the number of people walking past the PID without noticing it (passers-by); (2) the number of people that turned their head to look at the PID without interacting; and (3) the number of people interacting with the PID.

5.4.2 Results and Discussion

PID	Time (am/pm)	Total (am/pm)	Noticed (am/pm)	Interacted (am/pm)
Free standing	30 / 30 min	132 / 148	7 (5.3%) / 14 (9.5%)	0 / 2 (1.4%)
Fixed	30 / 30 min	94 / 203	2 (2.1%) / 6 (3%)	0 / 0
Chinatown	30 / 30 min	64 / 346	9 (14%) / 40 (11.6%)	0 / 2 (0.6%)
City wharf	30 / 30 min	170 / 476	7 (4.1%) / 18 (3.8%)	0 / 4 (0.8%)
PID prototype	60 / 60 min	60 / 100	N/A	3 (5%) / 4 (4%)

Tab. 5.1.: Observational data for each of the PIDs. The figures for the PID prototype (yellow) are averaged across 4 weekdays with 60 minute sessions.

Indoor PIDs

The indoor PIDs had similar functionality but differences in utilisation. As shown in Table 5.1, the free standing PID received interactions, while the fixed PID received none. An analysis of our field notes suggests that the difference could be linked to the PIDs' positioning and the way they conveyed interactivity. For instance, the free-standing PID was positioned in close proximity to one of the main entrances (Figure 5.2A). Its position and orientation meant that the PID was in line of sight when people entered the space. It was contained in a brightly coloured stand with a glowing "*i*", which may have helped it stand out in the space.

The fixed PID was installed in the wall next to the elevators on the ground floor (Figure 5.2B), behind the escalators and thus out of the main path leading to other floors and shops. Being fixed to the wall, the PID formed part of a larger media façade cycling through artwork and advertisements. This may have further decreased the visibility of the PID, as we observed on two occasions that people tried to interact with the media façade wall by touching it.

Fig. 5.2.: A comparison of user paths in relation to the fixed (A) and free-standing (B) indoor PIDs' locations. The arrows describe the common paths people take when they enter the space (red = main, orange = infrequent, blue = uncommon path).

Outdoor PIDs

As with the indoor PIDs, the outdoor PIDs were also affected by their positioning and the way they conveyed interactivity. Table 5.1 shows that the Chinatown PID was slightly more successful at being noticed, with 14% noticing in the morning and 11.6% noticing it in the afternoon. This could be explained by the Chinatown PID being situated in a smaller area and therefore was in line of sight for passers-by. The city wharf PID, however, was positioned outside the main path people took when walking through the space, which may have contributed to the low number of people noticing the display. In addition, we observed that during the afternoon session, sunlight was reflecting on the display making it difficult to see what was

displayed, whereas the Chinatown PID was always visible due to nearby trees and buildings. Consequently, the combination of the shaded environment and the screen brightness may have helped this PID stand out.

In terms of interactions, we observed two people independently interacting with the Chinatown PID but failing to sustain interactions for longer than 10 seconds, likely due to the display not immediately responding.

The city wharf PID had two couples interact with it. The first stopped and played with the weather app for 30 seconds and left, while the other couple simply brought up the map and left straight away, staying no longer than 10 seconds.

Design Suggestions

From our observations, we found two emerging themes: (1) placement of the PID; and (2) the way PIDs convey interactivity. These themes support previous studies of research PIDs (Kukka et al., 2013; Fischer and Hornecker, 2012), thus confirming that those findings also apply to non-research displays.

Placement - PIDs need to be carefully positioned considering the spatial characteristic of the space. Placing PIDs in the main path people take when passing through the space, has the potential to increase their utilisation. It is therefore important to consider the permeability of the space (Montgomery, 1998), such as the main paths people take and position displays accordingly. We also found that the way PIDs are mounted can influence their utilisation. For example, the indoor PID fixed into a wall blended in with the environment, leading to people being more likely to ignore it. Environmental aspects should also be considered. For instance, the position and orientation of the PID in relation to the sun needs to be considered as it can cause the display to be unreadable at certain times.

Conveying interactivity - Our observation study suggests that people are more likely to interact with a PID if its functionality and purpose are clearly communicated even before they interact with it. The indoor free standing PID was placed inside a cream coloured stand with a glowing white "*i*" on top, indicating that it provided information about the shopping centre. Compared to the fixed and outdoor PIDs, which had no visible external signage, the free standing PID managed to draw attention to itself and stood out in comparison.

The idle content is another aspect that can be used to convey interactivity. On the free standing PID, it displayed a large banner at the top of the screen with text stating "*Information*" inside. The portion below was taken up by advertisements. The

fixed PID used a similar approach but implemented a smaller banner with small text stating "*Touch screen to interact*". The majority of the screen however was taken by large advertisements. In the case of the outdoor PIDs, an animated hand touching the screen with a ripple effect was displayed. Above the hand it displayed "*TOUCH TO ACTIVATE*". While this may have conveyed interactivity, it did not make the PID's purpose clear.

When designing a PID, both external and internal signage or indicators are important to convey interactivity and functionality.

5.5 PID Prototype Evaluation Study

In this section, we analyse data collected from a prototype PID deployment (Figure 1D) to gain further insights into the factors that affect the utilisation of PIDs. The PID displayed a bus timetable along with places to visit. During the evaluation study, it was installed indoors next to the main entry of our school building. This provided us with a more controlled environment than a bus stop while still being in close proximity to a bus stop (located approximately 60 metres away). This location was also chosen as it had continuous foot traffic due to surrounding cafés and lecture theatres frequented by staff and students.

The PID stand was coloured bright red to be eye-catching and to help it stand out amongst competing displays within close proximity. The PID was housed in a booth structure and consisted of a 50-inch touchscreen in portrait orientation, connected to an Apple Mac Mini running Windows 7. The idle screen featured a question: "*Where are you going?*", thus clearly conveying interactivity, and allowed users to respond using large bright blue buttons on a white background with names of surrounding suburbs. Upon selection, the PID displayed an up-to-date bus timetable based on the suburb selected with the app coded as a webpage.

Previous work (Parker et al., 2016) found that contextual personalisation can potentially increase the relevance of displayed content. Following this suggestion we designed our prototype to do more than simply display transit times by personalising the content based on the user's interactions and the location of the PID. For example, as the prototype was near a bus stop, it would recommended catching a bus over a train. Furthermore, the prototype displayed a list of recommended places to visit based on the selected destination suburb. The recommendations could be explicitly filtered through four buttons shown below the list of recommended places. For example, selecting the 'bars' filter displayed recommended bars that were open at

the selected destination. The data also changed, based on the time, by filtering out closed places. The adaptation to time and place in the prototype was implemented using the Google Directions API.

5.5.1 Study Setup

We deployed and observed the PID over a period of four weekdays in order to counterbalance the novelty effect, which we expected to affect people's interactions with the PID. Observations were conducted for two 1-hour sessions per day, once in the morning and once in the afternoon. Additionally, to gain more detailed feedback on the PID's design and functionality we conducted semi-structured interviews with 12 participants (4 females), consisting of staff and students, after they had finished interacting with the PID. Observations were conducted on the opposite side of the space, away from the PID, to avoid any disruption to the natural flow of the space.

5.5.2 Results and Discussion

We observed people interacting during each session and, on average across the observation period, the conversion rate, i.e. the number of people converting from passing by to interacting, was higher than for the non-research PIDs (Table 5.1). However, the interviews revealed that despite our best intentions of making the display adaptive to people's interactions, 6 of the 12 participants did not find the display relevant. They commented that the information could be easily viewed on their smartphones, using either a real-time transport app or Google Maps. Viewing the recommended places was not perceived to be relevant to most participants; as one participant stated, "*I might already have somewhere I am going*". Other participants mentioned that they use a combination of smartphone apps and public displays at the train station - where they check the route on their smartphone before arriving at the station and then check the screens at the station to find the platform. Three participants mentioned that it is sometimes faster to check public displays than their smartphones in time critical situations, "*I had to make a decision very quickly because the train was about to leave so there was no time to pull out the phone and check*". This supports findings from previous research which found people preferring to get en-route transit information from public displays (Caulfield and O'Mahony, 2009; Rahman et al., 2013). Participants also suggested that PIDs could be useful in specific contexts, such as tourists looking for directions or if their smartphone battery went flat. This indicates that public displays may have a role to play in a

smartphone-centric society where they can be utilised as a complimentary device or redundancy measure for when personal devices stop working.

Participants also asked for the ability to read reviews about recommended places, a feature that is common in online directories. One participant suggested that reading recent reviews helps with decision making: "*I was expecting somewhere to read the reviews. The things that I normally look for in say Google Maps, is just quickly what people have said, but also the date of the last reviews*". Therefore, it appears that the content displayed in the recommended places feature may have either been: (1) generally not useful for the context; or (2) that the prototype was too closely emulating features found on smartphones, making our participants expect the same functionality and content provided by platforms such as Google Reviews.

5.6 Discussion

Through an analysis of the results collected from the two studies we identified the following factors that can affect the efficacy of PIDs, which we refer to as the interaction gulf: position, content and function. These factors overlap and at times and affect each other. Below we discuss each factor and provide suggestions for bridging the interaction gulf.

Position - Previous research has identified that the positioning of a PID contributes to it being noticed (Koeman et al., 2014), such as by ensuring they are at eye-level (E. Huang et al., 2008). The findings from our studies suggest two additional aspects regarding positioning that should be considered to potentially increase the occurrence of opportunistic interactions: (1) permeability of the space (Montgomery, 1998), on the main paths people frequently use in a space (J. R. Williamson and J. Williamson, 2014); and (2) the orientation of the PID, facing it towards the main source of people entering the space. The ideal positioning and orientation can be identified by observing the space at different times of the day and week to find out how the space changes over time. The observations can then be used to adjust the PID accordingly. Such observations can also be combined with other methods, such as the Space Syntax approach (S. N. Dalton et al., 2010), to gain further understanding of the space. However, the caveat with positioning a PID in this way is that it may make users more prone to social embarrassment and shoulder surfing. These problems could potentially be mitigated with subtle interactions (Tomitsch et al., 2014) and techniques such as implicit silhouette protection (Brudy et al., 2014).

Content - We found in the second study that participants preferred to use their smartphones to access local information, such as transit and recommendations on places to visit. This result is likely to continue as smartphone usage and internet availability increase (Ericsson, 2017). Therefore, PIDs should not replicate the content found on smartphones but instead provide supplementary information that cannot easily or quickly be accessed via a smartphone, such as a map of the space as seen on the shopping centre PIDs. The design of the content displayed on a PID should consider the space in which the PID is situated, the people using that space, and how the space changes over time.

Function - PIDs should react quickly and be responsive when interacted with in case the user is in a hurry, such as in transit contexts. Additionally, it should be easy to understand a PID's function and purpose even before interacting with it (Fredericks et al., 2017a). This can be conveyed through external signage, the PID's enclosure (if it is free standing), and clear messages on the display that are not competing with advertisements. The PID should also have the ability to adapt to different contexts in the space around it (Wouters et al., 2014; Fortin et al., 2014; Parker et al., 2016), including the time of the day, the day of the week, and events taking place in the space.

5.7 Conclusion

In this study we focused on exploring and understanding the factors that drive passers-by to become active users of PIDs. We contrasted the findings from two PID studies and identified three factors (position, content and function) which can be used to understand the interaction gulf and identify design strategies. These studies also highlight the need for PIDs to become more responsive and useful in the areas in which they are situated, taking advantage of opportunistic interactions. This is important in the era of smartphones and wearable technologies, to avoid becoming redundant.

Future research directions include investigating how PIDs can co-exist with personal devices and remain relevant. Additionally, more work is needed to create a standardised method or framework for evaluating the effectiveness of PID deployments.

6 Design Strategies for Overcoming Failures on Public Interactive Displays

6.1 Preamble

This chapter presents a subset of results from the field observation that was introduced in **chapters 4** and **5**. For a PID to be continually relevant for everyone, it needs to adapt to changes, both internal and external. We found that a number of non-research PIDs in the wild had visible failures. These results were not previously reported on in the last two chapters as they did not fit their focus. While we did not set out to specifically observe PIDs with failures, the observations gave us insights into the types of failures that can occur, thus allowing us to devise a set of design strategies to overcome these failures. Therefore, this chapter specifically contributes towards RQ2 (*What are the challenges with making PIDs relevant to communities and individuals? And how can they be overcome?*) as it identifies potential failures that can occur on PIDs and presents design recommendations for mitigating their effect.

This chapter was originally presented as a conference paper at the 7th ACM International Symposium on Pervasive Displays (PerDis) in 2018. Subsequently, the paper was also published in the ACM proceedings of this conference. The formatting and reference style differs from the original publication to fit this thesis.

6.2 Abstract

Public space is becoming increasingly augmented by public displays, bringing digital content into the real-world. Consequently, as public displays are a form of computing, they are prone to experiencing failure related to their hardware and software. In this paper, we investigate the types of failures that can arise on public interactive displays (PIDs) and how redundancy measures can be designed to ensure that a PID remains relevant even when a failure occurs. To gain an ecological understanding

of failures we focus on results that emerged from a field observation study and contextualise our findings within previous literature. From this, we contribute five design strategies for avoiding and mitigating the impact of these hardware and software failures. To assist designers and researchers of PIDs, we also present a failure matrix, which classifies failures along with suggestions on how they can be overcome. Our work specifically highlights the need for PIDs to become more adaptive and to include built-in redundancy measures, allowing them to at least partially recover from certain types of failures.

6.3 Introduction

Public displays are becoming increasingly pervasive features within urban environments. Typically, the purpose of a public display is to show advertisements to people passing through busy areas, such as shopping centres, or to find information about a local neighbourhood or space. Due to advances in display technology, public displays range from TV-scale displays (Alt et al., 2011; Steinberger et al., 2014; Parker and Tomitsch, 2017) to urban screens (Schroeter and Foth, 2009; Hespanhol et al., 2015) and large information displays (Tomitsch et al., 2014), and often offer interactive features, such as touch or gestures.

Over the years, research in the field of Human-Computer Interaction (HCI) has primarily focused on understanding how public interactive displays (PIDs) can attract attention, by making them playful (Tomitsch et al., 2014; Müller et al., 2012), responsive (Wang et al., 2012; Grace et al., 2013), and ensuring the content is relevant (Davies et al., 2014; Parker et al., 2016). However, an area that has received little attention in research studies is the effect of errors ocurring in the display application, which is likely to deter people from further interaction given the short attention spans observed for public technologies N. S. Dalton et al., 2015. Like other digital technologies, PIDs are prone to software crashes and complete system failures. In response to these public "failures" user groups have taken to uploading photos of affected displays to internet platforms[1], providing a comprehensive collection of failed public displays and an indication of the wide-spread occurrence of the problem. Replacing or repairing public displays when failures occur can become expensive, particularly when it is considered on a global scale (Davies et al., 2017).

Previous work by Kukka et al. (2015) showed that providing the user with some information and reassurance about what went wrong can help them persevere

[1]Public Computer Errors on Flickr - `https://www.flickr.com/groups/66835733@N00/`

through errors in a touch-based PID application. However, an alternative approach might be to consider the potential problems already in the design of PIDs by determining what redundancy measures could be put in place to minimise the impact of failures. Redundancy measures provide users with alternative ways of continuing their interaction rather than helping them to recover from failure. This approach implements the "escalator test" for public displays, which is based on the observation that escalators represent a technology that never fails as people can still use them as normal stairs in case the underlying electromechanical system breaks (Tomitsch, 2018).

This paper presents a first step towards understanding how public displays can be designed with redundancy measures so specific hardware or software failures can be mitigated or overcome when they arise. We utilise the results that emerged from a systematic qualitative field observation of existing non-research PIDs throughout Sydney, Australia. The specific focus of this study is in the failures observed. From this, we provide five design strategies for avoiding or mitigating the impact of failures that can occur on PIDs. We also contribute the failure matrix, which is designed to help designers and researchers to identify different types of failures.

6.4 Related Work

In the context of this paper, we define redundancies as additional functions built into the system to increase its reliability, such as duplicate components or procedures in response to errors or failure. Redundancy measures have long existed in computing; one common form of computing redundancy is an uninterruptible power supply (UPS) that switches the power supply to a battery or generator when a power failure is detected, enabling the connected computers to keep running without interruption.

Like all digital technologies, public displays can experience some form of failure, which can potentially cause significant or severe problems, particularly for people that rely on them. A complete failure of a certain component of a public display does not necessarily mean it is unusable. For instance, Fortin et al. (Fortin et al., 2014) demonstrated that if interaction and feedback are still working in some form, users will still persist and use the system. During their study, their interactive media façade experienced a complete failure. This failure was overcome in a way, as the microphone interaction and sound feedback continued to work. Therefore, having a redundancy in place allows public displays to recover from failures and keep running until the problem causing the failure is resolved.

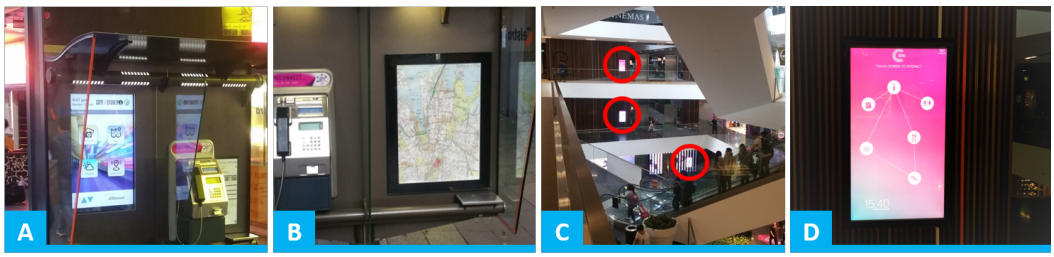

Fig. 6.1.: (A) an outdoor touchscreen PID contained in a large booth; (B) Some of the booths that the outdoor PID was contained in came with a static map instead of a PID; (C) Indoor PID network spanning across 3 floors of a shopping centre; and (D) Each PID contains wayfinding information for the shopping centre, allowing users to find shops and services on an interactive map;

Public displays are usually deployed in public space, both indoors and outdoors, and operate 24/7. However, this opens up public displays to challenges that can increase the rate of failures occurring. The first challenge is preventing hardware becoming overused and worn out. To tackle this, Davies et al. (2017) suggest that the duty cycle of public displays to be altered in order to increase the lifespan of the hardware components and save energy. This could be in the form of running public displays only during peak usage periods, sleeping or powering off during off-peak periods. Cloud-based tools are already used in industry to monitor peak times and remotely manage public displays, such as Convergent FusionDX platform[2] and the SpinetiX Cockpit[3]. Depending on the use case, an alternative is to use mechanical low-resolution displays that only draw power when they need it (Hoggenmueller et al., 2018).

A second challenge, relevant primarily to outdoor public displays, is making public displays usable and resilient to the changing conditions of the location in which they are situated. For outdoor displays in particular, one of the biggest challenges is withstanding different weather conditions (Ylipulli et al., 2014; Mäkelä et al., 2017; Dalsgaard and Halskov, 2010).

This work sets out to understand what redundancies should be built into public displays in case they experience some form of failure. We aim to formally understand the types of errors that can occur with public displays and how redundancy measures can be designed to overcome them

[2]Convergent FusionDX - `https://www.convergent.com/`
[3]SpinetiX Cockpit - `https://www.spinetix.com/products/cloud-services`

6.5 Study Design

This paper focuses on a subset of results from a larger field observation study on how people notice and interact with public displays in the city of Sydney, Australia (Parker et al., 2018d). The observation study was conducted as a manual field observation, where we only observed public displays and did not conduct interviews with people that walked past or interacted. This method was chosen for two reasons. First, to ensure ecological validity by avoiding any interruption to the space through our presence (Alt et al., 2012b; J. R. Williamson and J. Williamson, 2017). Second, regulations imposed by our university's human research ethics committee meant that we were not able to approach people for conducting interviews (for example after they had interacted with the display). For each PID we recorded through photographs, sketches and notes how PID was set up, the content it displayed, the space it was situated in, and whether the PID had any immediately visible problems. Before each field observation session, we tested each PID to: (1) explore the interface; (2) test the features; and (3) interact under different conditions, such as in full sunlight and shaded areas. These tests and the subsequent observation of the PIDs in each location took place once in the morning (between 9am and 11am) and once in the afternoon (between 4pm and 6pm) to gain a better understanding of the space and its effect on the PIDs at different times.

While we did not specifically design the field observation study to find failures, we came across PIDs from two different PID networks that exhibited a surprising number of diverse failures related to their hardware, software, and interaction. The paper, therefore, focuses on PIDs from two different PID networks observed in that study, as they were the only networks with PIDs that exhibited some type of failure.

The PID networks we focused on are described below:

Outdoor PID network. The outdoor public display network consisted of over 40 public displays built into large booths that were deployed around Sydney city. The booths usually house a payphone and a touchscreen PID (Figure 6.1A) on one side, which in some cases was replaced by a static map (Figure 6.1B), and a large advertisement public display on the other. For the purpose of the study we focused on the observations of the PID only and we did not notice any problems with the other features of the booth, such as the advertisement display.

The *touchscreen PID* at first displayed an idle screen with the text "*Touch to activate*" and an animated hand performing a touching motion. After touching the screen, users were presented with a menu displaying the current time and date in the top left

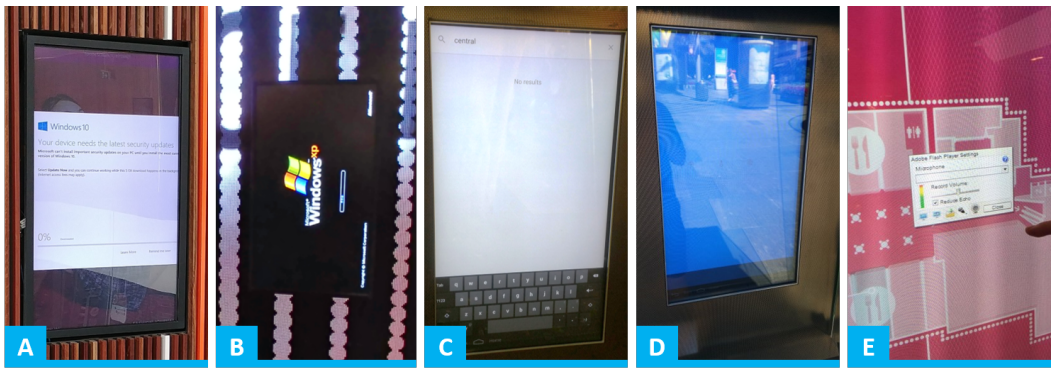

Fig. 6.2.: Problems with the PIDs: (A) Windows 10 update prompt popup; (B) Stuck on the Windows loading screen; (C) Searching provides no results or suggestions; (D) Features that are not working provide no feedback; and (E) Flash player popup window triggered by two fingers held down on the screen.

corner of the screen and four options to choose from displayed as tiles in the centre. The first option allowed users to swipe through photos of the city's landmarks. In the second option users were able to browse a map of the city and to search for a point of interest using the on-screen keyboard. The third option displayed the weather information for Sydney. The fourth option displayed a map and represented points of interest, such as landmarks and train stations, as icons that could be touched to view more information.

Although there were over 40 PIDs in the outdoor network, for this study we focused on three representatives chosen for their location which offered a mix of urban contexts: city wharf, business district, and Chinatown. In the city wharf location, the PID was situated in an open space next to a main outdoor thoroughfare, between a train station, ferry wharf, and a major tourist attraction. The business district PID was also situated in an open space, nearby a train station and large company buildings. Finally, the Chinatown location differed from the others as the PID was nearby the entrance to Chinatown, situated in a closed and shaded area, as a result of the proximity of the buildings and trees.

Indoor PID network. The indoor PID network was located in a shopping centre in a very student-centric part of the city. The centre had four main floors accessible by escalators and elevators. Next to the elevator on three of the floors was a touchscreen PID (Figure 6.1C) that displayed advertisements while idle. When interacted with by touching the screen, it allowed the user to access wayfinding information relative to the businesses and services within the shopping centre (Figure 6.1D). The language of the interface could be changed by pressing the language button in the top right corner of the screen, which displayed 12 different languages that could be chosen.

6.6 Findings and Discussion

In this section, the findings from our field observation and tests are discussed in terms of problems found with interactions, software, and hardware.

6.6.1 Hardware issues

The outdoor PID in the business district was switched off during both times when we conducted our observation. This may have been due to a hardware failure or the owner shutting it down (Davies et al., 2017). The static map of the city included in some of these booths in lieu of a PID provided a possible redundancy, which we observed people utilising on two occasions.

6.6.2 Software issues

During one of our testing sessions with the indoor PIDs, we observed that some were displaying an update popup for the Windows operating system over the public interface (Figure 6.2A), urging the user to keep their system secure with the latest updates. Interacting with the popup caused the Windows start bar to be displayed, providing access to the operating system. We observed on another occasion that the PID on the second (main) floor was stuck on the Windows XP loading screen (Figure 6.2B).

The outdoor PIDs seemed to have problems with internet connectivity. When using the search function to find local attractions using the on-screen keyboard, the system would not return results or even suggestions, unless specific keywords were typed (Figure 6.2C). Commonly, these types of interfaces on the web, such as search engines, will recommend terms similar to the one typed if no results are returned. The system was also difficult to use due to the touchscreen's poor accuracy, often resulting in the wrong interface button being pressed as the touch registered was offset from the actual touch location.

In one of the outdoor PIDs that we tested, which was located near a train station and a local tourist attraction, we found that the weather app was not working and the PID was simply displaying a background colour and no information (Figure 6.2D), possibly due to a failed internet connection. No feedback was provided to let the user know that an error had occurred or that the PID was still loading.

6.6.3 Interaction issues

During our testing of the indoor PIDs, we uncovered an exploit with the touch interaction. Holding down a finger on the screen triggered a right click after 3 seconds, making the system display a Flash Player menu callout (Figure 6.2E). This could then be used to access the Flash Player context menu and change the quality settings of the interface. The callout also had the option to display the on-screen keyboard, which gave us the ability to access the Windows desktop through keyboard shortcuts.

This problem was not present on the outdoor PIDs, which had different problems with interaction. All of the outdoor PIDs were very slow to respond to touches and usually only displayed the main menu after tapping the idle screen multiple times. The on-screen menu buttons were difficult to interact with as the touchscreen sensitivity and accuracy was very low, often registering touches up to 20cm from where they happened. This also made searching for points of interest frustrating as using the on-screen keyboard was slow, with a noticeable 3-4 second lag before characters appeared on the screen, with a chance for the wrong characters to be registered due to the touchscreen's accuracy. The problem of touchscreen responsiveness was present in all of the outdoor PIDs in the network. However, some were noticeably less responsive than others, such as a PID that was located in an area that received direct sunlight in the afternoon - making the PID virtually unusable.

6.7 Design Strategies

Ultimately, PIDs should be monitored remotely by PID providers to detect problems, which can then be fixed by sending a technician out. For instance, by identifying a sudden decrease in frequency of interaction in data logs may indicate that a problem may be occurring with the interaction or that the display is not working. However, even with such measures in place, it takes time for technicians to be sent out and to fix the issue. We therefore derive five design strategies from our field observations and tests of existing non-research PIDs as interim solutions to overcome failures.

Concealing errors. We noticed in our study that when PIDs encountered a problem, they did not give any acknowledgement that the problem had occurred. We suggest that PIDs should be adaptive to errors in that they either turn off a feature that is not working or automatically change into a limited functionality mode until the problem is addressed, similar to the "safe mode" feature on operating systems such

as Windows and Mac OSX. For instance, in the case of no internet connectivity, a PID could just display an interactive map of the city or allow the user to scroll through photos until the problem has been resolved. This approach has also been described as failing "gracefully" (Tomitsch, 2018), in that the application screen is replaced with content that is still relevant, concealing the error and/or providing users with access to alternative content.

Providing multiple input channels. Our observations and previous work suggest that failure of interaction can be influenced by weather, overuse, or vandalism (Davies et al., 2017; Ylipulli et al., 2014; Mäkelä et al., 2017). Therefore, as a redundancy measure in the case of interaction failure, multiple interaction methods should be provided. This measure can also serve a dual purpose as it gives users more options to interact (Yoo et al., 2015; Coenen et al., 2017). Alternatively, the PID could also guide the user to another PID if one is nearby.

Tweaking users' expectations. We observed that touchscreens, particularly in the outdoor PIDs, were generally unresponsive. Although, in some cases the issue was likely due to poor hardware design, there are opportunities to provide redundancy measures through design strategies. It is important to ensure that the interaction is working as expected since users would simply give up as they have no intrinsic attachment to the PID (Kukka et al., 2015). If the hardware fails, the application can respond by adapting its interface to tweak users' expectations. For example, if the accuracy or calibration of the touchscreen input is affected due to sunlight or hardware issues, the interface of the PID could respond by automatically increasing the size of buttons, making it easier for users to activate them. Another strategy is to provide physical buttons outside of the screen, similar to ATMs and parking meters, giving users an alternative option for providing input.

Providing a non-interactive fallback. When a PID encounters a problem where it cannot simply adapt its interface or turn features off, it should instead fall back to non-interactive content. For instance, when there is a complete failure of a PID's interaction method, such as a touchscreen that no longer even registers touches, then the PID system could simply display a non-interactive map of the area in which it is situated or cycle through information screens. This should also be combined with a physical label or sticker with contact details of the PID provider for users to report the problem.

Preventing unfettered access. The case of the indoor PIDs displaying prompts to update the operating system highlights the need for developers of these PIDs to ensure that the operating system is locked down and to schedule updates to happen outside of trading hours or in the background. If the system is not secure and can be

easily exploited by users to gain unfettered access, there is a risk that the PID will be used to display inappropriate content. This was the case in Indonesia (Lion, 2016) and China (Luk, 2016), where pornographic videos were played on a public display, caused by hacking and negligence of the display providers respectively. Therefore, to reduce the chance of users breaking into the system, it may be important to use non-consumer versions of operating systems that can be locked down to just certain tasks. Specialised Linux distributions exist that are designed for kiosk usage, such as JustBrowsing[4] and Webconverger [5]. However, locking a system down may have a negative impact on some types of PID deployments where the goal is to encourage user-led tinkering, gaming, or unexpected usage. This creates a challenging problem of ensuring there is a balance between a locked down system and one that allows for open usage or reappropriation by local communities Caldwell and Foth, 2014. This challenge can in some ways be paralleled with challenges experienced on desktop and mobile operating systems. For instance, Apple iOS is famous for being a "walled garden", where customisation is limited but the platform is very secure. Android on the other hand is more customisable than iOS, but it comes at the cost of decreased security.

6.8 Failure Matrix

The failure matrix (Table 6.1) emerged from drawing on both our observations made with PIDs in the wild and findings reported in previous literature. The matrix is presented to help identify failures and to assist in designing PIDs with redundancy measures in place for handling failures that might occur when the PID is deployed in the wild. We specifically describe the failures as two different types, partial and complete failure, in relation to the three components of a public display identified in the findings and discussion section: hardware, software, and interaction.

6.8.1 Partial failure

This type of failure is described as a component or feature that is not working as expected, but has not outright failed.

[4] JustBrowsing - `http://justbrowsing.info`
[5] Webconverger - `https://webconverger.com`

Tab. 6.1.: The failure matrix, used to describe the types of failures occurring on PIDs.

		Component		
		Hardware	**Software**	**Interaction**
Failure Type	**Partial Failure**	Non-critical failure of hardware component	Some software features stop working	Some interaction method functionality stops working
	Complete Failure	Critical hardware component completely fails	PID application crashes or freezes	All interaction method functionality stops working

Hardware

A non-critical failure of a hardware component. For instance, the media façade presented in Fortin et al. (Fortin et al., 2014) experienced a screen failure. However, the façade could still be interacted with and continued to deliver audible feedback.

Software

A software feature stops working. In the case of an outdoor PID that was observed, the weather feature was not loading the weather information. Despite this, the other apps on the PID were still functional.

Interaction

A partial failure of an interaction method causes it to become limited. For example, the touchscreen on the outdoor PIDs had low touch sensitivity resulting in poor accuracy. This problem was amplified in open spaces with direct sunlight exposure. Although users may persist through this (Khamis et al., 2016), backup interaction methods, like external physical buttons on ATMs or adaptive interfaces Parker et al., 2017, making elements larger when a failure is detected, could offer further redundancy measures to address this type of failure.

6.8.2 Complete failure

This type of failure is described as a critical component failing, rendering a PID non-functional.

Hardware

A complete hardware failure occurs when a critical hardware component, such as the screen itself, completely fails. We found this in one case during our observation study, where the screen of an outdoor PID was powered off. The static map that was used in place of the PID in some locations provides a redundancy measure for such extreme cases where the digital channel fails altogether. As display technology advances, electronic ink solutions could ensure that some content still remains visible on the display even when it is completely powered off.

Software

A complete software failure occurs when the PID software crashes or freezes. For instance, one of the indoor PIDs observed to never progress from the Windows operating system loading screen. Adding mechanisms to the software, such as a background application that monitors processes running on the computer driving the PID application, could help address this by automatically rebooting the system in case of such failures occurring.

Interaction

A complete failure of an interaction method on a PID refers to situations where the input mechanism allowing users to interact with the PID application completely stopped working. An example of such a case is a touchscreen not registering touches. Again, this could be overcome with alternative interactions or by simply displaying non-interactive content until the failure is resolved. Smartphone interaction could be provisioned as another form of redundancy measure to overcome this type of failure, enabling users to remotely interact with a PID application (Parker et al., 2016).

6.9 Conclusion

In this paper, we presented our initial insights that emerged from a field observation in relation to errors occurring in public interactive displays. Based on these insights we proposed the use of redundancy measures for allowing uninterrupted user interaction in the case of partial or complete failures. Through testing displays that were part of an indoor and an outdoor PID network, we identified three classes of issues: 1) failures associated with flawed application software design, 2) failures associated with poor hardware (e.g. inappropriate touchscreen technology) or hardware failure (e.g. failed internet connectivity), and 3) failures linked to the location of the PID having an environmental impact such as sunlight affecting the PID's interaction mechanism. The PIDs observed in our study failed to respond to these errors, instead leaving it up to the user to resolve them, which in most cases is not possible in public interfaces, or for maintenance staff to attend to the failure, which can take time as errors may not be noticed or reported immediately. Through five design strategies we suggest that redundancy measures should be considered as part of the design of PID applications. Additionally, we contributed a failure matrix for identifying failures, which emerged from our observation and findings reported in previous literature. Although this study was limited to one city and two PID networks, the paper makes a broader contribution to HCI by introducing the concept of redundancy measures to public interfaces.

6.10 Acknowledgements

We would like to thank the three PerDis reviewers for their comments and their suggestions for strengthening the contribution of this paper.

Part III

Designing Relevant PIDs

7 Keeping it Private: An Augmented Reality Approach to Citizen Participation with Public Displays

7.1 Preamble

In the previous chapters, we gained a better understanding of the current role of non-research PIDs in the wild. This chapter begins our exploration into understanding how relevant PIDs can be designed and the challenges behind doing so. Previous work reported that privacy is a problem with making PIDs relevant to individuals. In this chapter, we look at how privacy can be protected when using a public display to potentially encourage more people to use them. This chapter contributes towards RQ2 (*What are the challenges with making public interactive displays relevant to individuals? And how can they be overcome?*), in that we gain understanding around the level of privacy provided by common interaction methods with PIDs. The chapter also provides initial insights into RQ3 (*What factors influence the relevance of a public interactive display to individuals?*), where it contributes a design of prototype A, which is a PID system that can be personalised and controlled through mobile augmented reality, thus allowing for a more private view. The next chapter (**Chapter 8**) presents the implementation and evaluation of that design.

This chapter was originally presented as a workshop paper in the Pervasive Participation workshop during UbiComp 2015. Subsequently, the paper was also published in the Adjunct proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing. The formatting and reference style differs from the original publication to fit this thesis.

7.2 Abstract

With the availability of displays in public space increasing, they have been proposed and studied as platform for civic engagement. Due to their situated nature, public displays have the potential to enable a larger cross-section of the public to participate in community consultation processes when compared to focus groups or online surveys. Previous research has investigated a range of interaction methods for enabling this form of citizen participation with public displays. Through an analysis of related work we identified four main categories of interaction methods: remote indirect, kiosk, mid-air gestural and mobile. In this paper we propose a formerly introduced interaction method, based upon mobile augmented reality, which promises to enable pervasive participation by making interactions more private and simultaneous, through a familiar and convenient interface.

7.3 Introduction

Digital public displays that accept input are beginning to become commonplace, as the costs of touch screens are decreasing and basic input devices, such as smart phones, are becoming more affordable and ubiquitous. Public displays offer opportunities to make contextually relevant information or a message known to the broad public within a specific location.

In the case of promoting community engagement, digital public displays are used to display topics of civic interest or to publicize changes that may affect the community and its immediate environment (Kostakos and Ojala, 2013). A study by Hespanhol et al. (2015) found that the use of interactive digital public displays is not only able to give the community a voice, but also to entice people to participate in the consultation process. Additionally, works by Ackad et al. (2013) and Michelis and Müller (2011) demonstrated that interactive displays have the ability to draw attention, increasing the rate of passers-by becoming actively involved with the display.

However, an underlying issue that has plagued interactive displays is privacy (Baldauf et al., 2012a), as people may not appreciate their interactions being publicly visible to passers-by and bystanders. This is particularly an issue when asking people to vote on sensitive topics using a public community engagement interface (Hespanhol et al., 2015). Related to the issue of privacy is the observation that participants worry about the security of their personal information (Alt et al., 2011). People may

further be afraid to fail to understand how to use a display, leading to a phenomenon coined social embarrassment (Brignull and Rogers, 2003).

This paper extends previous research on community engagement with public displays through an analysis of current interaction techniques and their potential for pervasive participation. We further propose a new method for interacting with digital public displays based on mobile augmented reality, which allows for multiple users to interact simultaneously while retaining privacy.

7.4 Interactions with Digital Public Displays

Four main interaction methods are described in the following sections. These were chosen to categorize interactions that have commonly appeared in previous research. Table 7.1 below gives an overview of the privacy (Poor, Good), proximity (Near, Far) and accessibility (Low, Medium, High) offered by each interaction method. Additionally, a correlation exists between proximity and accessibility, where interactions from afar are able to support multiple users.

Interaction method	Privacy	Proximity	Accessibility
Remote indirect	Good	Far	Medium
Kiosk	Poor	Near	Low
Gestural	Poor	Near	Low
Mobile	Good	Far	High

Tab. 7.1.: Overview of interaction methods with ratings.

7.4.1 Remote indirect interaction

This form of interaction does not necessarily require the user to be in close proximity to the display, interaction can be performed from another location.

An example of such a system utilizing this interaction method was presented by Munson et al. (2011), who developed and tested a public display called the "Thank You Board", which allowed people within the university to post thank you notices to other colleagues using a specified web site that they could access from their personal desktop computers or mobile devices. An issue found with this system however was

that people did not appreciate posting from a web browser as it was slow to load the web page on a mobile device and accessing it from a computer was inconvenient.

7.4.2 Kiosk interaction

This is a direct form of interaction. The user needs to be standing in front of the display to interact. Although it is familiar to many users since the advent of portable touch screen devices, such as the iPad, it still has the inherent issue of privacy. This point was resonated by users of public touch displays, that were used in a study in Oulu, Finland (Alt et al., 2011), which displayed local user-generated advertisements such as jobs, items for sale, and events. Users felt uncomfortable viewing and inputting personal contact information, such as their email address, in case of onlookers.

Screen size can also limit touch interaction. As digital public displays need to spread a message, making the display larger can increase the chances that the display is seen. However, touch screen interaction at large-scale displays is either impossible or difficult for users to interact with onscreen elements and it also makes it harder to take all the content in when a person is standing close to such a large display (Tomitsch et al., 2014).

An alternative method of direct interaction allowed people to use their feet to vote on questions displayed on a large screen was presented by Steinberger et al. (2014). Users could step on tangible answer buttons, representing yes and no, to submit their vote. Although this method made it easier to participate, there were still concerns about privacy when it came to sensitive topics. Kiosk interactions therefore are a direct form of interaction that provides little to no privacy and are inherently limited by the available screen space.

7.4.3 Mid-air gestural interaction

This type of interaction can be used to effectively grab the attention of passers-by and engage them with potentially playful interactions that require no contact with the screen.

Media Wall, a digital public display situated at a busy area of a university campus, utilizes the 3D tracking capabilities of the Microsoft Kinect to allow mid-air hand gestures that control the navigation of the interface (Ackad et al., 2013). The gestures consisted of hand swiping (left or right) for navigating through the interface

horizontally and raising hand (up or down) for vertical navigation. It displayed content related to the university and a tracking skeleton (Figure 7.1) that mimicked the movement of the person being tracked, which can get the attention of passers-by. Additionally, a banner message would follow passers-by letting them know the screen is interactive.

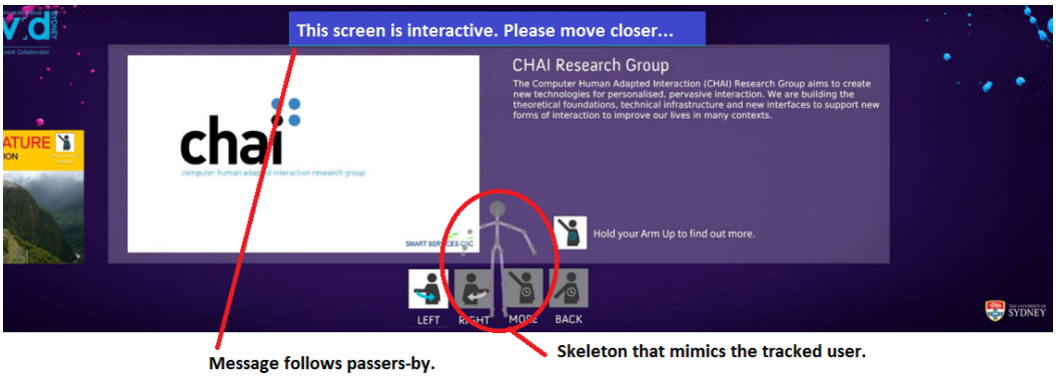

Fig. 7.1.: Media Wall - a Kinect controlled projected interface that uses on-screen elements that react to the people either standing in front or walking past. (Image adapted from Ackad et al.)

Hespanhol et al. (2015) investigated the use of gestures as an expression of full-body interaction, for engaging people on local issues that affect their community. Their study found that the interaction with a camera feed that allowed passers-by to vote on issues by standing on a certain side of the screen depending on which way they wanted to vote, increased participation as the interaction offered a more playful interface compared to a kiosk-type iPad setup. However, the iPad interface offered people some privacy and allowed them more time to consider their answer. Therefore, for people to notice the display and motivate them to use it, the researchers recommended that real time feedback and tangible or full-body interaction be utilized with just enough playfulness. The results match outcomes of previous research by Tomitsch et al. (2014), which found that having playful elements attracts users and that they can eventually become active users after they have finished exploring the interface through play.

Valkanova et al. (2014) presented a Kinect controlled polling system called "MyPosition" which allowed people to vote on certain topics by positioning themselves in front of their preferred answer and raising their hand to vote. It was found that such interactive visualizations can promote civic discussion on the topics.

Therefore, mid-air gestures are an effective method of gaining attention from passers-by due to the computer vision technology that can make them reactive (Michelis

and Müller, 2011). However, the interactions are still public, which means that the user's choice when voting on an issue for instance, is seen by everyone that may be watching, which may not be desirable if it is a sensitive issue (Valkanova et al., 2014).

7.4.4 Mobile interaction

Interaction with a digital public display using a mobile device is a promising method allowing multiple people to interact with a display at once while retaining privacy. Mobile interaction with public displays is indirect and can be used by a large number of people. An example of such a system was presented in a study by Schroeter and Foth (2009), which found that SMS and Twitter interaction with a public display enabled citizens to voice their opinions on certain topics related to the community. This method made participation more accessible as SMS is available with any mobile phone.

Baldauf et al. (2012a) studied mobile augmented reality (AR) to enable public, private displays. By pointing their smart phone's camera at the digital public display, the user can open and play videos by tapping on their smartphone's screen and the video would then proceed to play on their device. To contrast, a competitive mode was included as another condition where the videos would play on the public display. However, playing videos on the smartphone was preferred, as users did not appreciate competing with one another.

Therefore, interaction with public displays using mobile devices provides a higher level of privacy than direct interaction methods. Additionally, it enables multiple users to participate at the same time.

7.5 Augmented Reality for Enabling Direct Mobile Interaction

An issue that both touch and mid-air gestural interaction share is the potential for breaches of the user's privacy (Alt et al., 2011; Schroeter and Foth, 2009). Remote interaction and SMS resolve that issue but only allow one-way communication, such as posting content to the display. Baldauf et al. (2012a) and Baldauf et al. (2012b) suggested that smart phone interaction via augmented reality (AR) provides the following benefits: (1) it retains privacy; (2) it allows for multi user interaction; and

(3) it supports bi-directional interaction (posting and pulling information). Smart phone interaction can essentially allow interaction with digital public displays from the comfort of a user's own device. Although SMS interaction also allows for this, AR can potentially allow for personalized and relevant information to be overlaid. Additionally, potential exists for users to take information from the display to view it later (Baldauf et al., 2012b).

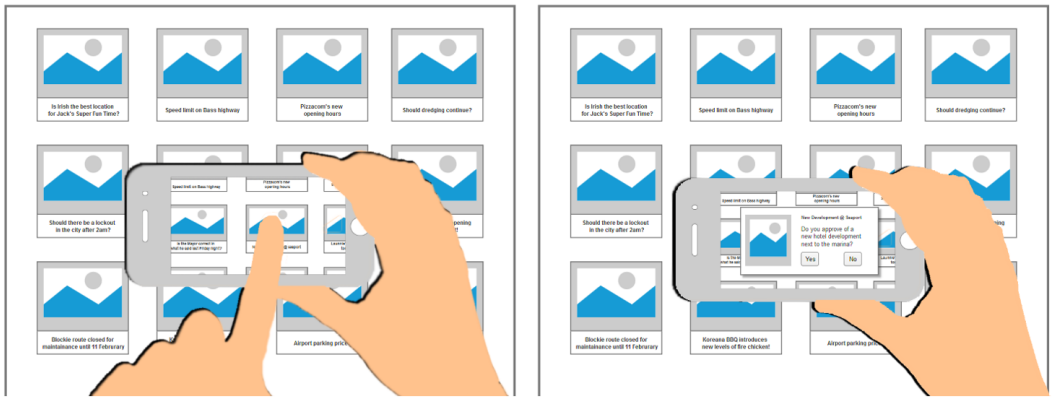

Fig. 7.2.: Concept design of the mobile AR interaction. The user points their smartphone at the public display to interact.

We propose to apply the formerly introduced interaction with digital public displays, mobile AR, to enable pervasive participation, as it solves issues present in the other interaction methods. This interaction method utilizes a smart phone and AR overlay to enable a private experience at a public display to the exclusion of others, therefore enabling multi-user interaction. As shown in Figure 7.2, while the AR app is open users can point their smart phone's camera at the public display, which uses an AR marker as the background with enough features to be tracked reliably (Vuforia, 2017). Virtual tiles will be overlaid over the smart phone's camera feed and if the user taps one of them it will open a virtual popup window on the smart phone for the user to read more or vote on a particular issue. The virtual items displayed do not necessarily need to be the same as the ones on the display, they could potentially be personalized according to the interests of the user based upon a predefined profile, a factor which may potentially incline them to participate.

Although this method still has inherent issues with shoulder surfing (Baldauf et al., 2012a) if the user is standing in a busy area, it supports multiple users and provides both grabbing and pulling of information from a public display, which will likely convenience users, and potentially lead to greater participation.

7.6 Discussion and Conclusion

In this workshop paper, we have discussed four different types of interaction with digital public displays. Smartphone AR was proposed as a method that enables pervasive participation while preserving privacy, allowing multiple users, and potentially personalizing content according to user interests. Additionally, this method is likely to be highly convenient due to its capability to run on portable devices. Therefore, smart phone AR has been proposed as showing great potential for enabling pervasive participation.

8 Design Implications for Interacting with Personalised Public Displays through Mobile Augmented Reality

8.1 Preamble

The work in this chapter reports on a field study that tested prototype A, that was based on the design presented in the previous chapter (**Chapter 7**). The core focus of this chapter is to evaluate the efficacy of augmented reality at providing a private view of personalised content on a public display. This method is compared against a non-personalised remote-control interaction method.

The contribution from this chapter informs RQ3 (*What factors influence the relevance of a public interactive display to individuals?*), where a set of design implications were outlined, providing insights into personalisation of PIDs through smartphone-based user profiles in order to make PIDs relevant to individuals. This chapter also highlights the social and technical challenges with personalisation using smartphones and mobile augmented reality, therefore informing RQ2 (*What are the challenges with making public interactive displays relevant to individuals? And how can they be overcome?*).

This chapter was originally presented as a conference paper at the 5th ACM International Symposium on Pervasive Displays (PerDis) in 2016. Subsequently, the paper was also published in the ACM proceedings of this conference. The formatting and reference style differs from the original publication to fit this thesis.

8.2 Abstract

Due to their situated nature, digital public displays have the potential to provide information and messages to large groups of people. However, in practice, non-

customised content typically is not relevant to every passerby, while personalising information tailored to individuals has associated privacy concerns. Previous research has identified mobile augmented reality as a promising method for keeping digital displays public, yet enabling customised views for interested passersby in a way that retains privacy. By building on this previous work, the aim of this paper is to understand user preferences for interacting with personalised information on digital public displays through their mobile device. The paper reports on a study that was conducted with a prototype augmented reality app and public display system. Findings from the study highlight the need for contextual personalisation based upon user activities and objectives at the time of the interaction. Additionally, interactions should be adaptable between public and covert, depending upon what the user wants to share. Based on these findings the paper presents a series of design implications for personalising public displays.

8.3 Introduction

Digital public displays are increasingly permeating urban spaces such as bus stops, shopping centres, and train stations. In many cases the content shown on these displays is limited to advertisements (Alt et al., 2011) that have little relevance to the viewer due to their generic nature (Davies et al., 2014).

In response to this, the HCI and pervasive displays community is increasingly focusing on issues that go beyond questions about how people will interact with public displays in the future, moving towards developing a better understanding about why, where and for what purpose people actually do engage with public displays (E. Huang et al., 2008; Veenstra et al., 2015). This involves, for example, research on making public displays more relevant and useful to the communities that they are situated in by providing situated, civic interfaces for the general public. This includes opinion polls on issues that affect a community (Davies et al., 2014; Dey, 2001; Machuca et al., 2014) or providing user-generated content consisting of news, current events, and sales (Baldauf et al., 2014; Dey, 2001).

Public displays, being in a fixed place may well be broadly relevant to a local community, but they may not necessarily be relevant to every individual. Davies et al. (2014) suggests that the “move towards personalised content in the signage industry precisely mirrors the shift towards personalised content that has occurred in the Web”. Personalisation on the internet is usually achieved through the creation of user profiles, such as a Google account, to make the search engine’s results more relevant to their users (Zamir et al., 2010). Making personalisation operate on a

public display could be achieved through a similar approach where the user (or their personal device) is identified and the corresponding profile is loaded. However, this requires displays to either build a profile of the user, which potentially raises privacy concerns (Davies et al., 2014), or alternatively to retrieve a user profile (Memarovic and Langheinrich, 2010), which could potentially be stored on a personal mobile device, such as a smartphone. The profile could then be sent to the display via a communication technology such as Bluetooth (Sharifi et al., 2006).

However, in contrast to personalised web pages, the adaptation of content on a public display raises new privacy concerns. One promising method to enable customised content, while mitigating privacy concerns, is to harness mobile augmented reality (MAR). This approach allows passersby to use their camera-equipped mobile devices, such as smartphones or smart glasses, to create personalised views over the display along with private interactions with public displays (Baldauf et al., 2012a; Parker et al., 2015).

In this paper, we will expand on previous work in this area by evaluating the effectiveness of AR as a method of enabling personalised interactions with public displays. A study with a prototype MAR public display system was conducted and the results informed a series of design implications for future research.

8.4 Background and Challenges

It is envisaged that digital public displays will become more than simply a medium that serves static content (Davies et al., 2014). Instead displays will be personalised to meet the needs and interests of passers-by, similar to personalisation on the internet (Memarovic and Langheinrich, 2010), but in the real world. The concept of viewing personalised content in an urban space is not new, it has been portrayed in science fiction movies, such as the "Minority Report", where people wear special contact lenses that allow them to see AR content seamlessly and privately (Figure 8.1).

This section discusses previous work and is structured around four challenges that we identified as associated with personalising digital public displays: (1) social considerations; (2) privacy; (3) interaction; and (4) content. In this section we describe these challenges and the previous work that addresses some of the challenges.

Fig. 8.1.: Minority Report scene where holographic advertisements on shopping centre screens and billboards targeted the main character, based upon factors such as his history with a certain company (http://www.viralblog.com/wp-content/uploads/2013/01/minority.png).

8.4.1 Social Considerations

Social perception can have an impact on whether an individual interacts with a public display. For some people the fear of social embarrassment if they do something wrong is enough to deter them from interacting (Baldauf et al., 2014).

Awareness of onlookers seeing the same content is another factor. If the content is personal, then it may not be appropriate for others to see it. One proposed approach to mitigate this effect, known as "shoulder surfing", is to black out parts of the screen that the user is not looking at to preserve the privacy of the personalised interaction (Brudy et al., 2014). However, this solution may not be sufficient when there are large crowds surrounding the public display, which may be the case if the interaction is performative and stands out (Tomitsch et al., 2014). Furthermore, studies have found that shoulder surfing is still a problem even with mobile device interaction (Baldauf et al., 2012a).

8.4.2 Privacy

Making content relevant to each user raises the need for protecting their privacy, as the user may not desire for their personalised content to be shown in public (Davies et al., 2014). This was the case in London, where rubbish bins with screens used Wi-Fi-collected MAC addresses of passers-by to track their movements, to personalise the content on the screens. The project was eventually shut down due to privacy

concerns from the public (Passingham, 2013). These concerns primarily related to the system not gaining consent before using this information to drive advertising.

A potential way to tackle privacy concerns associated with the public display of personalised content is through MAR. Baldauf et al. (2012a) demonstrated that AR can offer a private view in conjunction with a public display. This approach has potential as an effective means for people to interact with public displays as it could reduce the social concerns people may have about interacting in public (Parker et al., 2015). However, that research only considered how people would interact with public displays through MAR and did not investigate the potential of this method to provide a private view of personalised data.

8.4.3 Interaction

One of the challenges of providing a means for interaction with public displays is that user privacy may be compromised. Parker et al. (2015) identified four common interaction methods with public displays, based on a review of previous literature, each addressing different levels of privacy: remote indirect, kiosk, gestural and mobile. Interaction through a mobile device was found to offer an effective means for interacting with privacy-relevant content, as it is relatively private and enables users to interact from afar. Also it could, potentially, support multi-user interaction, making it a highly flexible approach compared to the others.

Ballagas et al. (2005) explored using a mobile phone's camera as a pointing device, allowing users to control a display's cursor by sweeping and pointing a phone through image processing techniques. Their study showed great potential, but was ultimately limited by technological constraints of 2005. A more recent study (Baldauf et al., 2013), in 2013, was able to expand upon pointing the camera by using the mobile device's orientation sensors to control remote screens. Although these orientation-aware techniques were considered intuitive, they were outperformed by orientation-agnostic techniques due to problems with accuracy.

Similar work allowed remote touching of a display using 3D interactions through MAR and was presented as an alternative method to interacting with a large display (Baldauf et al., 2012a; Machuca et al., 2014; Boring et al., 2010). This method enabled people to interact with the public display remotely, using their own device, by touching their device's touchscreen to manipulate objects on the public screen.

Mobile device interaction can also be used to lower the barriers of participation and interaction with public displays. Schroeter and Foth (2009) developed a system that

allowed the general public to voice their opinions on certain issues affecting their community using SMS or Twitter to submit messages, thus lowering the barrier for participation. The messages appeared on a large public display for all to read. This interaction, however, was not private, as the user's name or ID was posted along with their message.

8.4.4 Content

One of the reasons public displays often go unnoticed is that they show content that is irrelevant to some people (Grace et al., 2013). As reported in Alt et al. (2011), the right content depends on the use-case. For example, a local resident in the area where a public display is situated may have completely different content needs than those of a tourist. However, an inherent issue with personalising content for public displays is identifying users to determine their content needs without compromising their privacy (Memarovic and Langheinrich, 2010).

8.5 Prototype

The goal of our work is to evaluate the effectiveness of AR at enabling personalised interactions with public displays and to determine whether it can address some of the challenges reviewed in the previous section. To tackle this, we created a prototype consisting of a MAR app and a public display application in the form of a public bulletin board. The MAR app featured two modes: AR overlay and remote control. The design of these modes was informed by previous research into MAR interaction with public displays (Baldauf et al., 2012a; Parker et al., 2015). In the following sections, the interface and the two modes are discussed in detail.

8.5.1 Interface

The prototype was developed as two separate apps, one for the mobile device and the other for the large 50 inch widescreen public display.

Public Display

The public display app was created as a Google Chrome web app using HTML and JavaScript. It displayed the public content and the tracking image.

Figure 8.2 shows a user interacting with the public display. At the top of the public display (Figure 8.2a) is a navigation bar (with a red rectangle around it). It shows the user the available content categories, with the currently selected category in yellow. The available categories that a user can navigate are: News, University News (selected in the figure), Classifieds, and Property Rentals. The tiles in the centre of the screen are the content for the selected category. To see more information about a particular tile, the user taps it to open a popup window containing a larger version of the image, description, title, and the author.

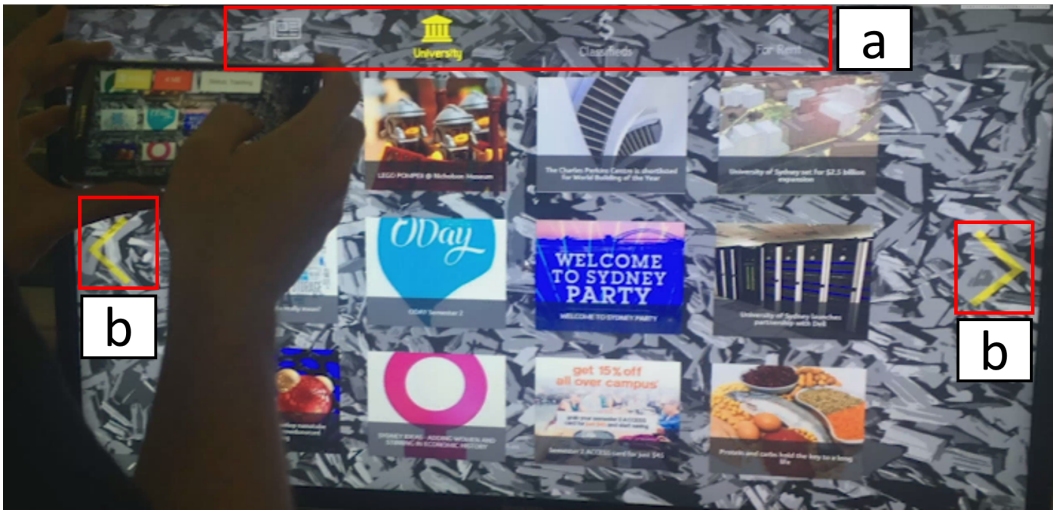

Fig. 8.2.: (a) Navigation bar, with the currently selected category, University News, highlighted yellow; (b) Arrows indicate horizontal navigation.

The arrows (Figure 8.2b) indicate horizontal navigation of categories. The woodchips background image is a modified example marker from the Vuforia website that the mobile device tracks. It was found to be the most reliably tracked image even with sunlight, reflections and occlusion.

Mobile App

The mobile app was created in C# using the Unity game engine (version 5.0.3) and the Vuforia augmented reality library.

To switch between both the AR overlay and remote control modes, the user needs to press the red interface button labelled “4 me” (Figure 8.3), which turns green when in the AR overlay mode. The yellow button is used to change pre-loaded user profiles and the white button indicates the tracking status. If tracking is lost during use of the prototype, pressing the white button makes the AR marker appear on the screen with no interface elements occluding it for 3 seconds. This allows for the tracking to be re-established.

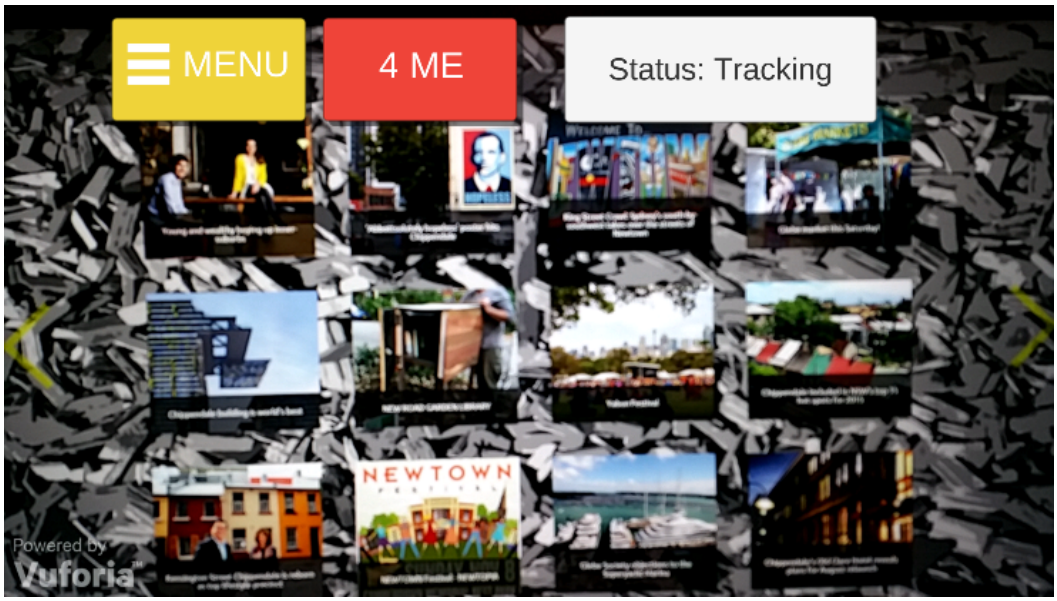

Fig. 8.3.: The mobile app interface, with the device’s camera pointing at the public display.

One way communication between the two apps is achieved through websockets via the university’s Wi-Fi network. The PC connected to the digital public display hosts the websockets server and receives interaction data from the mobile device. The data is generated from either a tap or a swipe (left or right). A tap sets the position in 3D space that it occurred, as the app was created in a 3D game engine. The 3D position is then translated into a 2D coordinate using a 3D projection algorithm. However, if the interaction is a swipe and is performed while pointing the mobile’s camera at the screen, the system transitions to the next or previous category, depending on the direction.

8.5.2 AR Overlay

This mode allows users to view their personalised content on their mobile device through a virtual content overlay using AR (Figure 8.4). They can interact using

touch to select a tile and swipe gestures to navigate to different categories of content on their mobile device.

Fig. 8.4.: Virtual personalised content that is overlaid over the public display and can only be seen through the mobile device's screen.

Upon the user tapping a tile, a virtual popup will appear, overlaid over the mobile device's camera feed. To close the window, the user needs to tap outside of the popup.

8.5.3 Remote Control

This mode allows users to have full control over the display, similar to a TV remote, using the mobile device (Figure 8.5). All of the interactions are visible to other people and are performed in the same way as the AR overlay mode, with touches and swipes. If the user taps a tile a popup will appear, similar to the AR overlay mode. However, the popup is shown on the public display.

8.6 Study Design

As discussed in the previous section, the prototype system consists of a MAR app and a public display Chrome app with an AR marker background for tracking.

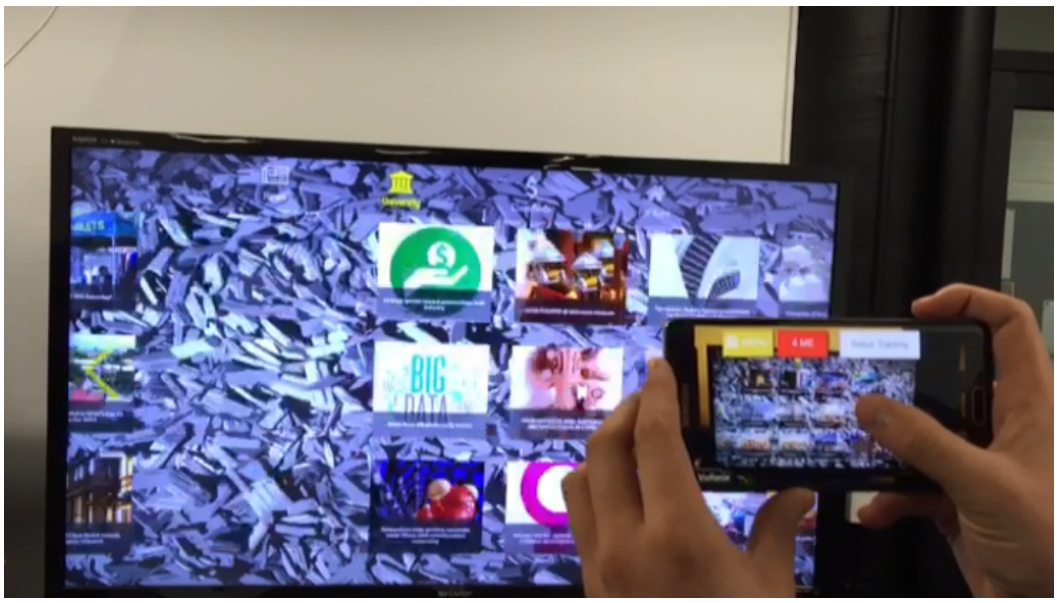

Fig. 8.5.: Remotely controlling the public display using touches.

The personalised content featured on the public display was generated based on a background pre-survey that participants were asked to complete. This asked about their field of study or work, their home suburb, and topics of interest. This information was used, in advance of the interaction session, to manually populate the personalised view of the application, drawing upon information from multiple sources, such as news, classifieds and events to create the personalised display. Non-personalised data was manually gathered in the same way.

In total, 10 participants were recruited to take part in the study. All were university students, 7 males and 3 females, aged between 19 and 30. The study was held between 12 noon and 2pm over 3 weeks of the semester. It was located in a busy public cafeteria area, within the university. This is near the main entrance to the building and has a stream of people passing by. We estimate that during each session, at least 20 different people walked past.

Each participant undertook the study in a separate session. The study was structured so that each participant could try both modes: AR and remote control. Each mode displayed non-personalised and personalised content, which was manually changed by the researcher. The initial mode for each participant was dictated by the researcher, to counter-balance the order of the two modes. At the start of each mode the participants were given a 30-second tutorial to learn the interactions. This was to ensure that participants were familiar with the prototype and the interactions before commencing the experiment, as the focus of the study was not on the

system's usability and learnability. Following each tutorial the participant was free to explore the system with that mode; they were not given any tasks, in line with the likely use of a new display encountered in a public space. Each mode took approximately 5 minutes. Once the participant had completed both modes, they were given additional free time to explore the system in any mode they desired. We observed each participant's use of the system. This data was later used in the grounded analysis.

After completing use of the prototype, participants were asked to take part in an interview, where the generated data was analysed using grounded theory.

8.7 Findings and Discussion

Findings from our observations and participant questionnaires are categorised into the themes that emerged from our grounded analysis of the qualitative data: Privacy, interaction, social considerations, content, and experience. In this section we discuss each of these themes.

8.7.1 Privacy

Privacy concerns were expressed by 7 of the 10 participants. One felt embarrassed at being in the spotlight and was worried about what others might think of them, "I was embarrassed. I feel like everyone's eyes are on me when using it". Other participants stated "I would not be happy for people to see content such as text messages from my girlfriend" and "if it would go and try and put personal things like the books I read or something like that I wouldn't be comfortable with it". Therefore, acceptable content is subjective and users should have the final say on what content is displayed. This was mentioned in a follow-up comment to a question asking what content is acceptable, "Depends on whether I really want to share or not. If you could share your photo on the big screen, that is really up to you. So I would like to share one. I can make a decision, then it will be fine".

To overcome such privacy concerns and make the content more readable, it was suggested that the popup window, which is activated when a tile is selected to display more information, should instead appear in fullscreen on the mobile device.

The remaining 3 participants had no concerns about interacting in public and their personalised content being seen by others. They mentioned that others must perceive

them as simply using their phone - “They were just normal gestures you would use on your phone. So I didn’t worry about people around me” - which is a common sight in first world countries. One of the unconcerned participants commented: “If I am the only the one that can control the big screen and can share with my friends I will be proud of it. Rather than feel embarrassed”.

8.7.2 Interaction

The findings from our analysis found three problems raised by participants in relation to interaction: zoom, orientation, and navigation.

Zoom

Zooming in and out with a mobile device’s camera is a common gesture that people are familiar with. It is performed using either physical buttons or a pinching gesture (Boring et al., 2010). However, this form of zoom was not implemented in our prototype as we thought of the mobile device in our design as a prototype interface for an AR see-through device, which would be worn on the user’s head at all times. Therefore, to zoom with our prototype participants had to physically move closer or further away from the public display.

Four participants specifically requested the ability to zoom without physically moving. They stated that this feature would allow them to view content covertly without making it obvious that they are linked with the display and its content and to make it easier to read from a distance, particularly if there were large crowds.

While device zoom may be more convenient and covert, one participant considered physical zoom more natural, stating that if there was device zoom it would be the same experience as simply using a website.

Orientation

Our prototype supported two possible ways of holding the mobile device, either in portrait or landscape orientation. The researcher let the participant select the orientation and, during the demonstration, would hold the device in a randomly selected orientation, either portrait or landscape. Three participants voiced complaints about the orientation, mentioning that holding the mobile device in portrait orientation

was easier, as their fingers sometimes obstructed the camera lens in landscape orientation. Additionally, as the mobile device had capacitive buttons next to the home button for opening the task manager and going back, participants reported that their thumb kept accidently touching the buttons in landscape orientation.

Landscape orientation was also considered "clunky and embarrassing", possibly due to this being an uncommon way for holding phones in public, which may make it seem like participants were taking a photo or playing a game.

One of the 3 participants who complained about the orientation attributed this to their small hands and suggested that landscape orientation may be appropriate if the mobile device was of a smaller form factor. They were concerned about accidentally dropping the phone as it felt big when held in landscape orientation.

Navigation

The navigation and arrow elements on the public display did not always behave in the way the participants expected. We observed that every participant tried to quickly access a particular category by tapping on it, instead of cycling through using taps. However, this feature was not implemented in the prototype. Arrow elements on the right and left indicated the fact that there was more content on either side. Participants attempted to tap on these arrows as they thought it was an alternative to swiping for navigation.

8.7.3 Social Considerations

Participants commented on concerns about sharing with others who might like to use the display. One stated that they felt "a little obnoxious using it directly in front and in the middle of the screen", further adding "You are essentially blocking the whole screen from others wanting to use it". This could potentially be resolved by users standing further back.

We also observed that passersby perceived participants as taking a photo and would walk around so as not to obstruct the camera. This phenomenon suggests that the existing social standards translate to a new system like this, similar to people queuing or opening doors for one another. Potentially in a multi-user remote control scenario these standards could translate to people cooperating with each other and negotiating the shared use of the display. This observation also points to opportunities

for future research, which could focus on studying shared, co-located interaction with such personalised displays and emergent social behaviours.

8.7.4 Content

An analysis of questionnaire responses indicated that participants were most interested in content relating to properties for rent, classifieds, events happening in the local area and keen concerns for students. This observation could potentially be linked to the fact that all participants were students, but it also suggests that content which is locally relevant is of more interest to users, which is in line with previous research (Alt et al., 2011).

Some participants mentioned that the rentals category would be interesting when they were ready to move house.

Another popular class of content related to activities that a particular individual needs to do. Eight participants mentioned they would like to see more specific content related to what they are currently doing and social events on campus. For instance, one of those participants wanted a timetable for the nearby train line, which they were about to catch, their class timetable, or the traffic conditions on the route they regularly take if they were driving. Another suggestion was a student forum, which could create more social connectedness for students in the same building. Examples given included “today I lost my wallet in room 261” and “you saw a girl in a certain classroom and you can’t remember her name”.

8.7.5 Experience

Participant interview responses about the overall experience were mostly positive, with many stating that the system was “different to other public displays”. One of the participants described the system as “thrilling”, stating that “to be able to interact with this content in a public space gives a feeling of social connectedness and sharing. It is kind of a social media type feeling”.

The feeling of control over such a large display (50 inch widescreen) was also appreciated with some stating that it felt like they were in a futuristic movie like “Avatar”. This is likely a novelty effect.

Interaction was also highlighted by every participant as natural and intuitive for anyone to pick up, as the interactions were based on existing interaction techniques common on typical touchscreen mobile devices.

8.8 Implications

The following series of design implications were identified following the grounded theory analysis.

8.8.1 Personalisation should be responsive

To be more relevant personalisation should be based upon the current user activities, such as going to a class or catching a bus. For example, an interactive train timetable, where a user chooses the destination, to see a list of events happening in that area presented below the route map. These events can be matched to the time of day and the user's interests. This could also include showing content that is contextually relevant, linking public displays with the area of contextual computing (Dey, 2001).

8.8.2 Consideration for others

Public visibility is not the only concern users have. They also worry about intrusion into the personal space of others or blocking the screen. Therefore, interactions from afar and non-competitive multi-user interactions seem promising.

8.8.3 Familiarity is important

Interaction using a mobile device should operate similarly to other apps. An example of this is the zoom. Most of the participants expected zooming through the device rather than physically zooming by walking closer or further away. The reasons include the preference expressed for a more covert device zoom that does not identify the individual as obviously as physically zooming. This also applies to mobile device orientation, as holding the device vertically was seen as more covert than the non-standard landscape orientation, rather than portrait orientation which is the usual way to use the phone.

8.8.4 Covert interactions to protect a user's privacy

Four participants were worried about embarrassment, while others were concerned with other people linking an interaction to them and identifying them as the person for whom the content was created and personalised. To address these concerns MAR interactions with a public screen should be similar to normal phone use, to allow the user to blend in.

8.9 Conclusion

In this paper we identified four challenges for personalised public displays. To gain insights into how, why, where and for what purpose people would use personalised public displays, we conducted a user study to tackle these challenges, where a public display prototype that can be interacted with through MAR was tested.

For our study, we prepared personalised content based on a pre-study questionnaire. The personalised content included general news, university news, classifieds, and property rentals. Although participants enjoyed the interaction method, perhaps because of its novelty, they commented that the categories of personalised content we created were not entirely relevant to them. Our findings suggest that personalised content needs to carefully take account of what the individual is doing at the time, such as if they are on the way to go grocery shopping, catching a train, or if they are looking for a place to rent while studying at university.

Future research opportunities in this area include the investigation of contextual personalisation and approaches for mitigating shoulder surfing, such as the use of see-through head-mounted displays. Another avenue for future work is to link personalised public displays with contextual computing.

9 Towards Adaptive Height-Aware Public Interactive Displays

9.1 Preamble

While the previous chapter (**Chapter 8**) discussed personalising content on a public display, this chapter reports on a more implicit type of personalisation for making a PID relevant to individuals. It discusses the evaluation of an adaptive *height-aware* PID. This study stems from the observation study, discussed in **chapters 4**, **5**, and **6**, which found that PIDs are usually designed around an average height specification, such as being positioned at "eye-level". However, this is not a universally accessible solution, particularly for public technologies. Therefore, to gain further insights into how an adjustable PIDs can be designed, prototype C was created to test four different *height-aware* modes.

This chapter addresses RQ2 (*What are the challenges with making PIDs relevant to communities and individuals? And how can they be overcome?*) as it unveils the challenges with designing height-aware PIDs. The chapter also addresses RQ3 (*How can public interactive displays be designed so that they remain relevant to communities and individuals in a hyperconnected society?*) as it makes insights into how height-aware modes for PIDs should be designed so that they make relevant adjustments to individuals. Overall, the chapter highlights two aspects that should be considered when designing such systems: (1) the physical relationship between the display and the user, to ensure people of different heights and abilities can interact; and (2) convey accessibility so people know if and how a public interactive display can adapt.

This chapter was originally presented as a workshop paper in the Human Aspects in Adaptive and Personalised Interactive Environments workshop (HAAPIE) during UMAP 2017. Subsequently, the paper was also published in the Adjunct Publication of the 25th Conference on User Modelling, Adaptation and Personalisation. The

formatting and reference style differs from the original publication to fit the style of this thesis.

9.2 Abstract

Public interactive displays (PIDs) are becoming more pervasive in urban environments as a means to engage passers-by and to provide interactive features such as wayfinding. However, one of the problems with current PIDs is that they are typically designed around an average specification, potentially excluding a large range of users that for instance might not be able to reach interactive elements. To address this challenge, we propose a number of design concepts for adjusting PIDs to users of different heights. We present a preliminary evaluation of our concepts through a cognitive walk-through study with 10 design experts using a custom-developed experience prototype featuring four height-aware modes. Based on qualitative feedback and observations we discuss design suggestions for future work.

9.3 Introduction

The presence of public displays in urban environments has seen a sharp increase over the past 10 years due to falling display technology costs, their immediate benefits for the advertising industry, and the ability to display information in real-time (E. Huang et al., 2008). At the same time the rise of public displays has prompted a large body of research on the design and evaluation of interaction techniques for public displays (e.g. (Yoo et al., 2015; Davies et al., 2009; Parker et al., 2016)) and communicating their interactivity to passers-by (e.g. (Grace et al., 2013; Wang et al., 2012)). Public displays with interactive features, referred to in this paper as public interactive displays (PIDs), can also be increasingly found in public spaces, ranging from shopping centres and train stations to city squares.

One of the main problems that exist with public displays is that they are often ignored and fade into the background. To potentially resolve this problem, public displays are recommended to be positioned at eye-level (E. Huang et al., 2008). However, 'eye-level' is a subjective specification as potential public display users may have different heights. For example, the appropriate eye-level for a young child would be lower than for their parents and the eye-level for a person in a wheelchair would be lower than for most other users. This issue becomes even more critical when deploying public displays with interactive features, as generalising

the definition of 'eye-level' by for example using the average height of users may potentially make using PIDs difficult or impossible for people who fall outside this average specification (Yoo et al., 2015).

In Australia, the digital signage industry is self-regulated, with organisations like the Outdoor Media Association (OMA) specifying guidelines concerning brightness and viewing distance of displays (Association, 2017). In the US the standards fall under the 'Americans with Disabilities' Act (Justice, 2010), which defines interaction design parameters such as the minimum and maximum reaching distance.

Some commercial PIDs address this challenge by supporting manual adjustments to their interface. For example, an interactive directory display located in a shopping centre in Sydney allows users to adjust the height of the on-screen elements through an 'adjust height' button. The feature removes advertisements displayed in the lower area of the screen enabling other on-screen elements to move down (Figure 9.1). This solution allows users to change the height of interactive elements, but is limited to only one pre-set height and requires users to explicitly activate the feature.

In this paper, we present four design concepts of height-aware modes for PIDs that implicitly adjust their height to personalise their interface based on a user's height. The paper contributes to the field of PID research through an evaluation of our height-aware modes, yielding a better understanding for how PIDs can be designed so that their interface can be personalised according to the height of their users.

9.4 Height-Aware Display Prototype

We designed a semi-functional PID prototype allowing people to take self-portraits ('selfies'). This functionality can be found in public display applications and kiosks in cities and at airports around the world and was chosen as it represents a realistic scenario and for its simplicity. The prototype consisted of a 50-inch touch screen in portrait orientation, a Mac Mini running the display application and a web camera for taking selfies, housed in a custom-made stand. We used a touch-based display to mirror the current standard of commercially deployed PIDs. The height-aware modes were designed to augment the PID, making it aware of a user's height. The PID prototype was able to respond to a user's height using four different modes: (1) Touch; (2) Proximity; (3) Height Sensing; (4) Reaching. The selfie application was created in HTML and JavaScript for rapid development.

Fig. 9.1.: A public interactive display deployed in a shopping centre, allowing for height adjustment through a dedicated on-screen button.

9.4.1 Touch

Adapting the height of on-screen elements can be achieved without any external cameras by detecting the position of where the user touched. This mode required participants to walk up to the display and touch the screen for it to proceed to the selfie taking page (Figure 9.2a). The selfie taking window on the second page would then be implicitly displayed at the same height as where the initial touch occurred (Figure 9.3), enabling people of different heights to reach the button. In case of an accidental touch in the wrong position, the selfie taking window's position can be adjusted manually afterwards by tapping on a blank space in the screen.

9.4.2 Proximity

Proximity (Figure 9.2b) has been explored in previous research as a way for information stored on an on-body sensor, such as a mobile device (Davies et al., 2009; Parker et al., 2016) or RFID card (Prante et al., 2003), to be read by a public display

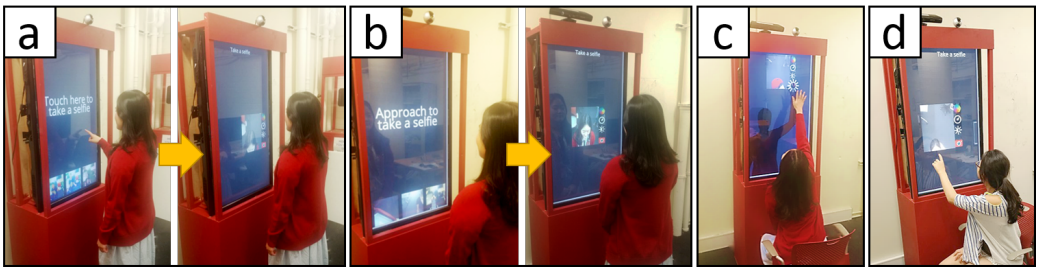

Fig. 9.2.: (a) Touch mode: Implicit height detection based on the position of touch input; (b) Proximity and Height Sensing modes: Implicit height detection through on-body (e.g. RFID) or on-display (e.g. Microsoft Kinect) sensors; (c) Reaching mode: A digital mirror representation is displayed to assist the user in activating elements out of their reach; (d) Interacting from the side for easier reaching.

system to automatically adapt its content. In our study, we used a dummy RFID card as a way to store the user's approximate height which can be read by the display. The scenario used in the cognitive walk-through study imagined the display having long-range sensors, allowing the feature to work without the user having to take the card out of their pockets. The functionality was simulated in the experience prototype through a study facilitator pressing a keyboard button as the user approached, which triggered the transition to the second screen with the selfie taking window positioned at the user's eye level.

9.4.3 Height Sensing

The height sensing mode imagined the use of an on-display sensor, such as a Microsoft Kinect depth camera, to determine the user's height as they approach and to automatically adjust the interface accordingly. The experience prototype featured a dummy Microsoft Kinect mounted on top of the display for visually conveying height detection capability in the cognitive walk-through scenario.

9.4.4 Reaching

The reaching mode (Figure 9.2c) provides assisted pointing functionality. As the user reaches for an interactive element, a digital mirror representation in the form of a silhouette appeares as an extension of themselves. The user can then activate elements by dwelling on them, akin to the gesture-based dwell interaction used in commercial Microsoft Kinect applications. This method has been previously used to reach elements on-screen Shoemaker et al., 2007 and to convey interactivity while

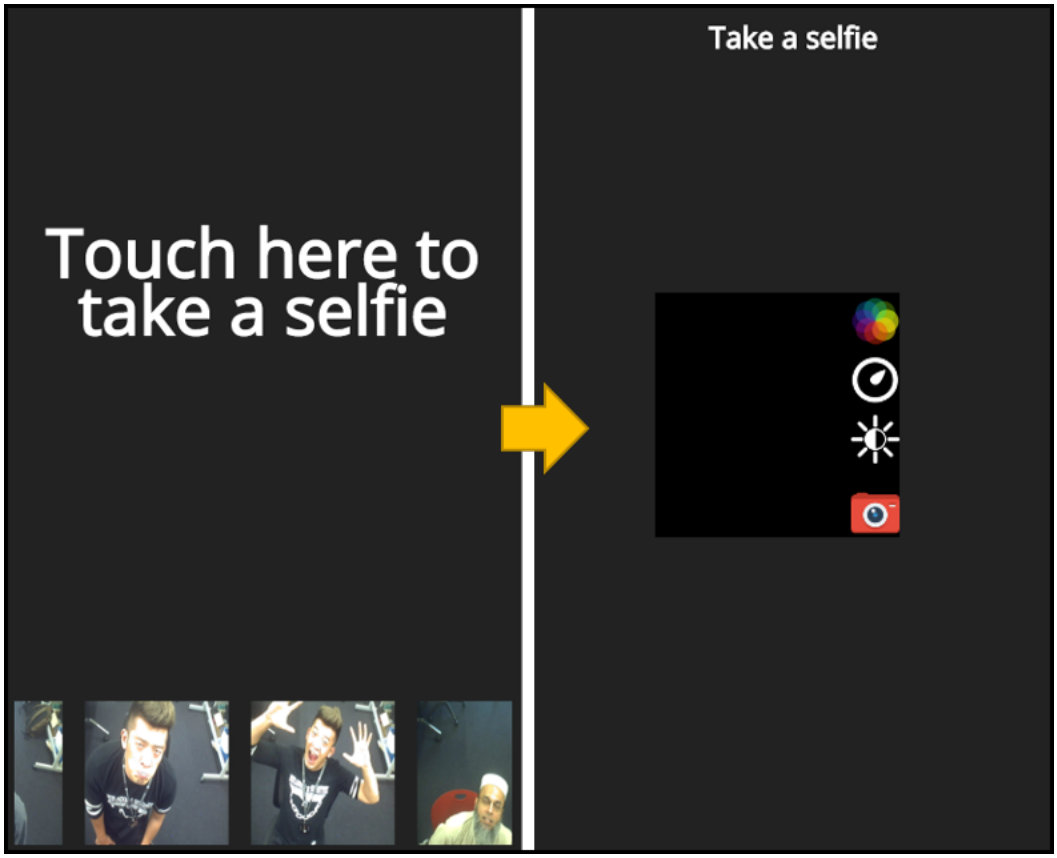

Fig. 9.3.: Touch mode: The selfie taking window's position on the y-axis is determined by the position of the user's initial touch in the previous screen.

at the same time supporting serious interactions Ackad et al., 2016. As with the previous mode, a dummy Kinect sensor was used in our experience prototype to convey depth camera sensing capability to the user.

9.5 Study Design

We evaluated our experience prototype featuring the four height-aware modes through a cognitive walk-through with 10 design experts (4 female and 6 male) between 24 and 50 years. Eight participants were UX designers and lecturers from our university; the other two participants worked as designers in the industry. Participants individually interacted with our prototype and were asked to follow the set task of taking a selfie using the four modes, which were counterbalanced across participants. Each mode was first completed standing, followed by sitting in a mock wheelchair to simulate a scenario where someone could not reach, such as wheelchair

users or shorter adults. Participants were asked to think aloud while performing the task and all sessions were audio recorded. We interviewed the participant after each mode, asking them about their experience with that particular mode and whether they had any suggestions for improvements. We further conducted an exit interview with each participant asking them to compare each interaction mode and whether they had any further suggestions. The aim of the evaluation study was to collect feedback and insights from our expert participants in regards to the design of each mode, suggestions for improvements, and ideas for alternative modes.

9.6 Results

After running the study we analysed the audio-recordings of each session and compiled the comments participants made about each height-aware mode. In this section, we discuss results from the study relative to the height-aware modes and additional ideas that were generated during the study.

9.6.1 Suggestions for Improving the Height-Aware Modes

Touch. Participants were observed not to understand that the selfie taking window moves with the touch position straight away, with one participant mentioning that there needs to be "*tap suggestions around the screen*" to help people realise the functionality. However, another participant mentioned that tapping may not be intuitive to most and that a more accessible interaction would be to "*have some type of magnetic effect to gravitate elements towards the touch point*". Two other participants had the idea of touching and dragging the element for precise control over its position.

Height sensing. Participants appreciated the pervasiveness of this mode, with one describing it as giving them a "*welcoming feeling*", which may also be appreciated by short adults, children, and wheelchair users as it "*does not make any physical adjustments*". This links back to the problem of social embarrassment (Brignull and Rogers, 2003), where users are afraid of doing something wrong in front of others and being in the spotlight.

Proximity. Participants brought up privacy issues and barriers to entry that would potentially prevent people from interacting if this mode were implemented. In particular, the issue of storing specific information about someone, such as their disability, was considered by two participants as difficult for people to accept as

it could raise privacy issues. Another participant mentioned that if the card had a purpose other than "*exclusively being utilised for a public screen*", such as height information stored on a driver's license or conference badge, then it may be fine. However, this interaction would be limited to only those with cards and therefore having an automated depth-camera or touch based height detection system would lower the barrier for interaction.

Reaching. Participants suggested that reaching should involve more visual cues indicating that it is an option, such as an on-screen Kinect skeleton, echoing findings from previous research (Grace et al., 2013). An alternative suggestion was for the silhouette to grow from the user's arm position on-screen, rather than a whole body silhouette. This would give more hints about how to perform this interaction and not block as much of the on-screen content from view.

One of the participants tried to reach from afar when they saw the Kinect, later stating that they were "*familiar with the Kinect and therefore expected that functionality*". This may be resolved with more specific on-screen and physical cues, such as a sign on the ground indicating the location of where to stand.

9.6.2 Suggestions for Improving the Prototype in General

Physical relationship between display and user. While one of the participants was sitting in the mock wheelchair, they mentioned that it was hard to reach the screen at times, with another participant stating "*imagine if I have paralysis and I need to bend over to reach this*". Another participant managed to find an easier way around reaching by using the display from the side while sitting in the chair so they could get closer (Figure 9.2d). However, this made taking selfies difficult as it took time to get into position.

Another suggestion was to have the screen physically move up and down based on someone's height or ability. However, one participant highlighted that this could cause potential social issues by drawing attention to a user's physical limitations, therefore embarrassing the user and making them feel like they are "*bothering others*". The participant further suggested that on-screen adjustments are better as it "*gives a welcoming feeling that works the same for everyone else*".

Conveying accessibility. Being specific is important when trying to convey that a screen is interactive. All participants had trouble understanding what '*Approach to take a selfie*' meant, with some assuming they could interact from a distance and one participant stating that "*for someone familiar with mid-air gestures I might not know I*

need to touch", as the height sensing mode still required touch interaction to take a selfie. Therefore, mixing of interaction modes may be confusing if not explained adequately. A potential solution could be to change the message based on proximity, beckoning interactions.

For the height sensing and reaching modes, participants mentioned that a marker on the ground informing people of how far they needed to approach would be useful. An approach also commonly found in other public gesture-based installations (Tomitsch et al., 2014). The screen should also react according to proximity to convey interactivity. This could be in the form of already detecting the height of a passer-by and bringing the interface to their eye level. One participant particularly mentioned that combining the height sensing with the touch would enable implicit interaction in the form of automatically detecting height, so people immediately understand the display is adaptive, with a familiar explicit touch interaction.

9.6.3 Limitations and challenges

Selfie taking. As the camera was placed on top of the display, every participant mentioned that users would need to look up and away from the feed which makes it difficult to be in a desired pose. Three participants explicitly mentioned that this issue is common with laptops and web-cams because the feed is far from the camera. However, according to one participant, this issue is less prevalent with smart-phone selfies, "*the camera is close enough to the screen so I can see my face and my eyes don't move too much*".

One participant mentioned that it is not as simple as making the camera low enough because when someone taller than the camera's position takes a selfie it can create a double chin effect, as described by another participant "*People are very conscious about double chins, which is why they normally hold selfie sticks up high*".

It could be argued that making the screen smaller might solve this issue, however this limits the amount of screen real-estate and may create a height issue where the screen placement is either too high or low. Therefore, an adjustable solution may be necessary.

Outdoor use of computer vision. As public displays are commonly deployed outdoors, it is important that natural elements do not affect functionality. However, participants raised the problem of Kinect's outdoor limitations, as it uses an infra-red camera for depth sensing and therefore tracking would be affected by sunlight. Blob tracking with a normal camera was suggested as a more robust option.

9.7 Discussion and Conclusion

We presented an evaluation of a height-aware PID experience prototype and reported on the feedback and ideas generated during a cognitive walk-through study with 10 design experts. Based on the findings from the study, we derived accessible design suggestions for public displays.

Our study uncovered some of the complexities and challenges in terms of user experience and usability when designing PIDs that can be personalised according to the height of their users. The adjustments on the display should be subtle and empower the user without impacting on others, otherwise there is potential for social embarrassment. Current commercial solutions simply offer an on-screen button that moves the content up or down. In this paper we have suggested alternative height-aware modes that cater for a wider range of physical differences in users and support implicit height personalisation.

Ultimately, future work would be needed to test the identified solutions with a broader range of participants of different heights.

10 Device-free: An Implicit Personalisation Approach for Public Interactive Displays

10.1 Preamble

The work in this chapter builds on **chapter 4** by reporting on a study that explores how public interactive displays can be made relevant to individuals through personalisation that is based on the context of users, without the need of any external devices; to reduce potential barriers and privacy concerns. To test this, two types of personalisation are discussed:

- Goals-based: Prototype B from **chapter 5** is discussed as the system could implicitly display and recommend content based on explicit interactions from users.
- Characteristics-based: Prototype C from **chapter 8** could adapt to the height characteristics of a user.

This study contributes to RQ3 (*How can public interactive displays be designed so that they remain relevant to communities and individuals in a hyperconnected society?*) by providing three design suggestions to improve implicit personalisation further: complementing smartphones, conveying that a public interactive display is personalised, and keeping information private.

This chapter was originally presented as a conference paper at the 2018 Australasian Computer Science Week Multiconference. Subsequently, the paper was published in the ACM proceedings of this conference. The formatting and reference style of this chapter differs from the original publication to fit the style of this thesis.

10.2 Abstract

Previous research on making public interactive displays more relevant to passers-by has focused on using profiles to personalise the content. However, profiles can potentially compromise privacy and may also create barriers for interaction as implementations usually require users to set up a personal profile, for example, through a smartphone app. In this paper, we explore an implicit personalisation approach for public interactive displays as an alternative to user profiles. We present findings from two evaluation studies of public interactive displays that implicitly adapt the display based on a user's goals and characteristics. From these studies we build on our definition of implicit personalisation and derive insights into how the user interface and content on public interactive displays should adapt in order to be perceived relevant by their users.

10.3 Introduction

Public interactive displays (PIDs) are often found in shopping centres, airports, and busy locations in cities. This technology is typically used to find specific information about a space, such as wayfinding at a shopping centre. Other uses include allowing communities to have their say on local issues (Baldauf et al., 2014; Hespanhol et al., 2015; Steinberger et al., 2014), and to post or view user-generated content consisting of news, current events, and sales (Alt et al., 2011). However, situated content, while relevant to a community, may not necessarily be relevant to individuals.

Ultimately, PIDs have the potential to go beyond simple information terminals and become truly smart technologies that augment the space with useful and relevant content for individual passers-by, similarly to the way public technologies have been depicted in science fiction films, such as *Minority Report* [1] and *Ghost in the Shell* [2]. To achieve this level of personalisation the technology needs to have some knowledge of the passer-by and the location in which it is situated to make useful inferences. Such knowledge can be achieved with user profiles that contain information about the user's preferences. This approach is commonly found in web applications, such as Google and Facebook, which create a model of the user and their preferences based on personal information such as the user's usage history to return relevant search results and display advertisements that may be of interest to the user (Hannak et al.,

[1] Minority Report - `http://www.imdb.com/title/tt0181689/`
[2] Ghost in the Shell - `http://www.imdb.com/title/tt1219827/`

2013; Granados, 2016). Users however typically access the web on personal devices where they are able to privately log in through authentication screens to gain access to their profile. In a public context this is challenging (Memarovic and Langheinrich, 2010; Davies et al., 2014), as signing in with a username and password may not be secure or convenient.

Therefore, a way is required for the PID to either read the profile or identify the user. Personal devices, such as smartphones, have been suggested as a way to be the mediator for this process in a public context to generate *digital footprints* (Cardoso and José, 2009). The information could then be transferred through RFID (Prante et al., 2003), WiFi (Parker et al., 2016; Kubitza et al., 2013) and Bluetooth technologies (Davies et al., 2009).

We observe two main challenges that come with this approach. Firstly, getting people to provide information to create profiles requires an investment of time that may not be attractive to certain groups of users, such as time-poor citizens (Fredericks et al., 2015; Schroeter, 2012). Secondly, displaying personalised content can pose privacy issues as it can link content displayed on-screen with the user (Parker et al., 2016). The third challenge is public sentiment towards being tracked by these technologies. Gaining consent is important to avoid potential legal issues (Campbell-Dollaghan, 2013; Savage, 2013) and vandalism (Licoppe and Levallois-Barth, 2011).

Due to these challenges personalisation in public spaces needs to be approached differently. Our research, therefore explores an alternative approach for making PIDs relevant to individuals that does not rely on external devices for information and instead makes inferences based on explicit interactions, thus making implicit judgements on the goals of the user based on their interactions. Our research investigates how PIDs can become more meaningful and ambient in the place they are situated, transcending from being simple information terminals.

To achieve this, we posed the following question:

1. How can personalisation be designed for PIDs to minimise the impact on privacy, while maximising usage?

To answer this question, we defined a framework for personalising PIDs that does not rely on external devices. We tested this framework in the context of two studies and discussed the results and how this framework can be improved.

10.4 Related Work

Content relevance is an on-going problem being tackled in public display research, as researchers try and find the right balance of how much the display knows about users and their privacy. This section reviews previous research on user profiles, proxemics and context-awareness as a means of making content on public displays more relevant.

10.4.1 Device-based Personalisation

Personalisation using a personal device, such as a smartphone, has been demonstrated as an alternative to signing in directly on the PID which can help retain privacy (Baldauf et al., 2012a), while being able to provide rich data relating to the user.

Logistically, the data from personal devices can be transferred through Bluetooth (Davies et al., 2014; Sharifi et al., 2006). Personalisation can be achieved either by transferring data or using the device's Bluetooth name to specify queries or preferences. Such a method however may not be widely adopted as people's devices may already be connected to something such as wearables, which are becoming popular (Riccio, 2016).

WiFi is an alternative approach that allows personal devices to transfer data to others over a longer range. Previous work has investigated the use of personalisation over WiFi through custom apps that store the user's preferences (Kubitza et al., 2013; Davies et al., 2014; Parker et al., 2016), which are collected when the app is first started and can be added to later. Once set up this allows the personal devices to automatically send data to the PIDs, which then enables them to ambiently display relevant content, such as the weather forecast from a user's hometown (Kubitza et al., 2013).

The device-based approach does have drawbacks however, as previous work found that a device-based approach may not be relevant as it does not take into account the context of the situation a particular individual may be in (Parker et al., 2016), such as being called in to work. In addition, it requires that the passers-by are connected to the same WiFi network as the PID, meaning that it may only work well in certain contexts, such as at universities, where everyone is already connected to the WiFi. This approach also has a risk of excluding certain user groups such as tourists.

10.4.2 Proxemics

An alternative method for making content relevant, without the need for user profiles, is to use sensors that can detect people and assess their behaviour within close proximity of the display. Early work (Prante et al., 2003) explored the use of long and short-range RFID sensors to make an LED display change patterns based on a user's proximity. Wang et al. (Wang et al., 2012) presented a prototype that could detect passers-by with a depth-camera and would beckon them to come and interact. Once the screen was being interacted with it would then suggest items of interest according to the on-screen items selected, similar to the way Amazon and other online retailers recommend items based on customer interactions. This type of interaction can be accessed by a broader range of people as it lowers the barrier to entry compared to user profiles. Emerging face recognition also has the potential to offer off-the-shelf mechanisms for recognising repeat visitors.

10.4.3 Context-aware Computing and Public Displays

Dey (2001) defines context-aware computing as a system that can adapt its information and services depending on the user's task. Context-aware public displays work differently from other applications, such as smartphones, as the context changes around the public display (Tomitsch et al., 2014) whereas smartphones move from context to context (Pinder et al., 2016).

To address this Cardoso and José (2009) created a framework that used different interaction mechanisms and *digital footprints* to adapt to a user. However, as with the examples in section 10.4.1, it is device-based. Lemme et al. (2014) demonstrated a simpler concept of a context-aware public display used for transport which changed colours based on the time of day. Its interface would become brighter during the day and darker at night, and also highlighted different transit routes based on what was explicitly selected.

10.5 Defining Device-free Implicit Personalisation for PIDs

We propose a framework for device-free implicit personalisation for PIDs that addresses two goals: (1) to reduce the impact on the user's *privacy* when personalising

Factor	Property	Description
System	Interaction methods	How the PID accepts input: Example: Kinect gestures, touchscreen, smartphone-based.
	Stand	The PID is either free-standing or fixed into a wall.
	Display	Refers to the interface and content shown on the PID.
	Location	The location in the space where the PID is situated.
Environment	Purpose	What is the space used for. Example: shopping, school, events.
	Users	Who uses the space. Example: students, workers, general public.
Person	Goals	What the person is trying to achieve by using the PID.
	Characteristics	The physical traits of the person interacting. Example: height, age, gender.
Time	Day/Month/Year/Hour/Minute	This factor can affect the environment around the PID and the content it shows.

Tab. 10.1.: The device-free implicit personalisation framework describing four factors that contribute to this type of personalisation.

a PID; and (2) providing some levels of *personalisation* at PIDs without any reliance on additional devices, such as smartphones, for identification.

The framework consists of four closely related factors (Table 10.1) that make-up a PID: System, Environment, Person, and Time. *System* refers to the properties of the PID, such as the input methods, the representation of the stand, what is displayed on the screen, and the location of the PID in the space. *Environment* is related to the space itself, specifically what it is used for and who uses it. *Person* refers to the goals and characteristics of the individual who is interacting with the PID. *Time* is a factor that affects the environment, such as the people moving through the space and the content that is shown on the PID.

To explore our concept of implicit personalisation we present two evaluation studies that primarily demonstrate the two aspects of the aforementioned person factor:

goals and characteristics. We focus on these aspects from the person factor as they are the only aspects that differ from person to person.

10.5.1 Goals-based Personalisation

We implemented a fully functional prototype PID system that is personalised following our definition of implicit PIDs that adapt according to the goals of the person using them. The approach was inspired by the way Google Search responds to a search request with two responses: the result of the search and sponsored links that are intended to be relevant. Although Google makes use of a user model, based on an individual's search behaviour and other information available to Google, we take inspiration from this work to establish a similar idea that returns results based on contextual factors: time, location, and the explicitly chosen search query.

Design

Our prototype system's interface consisted of two parts, suburb selection (Figure 10.1a) and results (Figure 10.1b). The suburb selection screen allowed users to quickly search without text input, alternatively offering 12 nearby suburbs to make the PID more relevant to the local area. After a suburb was selected, the results screen displayed the next three buses heading to the chosen suburb leaving from nearby bus stops. This information is displayed in the top half of the screen under the heading "*TRANSIT TO <SUBURB CHOSEN>*". The individual timetable results are contained in ribbons with the following information: bus id, departure time, and the closest departing stop. Users could select the ribbons to view where the nearby departing bus stop is on a map. Essentially, the design used the selected destination and the current time to personalise the information displayed. The individual had only to provide the broad destination, so that they would not feel their privacy was any more threatened than if they had been standing at the relevant bus stop and were seen waiting for or catching their bus.

The lower half of the results screen displayed the adaptive '*places to visit*' feature. It displayed the top three recommended places based on three factors: (1) what is open at the time; (2) Google's user rating, where preference is given to the higher ratings; and (3) places from the selected suburb. Users can then filter the places specifically by selecting one of the four different category buttons under the results: general stores, bars, cafés, and restaurants. The places are presented as three rows

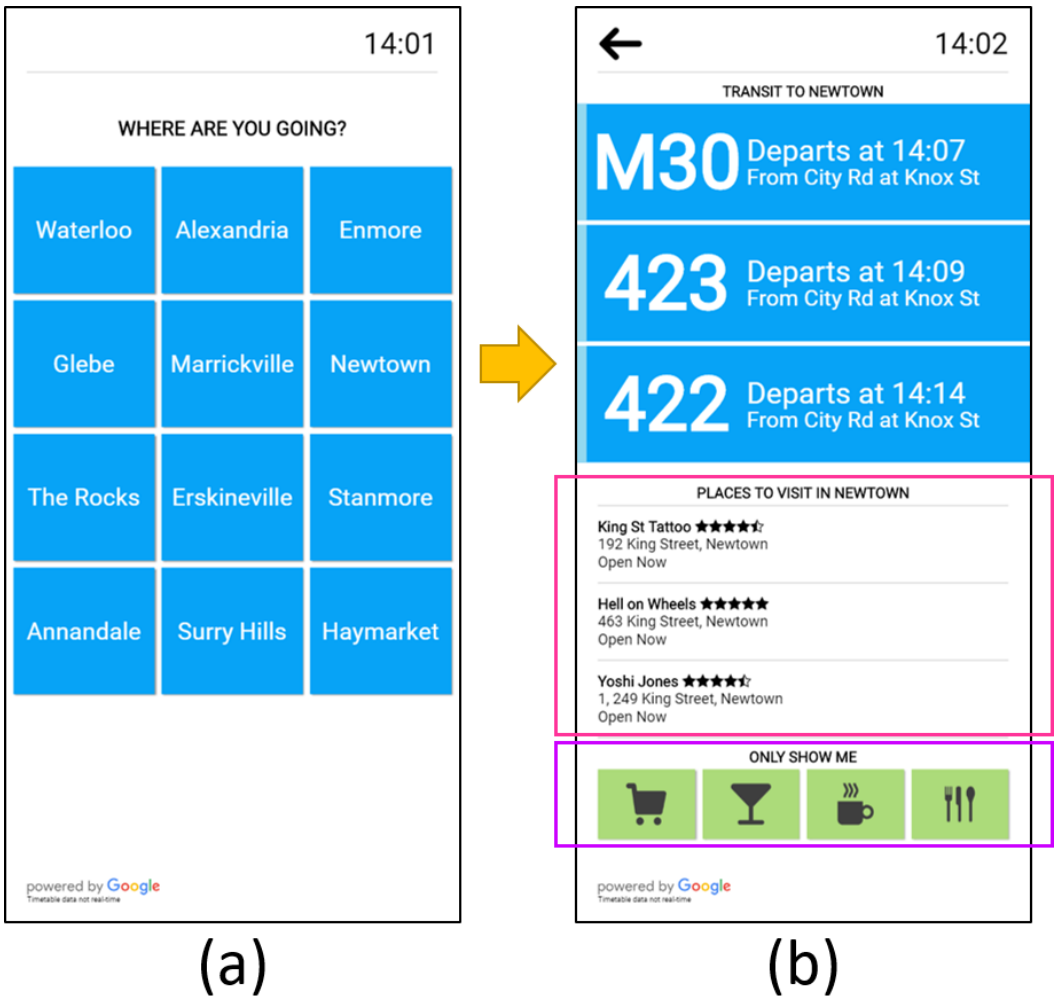

Fig. 10.1.: Upon selecting the suburb Newtown in the left screen the user is presented with a live transit timetable and recommended places to visit in Newtown.

and include name, opening hours, address, and a 5-star scale rating of the particular place.

After users have finished using the display they can walk away. After being idle for one minute it automatically returned to the main suburb selection screen. Alternatively, users can press the back button in the top left corner of the results screen to go back to the previous screen.

In addition, we logged all interactions on each element on the screen, including each time a suburb button was selected, and follow-up actions tied to it, such as filters selected and maps opened.

Study

We deployed the prototype PID indoors at the main entrance of the School of Architecture building (Figure 10.2). This location is in close proximity to a bus stop (approximately 100 metres away).

Ideally, the prototype would be deployed at an actual bus stop. This would have the advantage of being in the place that people need to wait for a bus and so have time to interact with a PID that can deliver information relevant to their bus route and bus departure time, as well as the place they are travelling. We opted for an indoor deployment for two reasons: (1) as the touch interaction is enabled by an infrared touch panel it would be prone to interference from sunlight; (2) strict council and traffic authority regulations and the prototype nature of the PID made it impossible to gain approval for such a deployment.

The chosen location had several advantages for this work. It is a major thoroughfare for staff and students, as there is a cafeteria, main entrance, and lecture theatre near the PID. This means many people pass it. It is also a place many people wait in, for example between classes, to meet friends, to eat at the cafeteria, or to travel away from campus. We aimed to provide information that these people might find interesting.

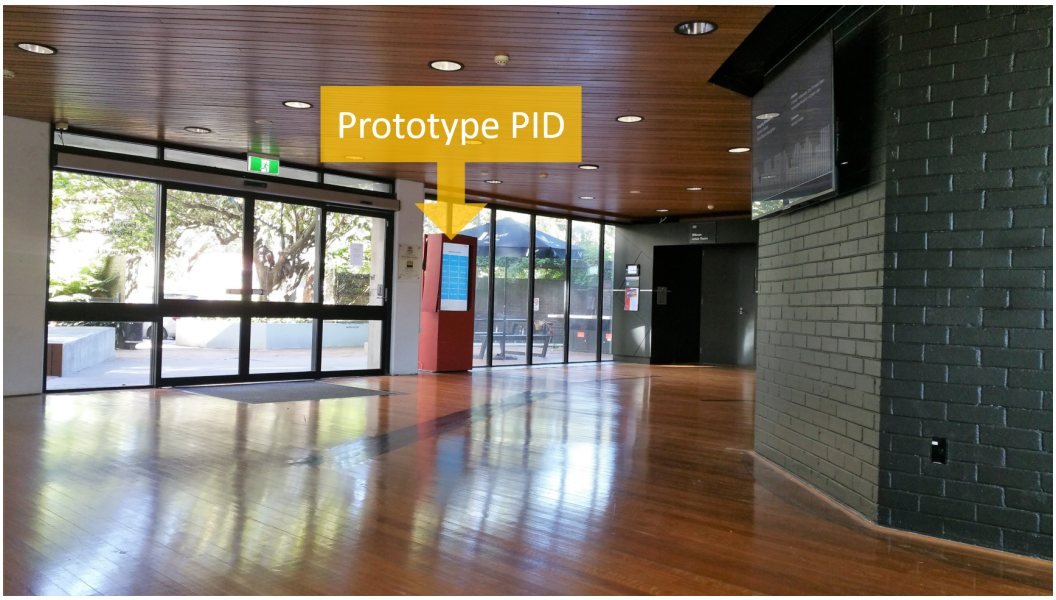

Fig. 10.2.: Touchscreen prototype setup next to the main entry/exit of the building.

The prototype was deployed for ten days from Tuesday through to the following Thursday. The researcher was present every day to observe user interactions for

one hour in the morning and one hour in the afternoon - excluding Saturday and Sunday. The screen was placed next to the main entry for the Sydney School of Architecture, Design and Planning building at the University of Sydney. We kept the screen running 24 hours per day as well as over the weekend to find out what times people interacted.

Outside of the observation times the researcher interviewed people after they finished using the PID. The interviews focused on the usefulness of the personalisation, privacy, and design aspects related to the PID.

Results and Discussion

We interviewed 12 people (4 female), all staff and students at the university. The system also logged the number of sessions and interactions with the implicit *'places to visit'* feature.

Figure 10.3 shows that the number of sessions gradually dropped over the week the PID was deployed, despite the spikes occurring Friday and Tuesday. On average, there were 25 sessions daily with 7 (28%) of those sessions involving interaction with the implicit *'places to visit'* feature.

Participant feedback indicated that, despite being *close* to the bus stops, the participants did not value the bus information. The comments suggest that if they had been waiting at a bus stop the convenience of exploring multiple bus departure times might have been useful. However, in the current location participants felt they would prefer to use smartphone apps. With widespread adoption of them (Ericsson, 2017) and their deeply personal nature, the precise location of PIDs may be critical for their usefulness. Our participants were regular travellers and some felt they might have already determined their route and what they will do at the destination at the time of the interaction: "*I might already have somewhere I am going - why do I need to use the display*". Participants suggested that the recommendation of future events would be more useful as it may be hard to change plans at the time of the interaction.

There are however, situations where smartphones are less convenient than PIDs. Smartphone apps are great for planning but not for time critical decisions (Caulfield and O'Mahony, 2009; Rahman et al., 2013). The small screen of smartphones means that when a user needs more information than gracefully fits on one screen, there may be considerable navigation, potentially to and fro. In such a case PIDs offer an opportunity to complement smartphone usage. To best achieve this they should

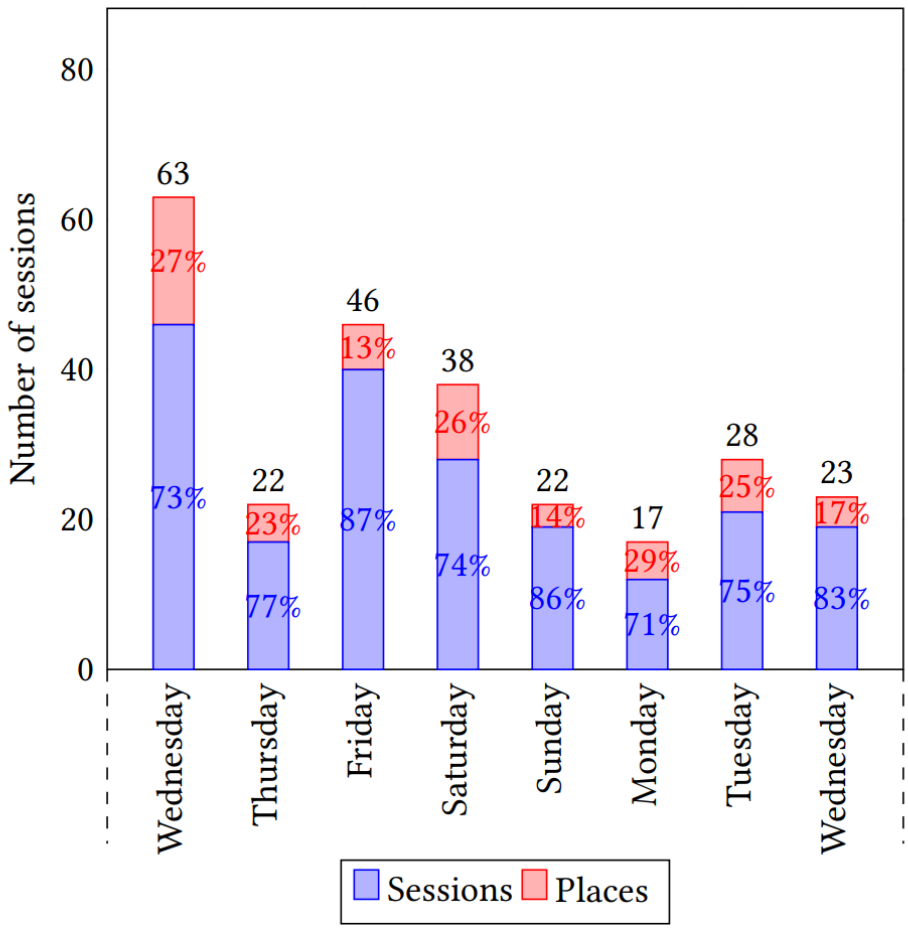

Fig. 10.3.: Total sessions (blue) and sessions that involved interactions with the *'places to visit'* feature (red).

adapt their content in a way that capitalises on the shortcomings of smartphones, such as making the information easy to read and relevant to the context, for example giving preference to trains leaving soon or displaying dining options at lunchtime based on the businesses in the local area.

Participants gave examples of cases where they thought that such a feature would be useful, such as visiting a new place and viewing information about things to see and do. Reflecting on this feedback, it appears we under-estimated the impact of the distance from our display to the relevant bus stops. We also over-estimated the potential to make use of time when people were waiting in the foyer and contemplating catching a bus.

Participants did appreciate the simplicity of the interaction and felt that it enabled them to access the information quickly. Although feedback on the interface was positive, responses on the relevance of the content was mixed with five (of the

10) participants stating that the transit information was relevant to them, as they used public transport regularly. In addition, one participant commented that the recommended places helped them discover a new bar in their suburb *"there was one bar that I didn't know was listed in my area so I thought that was interesting. So that was good, it was relevant"*. However, another participant suggested that the *'places to visit'* feature could be improved by displaying the place on a map when it is selected, rather than only displaying the address.

The ability to read reviews about the recommended *'places to visit'* was another requested feature, which is commonly found on social media and search engines. One participant suggested that reading recent reviews helps with decision making: "*I was expecting somewhere to read the reviews. A quick overview. The things that I normally look for in say Google Maps, is just quickly what people have said, but also the date of the last reviews*". It appears, therefore, that the content displayed in the *'places to visit'* feature may have been too similar to features that people use on websites and mobile devices, making our participants expect the same functionality and content provided by Google Reviews.

When asked if they had any concerns about privacy, none of the participants indicated that they had concerns. Nor were they aware of others around them, despite previous work suggesting that this is a potential detractor (Brudy et al., 2014; Parker et al., 2015). When asked about this, one participant stated that there is not really any private information displayed but "*there is a chance for someone to know where you are going, which may be dangerous late at night*". We also asked participants about personal information they would be willing to share and view on the display. Every participant was against any personal information being shared that could be linked back to them, such as their full name, email, phone number, and specific address: "*I don't like the idea that it has anything that relates to me. I like that it is absolutely anonymous*", "*I'm more worried about my name than other data, because my name is like a handle, you can search me on Google and find out who I am*". In addition, participants were clear about being wary of providing personal information, with one participant stating, "*I am not sure about giving too much of my personal information because it is a public display and I am not really sure who made it and where all my information is going. So I am not sure if it is clean and clear after I leave*". This concern could potentially be resolved by making the display look official with well-known branding or some form of trust certification, similar to certificate authorities that are used to certify genuine websites.

10.5.2 Characteristics-based Personalisation

To test our characteristics-based definition of personalisation we implemented and evaluated a system that is height-aware and therefore personalised based on the height characteristics of a user (Parker et al., 2017). This method works by not directly prompting the user for their personal information but implicitly gains this information through their usage.

Design

We designed a semi-functional public display prototype around the playful concept of taking self-portraits (Fredericks et al., 2016a; Fredericks et al., 2016b). This functionality can be found in public display applications and kiosks in cities and at airports around the world. The concept was chosen as it represents a realistic scenario, and for its simplicity – as the focus of the evaluation was not on the interactions but on the height adjustment mechanisms. The prototype consisted of four components which were housed in a custom-made stand: (1) a 50-inch touchscreen in portrait orientation; (2) an Apple Mac Mini – running Microsoft Windows 7 and the public display interface; (3) a webcam for taking selfies; and (4) a dummy Kinect for imagining automatic height detection and assisted reaching, which was mounted on top of the display. The selfie application was coded as a webpage and consisted of an on-screen selfie box (Figure 10.4) that would either move to where users touched on-screen or automatically move to a reachable position according to the user's height.

The prototype responded to a user's height through three types of interactions: (1) Touch (Figure 10.5a); (2) Proximity and Height Sensing (Figure 10.5b); and (3) Reaching (Figure 10.5c). These were chosen as touch input and depth cameras are commonly used for interaction with public displays.

Study

We recruited 10 design experts (4 female) between 24 and 50 years of age as participants in a think-aloud study. Eight participants were lecturers and tutors in design from The University of Sydney while the other two were from industry (one web designer and one user experience designer). Participants individually interacted with our prototype following the set task of taking a selfie with each interaction method while both standing, and sitting in an office chair to simulate scenarios

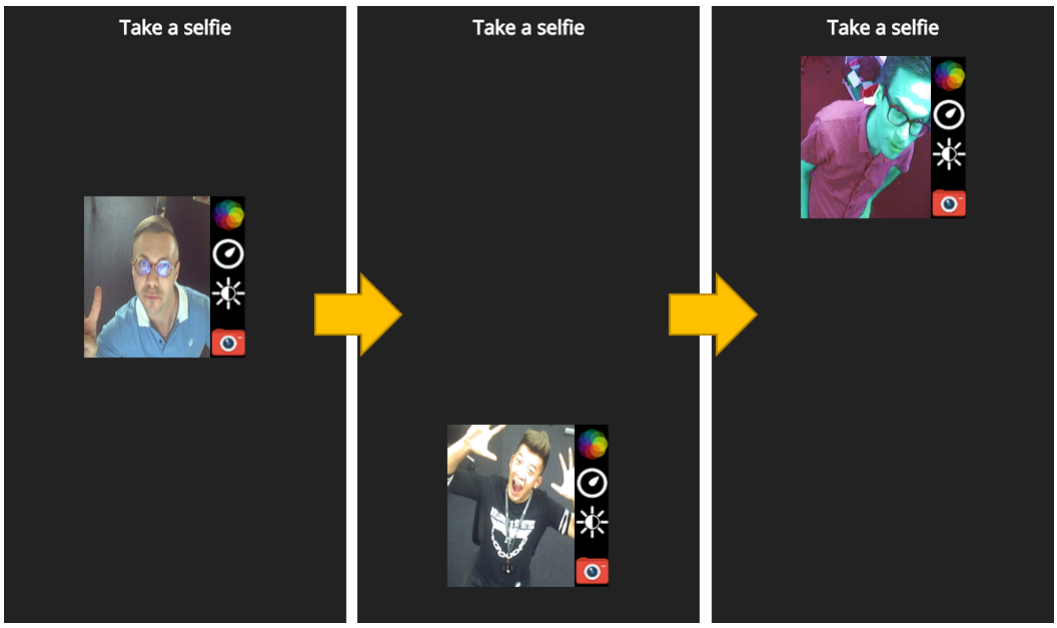

Fig. 10.4.: The on-screen selfie box moves corresponding to the touch location or the user's height.

where someone could not reach (such as the wheelchair bound). The interaction method was counterbalanced across participants.

Each interaction method was first completed standing, followed by sitting in the chair. Participants were asked to think aloud while they were performing the task and all sessions were audio-recorded. After completing all the interaction methods, we interviewed each of the participants, asking them about their experience and to evaluate the four modes.

Results and Discussion

Overall, the on-screen adjustments were appreciated with one participant mentioning that physical adjustments could cause potential social issues by drawing attention to a user's physical limitations, therefore embarrassing the user and potentially making them feel like they are "*bothering others*". The participant further suggested that on-screen adjustments are better as it "*gives a welcoming feeling that works the same for everyone else*".

While seated in the chair, all participants were observed as having trouble reaching the screen. One participant specifically mentioned that it was hard to reach the screen at times, stating "*imagine if I have paralysis and I need to bend over to reach*

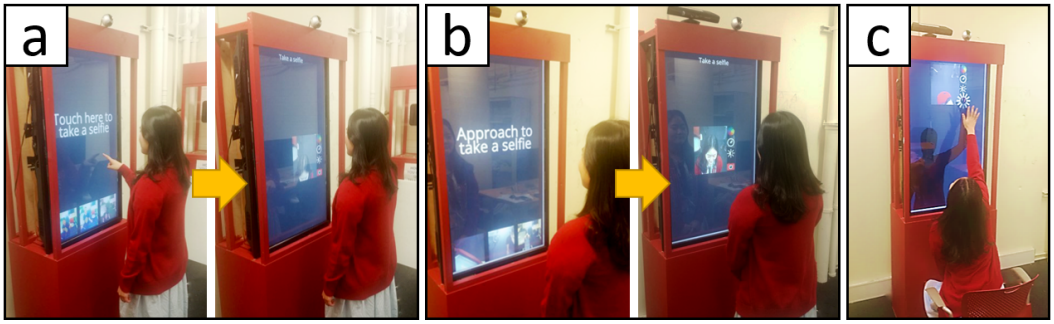

Fig. 10.5.: (a) Touch mode: height is implicitly detected based on the touch position; (b) Proximity and Height Sensing modes: height detection is implicitly determined through on-body (e.g. RFID) or on-display (e.g. Microsoft Kinect) sensors; (c) Reaching mode: A digital mirror representation provides assistance to users that are reaching and activating on-screen elements.

this". Another participant managed to find an easier way around reaching by using the display from the side while sitting in the chair so they could get closer.

Participants were observed to not immediately understand that the on-screen selfie box moves with the touch position, with one participant mentioning that there needs to be "*tap suggestions around the screen*" to help people realise the functionality. However, another participant mentioned that tapping may not be intuitive to most and that a more accessible interaction would be to "*have some type of magnetic effect to gravitate elements towards the touch point*".

It was suggested that reaching should involve more cues indicating that it is an option, such as an on-screen Kinect skeleton, echoing findings from previous research (Grace et al., 2013). An alternative suggestion was for the silhouette to grow from the user's arm on-screen, rather than a whole-body silhouette. This would provide a better indication about how to perform this interaction. One of the participants tried to reach from afar when they saw the Kinect, stating that they were "*familiar with the Kinect and therefore expected that functionality*". This may be resolved with more specific on-screen and physical clues, such as a sign on the ground indicating the location of where to stand.

Apart from the concerns with where selfies are going and how long they stay on-screen, which are not being investigated in this study, there were no privacy concerns related to an individual's height. However, participants pointed out potential privacy concerns in the proximity mode around using an NFC card, which would store specific information about someone's disability. One participant mentioned that if the card had a purpose other than "*exclusively being utilised for a public screen*", such as height information stored on a driver's license or conference badge, then it may

be fine. However, this interaction would be limited to only those with cards and therefore having an automated depth-camera or touch based height detection system would lower the barrier for interaction.

10.6 Discussion

The two studies are discussed in relation to displays gaining an understanding of the user through the device-free implicit framework we defined in section 10.5. Through an analysis of the findings from these two studies we revisit the question posed in the introduction: *How can personalisation be designed for PIDs to minimise the impact on privacy while maximising usage?*.

Complementing smartphones. While these were small studies, the first study appears to have been less successful than we had hoped. All participants judged the interface was easy to use. Even so, for this group of participants, the PID was less useful than we had hoped. This was partly because many of the participants knew the location of the bus stops that were relevant for them. In addition, this was not the place that they wanted to explore information about the places to visit. In this location these participants felt their smartphone provided similar functionality. Therefore, PIDs should provide content that is unavailable or inconvenient to view on smartphones. This would make PIDs useful in very precisely situated places that are a good match to the information needs of the people who are in that location, and to match the time they have.

A PID like ours might well be valuable at a bus stop where people need to wait anyway and have time time to explore an information space. Similarly, it requires careful definition of information needs in a particular building or shopping centre.

Conveying personalisation. With the current state of technology people may not be aware that PIDs can be personalised such as in our second study. Therefore, it is important to convey this ability to passers-by. This could potentially be achieved through on-screen prompts demonstrating how the PID works, or physical signs on and around the PID explaining that it is personalised. If the user does not expect personalisation they may not notice these and adding playful elements, such as skeletons, may mean that people will be distracted and play (Ackad et al., 2016).

Keeping it private. One major issue with both of these studies is that there is potential for shoulder surfing (Eiband et al., 2017). When personalising a PID based on a user's goals or characteristics the information displayed on-screen may reveal their intentions, for example visiting a certain shop, or their abilities, including

their height, in the case of the second study. Therefore, designers need to revisit methods to help mitigate this issue, such as using cameras to black out parts of the screen the user is not viewing (Brudy et al., 2014). Augmented reality may well become another viable approach (Parker et al., 2016). However as it is device-based, it may not be fully-inclusive until it becomes integrated into widely owned consumer devices.

10.7 Conclusion

In this paper, we presented two studies to test our implicit personalisation framework, which utilises the users' goals and characteristics to provide them with personalised content and interactions. Our results showed that there is much potential for this type of personalisation, however more consideration is needed towards the types of contexts that exist within public spaces, concerns around privacy, and how users' needs change over time. In these two studies, we discussed design suggestions that may further improve the effectiveness of personalised PIDs and add an additional layer for designers to consider when applying this framework. Future research opportunities in this area include further exploring methods to better detect user behaviour and characteristics while not being intrusive yet remaining useful and relevant.

Part IV

New Opportunities for PIDs

11 Design Patterns for Making Relevance-Driven Public Interactive Displays

11.1 Preamble

The work in the previous chapters focused on specific aspects of making a PID relevant, such as responding to user characteristics. In this chapter, the work from the previous chapters (contained in **parts II** and **III**) and the collective knowledge from the research community is brought together to gain a broader understanding of how PIDs can be designed so they are relevant to individuals - which we term as relevance-driven PIDs. This understanding is synthesised into seven design patterns that can be used to guide the design of future PID deployments. The approach used to create the design patterns followed work by Schuler (2008) and Fredericks et al. (2017b). In these works, each pattern is set out with an outline of the problem and its context, a discussion around the problem and approaches to overcome it, and identification of a solution for each pattern. The specific aim of this chapter is to develop design patterns that can help inform future designs of PIDs and address the challenges in making relevance-driven PIDs. This chapter addresses RQ3 (*What factors influence the relevance of a public interactive display to individuals?*), and more broadly the overarching aim of this research, by synthesising both the research community's and our current knowledge of designing relevant PIDs and presenting it in a form that is usable by future developers, designers, and researchers, thus informing the designs of future PIDs. Consequently, this work also outlines new opportunities for designing relevance-driven PIDs, through a discussion of the problem and solution for each of the seven design patterns.

This chapter was further developed and adapted for the 2019 Computer Human Interaction (CHI) conference. At the time of the thesis submission the paper is still under review. Should the paper not be accepted, it will then be improved based on the reviews and submitted to the International Journal of Human–Computer Interaction or the ACM Transactions on Computer-Human Interaction (TOCHI) journal.

11.2 Abstract

Public spaces within cities are increasingly becoming digitally augmented by public interactive displays (PIDs). This technology has become more ubiquitous in recent years and is commonly used for purposes such as advertising, wayfinding, and information. However, PIDs are not always relevant to the people within the space and their changing needs. This issue of relevance is amplified due to the increasing hyper-connectedness of modern society, where information has become readily available through smartphones. While much work has focused on gaining an understanding of how PIDs can be designed so they are relevant to the context of place and space, there is an opportunity to define guidelines for the design of PIDs that are relevant to individuals (relevance-driven PIDs). Therefore, in this article we investigate the factors that make relevance-driven PIDs. From a discussion of previous research and reflection on three of our own past PID studies, we synthesise the findings into three core factors that influence the relevance of a PID to individuals: User, Locale, and Time. Based on these factors, we identify a set of design patterns for guiding the design of relevance-driven PIDs.

11.3 Introduction

Public spaces within cities are heterogeneous social areas that are generally accessible to all people (Low and Smith, 2013). Globally, as a result of decreased hardware costs and smaller computing form factors, there are now more opportunities to embed digital information into the fabric of physical public spaces, therefore increasingly augmenting cities with dynamic information. Public displays are a common medium for embedding such information in cities. This technology is often found in spaces such as airports, shopping centres, and train stations. While outdoor advertisers may use public displays to deliver dynamic advertisements to the masses, research has demonstrated that public displays, particularly public interactive displays (PIDs), can provide a mechanism for bringing people together, essentially becoming a digital version of existing community infrastructure like community noticeboards (Alt et al., 2011) and voting booths (Steinberger et al., 2014; Hespanhol et al., 2015).

Despite the potential of PIDs for empowering communities, it is often assumed that the deployment of PIDs in public space services the needs of all urban dwellers, taking a "*one size fits all*" approach, with little regard for the differences of the

individuals that use the spaces (Parker et al., 2017; Parker et al., 2018d). Ensuring that PIDs are relevant and accessible to everyone is especially critical in situations where the objective is to engage local communities around civic topics, such as the development of new infrastructures. To disregard people that pass through public space risks the technology becoming unused and has the potential to exclude portions of the population, such as those who come from marginalised communities (Fredericks et al., 2017b; Parker et al., 2017; Schroeter and Foth, 2009), including lower socio-economic backgrounds, culturally and linguistically diverse communities, and those with physical or cognitive impairments. Furthermore, society is becoming increasingly hyperconnected as information access is ubiquitous through personal technologies, such as smartphones and smartwatches. This has resulted in urban dwellers, particularly from younger demographics (Berenguer et al., 2017), that visit or pass through a public space having ubiquitous access to information on the web. More specifically, personal technologies play a key role in the communication of civic information to local communities, often used in conjunction with traditional media (Fredericks and Foth, 2013) such as newspapers and radio. Therefore, the challenge is to design PIDs that are relevant for everyone in hyperconnected societies.

In an effort to address relevance of PIDs for individuals, research has been directed at personalising PIDs (Cardoso and José, 2009; Davies et al., 2014; Parker et al., 2016). Having people provide preference information requires an investment of time which may not be possible for time-poor individuals (Schroeter, 2012) and can raise concerns around privacy (Memarovic and Langheinrich, 2010; Davies et al., 2014; Parker et al., 2015). Due to the public nature of PIDs personalisation becomes a complex challenge. Other research has avoided the need for getting information from individuals by making PIDs implicitly respond to presence (Wang et al., 2012) and user characteristics (Parker et al., 2018c). While these methods for making PIDs relevant to individuals show much potential (Davies et al., 2014; Davies et al., 2009), there is little in the way of compiled knowledge for future designers and researchers to reference.

In this article, we aim to gain further understanding of how PIDs can be designed so they are relevant to individual urban dwellers within the communities they are situated - which we refer to as relevance-driven PIDs. To achieve this aim we first discuss how previous research has tackled the challenge of relevance and introduce the concept of pattern languages through examples of previous work that has used them. Secondly, we reflect on our previous PID deployments to identify three overarching factors (User, Locale, and Time) which are contextualised as the relevance triangle. Finally, we synthesised the core findings from our PID

deployments into 7 design patterns, which can be used to inform the design and development of relevance-driven PIDs.

11.4 Background

We review three areas of related research: (1) Engaging Urban Dwellers through Public Interactive Displays; (2) Making Relevance-Driven Public Interactive Displays; and (3) Pattern Language and Design Patterns. The first discusses work that has focused on giving PIDs a new purpose in the space in which they are situated, attempting to make PIDs relevant to individuals by providing them a platform in which they can connect with their respective communities. Secondly, we review work that has studied methods to make PIDs relevant to individual users, thus grounding the discussions of our studies later in this article. Thirdly, the concept of pattern language and design patterns is discussed, providing a basis for the structure of our own patterns presented in section 11.6.

11.4.1 Engaging Urban Dwellers through Public Interactive Displays

Previous research has demonstrated that PIDs can be effective mediums for people to have their say on relevant topics affecting their local community. For example, Valkanova et al. (2014) designed and evaluated an interactive projected poll visualisation. People could vote using one of the four voting options for a topic by positioning themselves in front of their intended answer while raising their hand. Similar work by Hespanhol et al. (2015), also deployed a full-body voting application running on an existing public display as a mechanism to engage urban dwellers around local topics. Located in a busy outdoor civic square, the PID could be used by passers-by to vote on specific questions posed. Users needed to position themselves appropriately using the on-screen camera feed. Through computer vision techniques the system would track the presence and movements of people within the interaction area by displaying the live feed split into two zones, each representing a respective answer to the posed question. Other work by Steinberger et al. (2014) investigated polling locals by displaying questions on a public display at a bus stop. The system allowed passers-by to interact and vote yes or no by using a more discreet approach of stepping on buttons below the display.

The findings from these studies highlighted the importance of real-time feedback, tangible user interfaces, full body interactions, and playfulness as important drivers

for motivating people to participate. Their findings also showed that novel PID voting systems have the potential to spark discourse in the community and engage more people.

At the same time however, the public nature of these systems may deter people from participating and have the potential to cause social embarrassment or link the user to the interaction (Ojala et al., 2012; Tomitsch et al., 2014; Steinberger et al., 2014). This might affect participation when discussing controversial topics such as politics. Schroeter and Foth (2009) presented a more private method for giving opinions, while at the same time enabling those opinions to be presented publicly. Utilising an existing public display located in a busy urban space, passers-by were encouraged to text, email or tweet responses to localised questions displayed, such as questions related to new building developments in the local area. These different interaction options enabled a broader range of people to participate.

Work by Behrens et al. (2014), presented the Smart Citizen Sentiment Dashboard. This system utilised an existing large LED media façade on a building in Sao Paulo, Brazil. Citizens could swipe their RFID card on an emotion that was presented on the display to transmit it to the façade, which then aggregated and visualised people's input; representing the mood of citizens on local urban challenges, such as safety in the city.

Other work by Alt et al. (2011), tested a PID application called Digifieds. It harnessed the existing UbiOulu public display network and provided citizens with a digital version of a community noticeboard. Users could post content, such as advertisements, using the screen or their own personal devices. The content could then be read by other users. This system demonstrated the need for contextual content and the power of giving people control of the content on PIDs. In similar work public displays were deployed in a local community, enabling citizens to post public messages, thus creating discourse relevant to the local community (Redhead et al., 2009). Giving urban dwellers control over the content on public displays can be an effective way to keep content relevant and give people in communities an accessible platform to reach out to one another.

The work that was discussed in this section demonstrates how PIDs can be used to engage urban dwellers within the communities in which the PID is situated. The input mechanism in each of the studies was carefully designed to complement the public display while also responding to the typology of the space and the local demographics. For example, in the Smart Citizen Sentiment Dashboard study (Behrens et al., 2014), passers-by were able to vote using their local transport smart card. The type of input, however, raises issues around inclusive participation. For

example, smart-phone enabled displays exclude participation by people who do not own a smartphone and are therefore not relevant to everyone.

11.4.2 Making Relevance-Driven Public Interactive Displays

While the examples in the previous section were successful at fostering engagement and discourse through civic topics, community-centred content may not always be relevant to all urban dwellers. Previous studies have found that the way people engage with PIDs in urban environments changes depending on the current goals of an individual, the location, the day of the week, and the time of the day (Hespanhol et al., 2015; Tomitsch et al., 2014; Parker et al., 2018d). A study on people's engagement with urban screens suggested that the socio-demographic perspective also plays an important role, not only in terms of people's engagement but also regarding their acceptance of displays in urban environments (Moere and Wouters, 2012). For example, the study identified a case of vandalism, where people attempted to physically damage an urban screen that was located in an area with a high unemployment rate while displaying information about events in upper-class shopping streets.

Schroeter et al. (2012) introduced a conceptual framework linking people, content, and location as key parameters for designing interactive systems for situated community engagement. Based on the study of an interactive urban screen application, they discussed in what ways factors such as the nature of the location, the positioning of the screen, and the content displayed on the screen influence both frequency and quality of interactions. These previous studies and their findings suggest that people's engagement with PIDs is linked to the perceived value attributed to the display and the content provided through the display. They further highlight that getting this right is especially difficult in urban environments, where displays might be deployed in different physical contexts and which feature a wide range of people and demographics that change over time. In this chapter, we specifically focus on "relevance" as one of the elements that contributes to the perceived value that a PID provides. José et al. (2014) link relevance to the "situatedness" of a public display, introducing the term "situational relevance" to describe the level of integration between digital displays and their physical and social context. They argue that most digital displays in public settings fail to achieve the same level of situatedness compared to their non-digital counterparts. E. Huang et al. (2008) found that when looking at a display people very quickly decide about the value and relevance of its content. They further highlighted that the majority of public displays deployed in public spaces fail to consider the space in which it is deployed, the people around it, and the local activities, and how these factors may affect the perceived relevance of

those displays. E. M. Huang and Mynatt (2002) observed that the success of awareness applications, which includes "semi-public displays" is linked to the application's ability to provide relevant content.

To actually make PIDs relevant to the needs of individual urban dwellers some research in the pervasive displays community has suggested personalisation (Davies et al., 2014; Davies et al., 2009). Personalisation commonly seen on web services like Google and Amazon, usually have ready access to the user's information, such as their demographic, interests, and search history. This results in some web services having a comprehensive model or profile of an individual user (Kay et al., 2003; Kay, 1994). When this approach is applied in the public sphere however, it can have implications for privacy, particularly if the user is required to sign into the screen to identify themselves. Therefore, it was concluded in work by Memarovic and Langheinrich (2010) and Davies et al. (2014) that personalisation of public displays and PIDs needs to be approached differently to ensure the privacy of individual users is protected.

One way private personalisation has been explored is through smartphones, which act as a bridge for the PID to gain access to information about the user. For instance, Bluetooth has been demonstrated as a convenient communication method between a smartphone and public display to achieve interaction and customisation of the content displayed (Davies et al., 2009; Sharifi et al., 2006). Further work by Davies et al. (2014) presented a system that detected whether a person was close to a certain display using location data from a pre-installed app on their smartphone. The display would then show personalised content based on the preferences users pre-set in the app on their smartphones, such as the weather forecast from the user's hometown.

Other work explored more implicit approaches. Prante et al. (2003) investigated the use of long and short-range RFID sensors to make an LED display change patterns based on the proximity of the user. Other work by Wang et al. (2012) presented a PID prototype inspired by the way Amazon recommends items on their site. Their PID could detect passers-by with a Kinect and would beckon them to come and use it. Once the screen was being interacted with it would then proceed to suggest items of interest based upon the on-screen items selected, similar to the way Amazon recommends items online. It would also focus on items of interest based on the proximity of the user.

The work discussed in this section shows that personalisation can help make PIDs more relevant to individuals. While personalisation can be technologically achieved in a number of ways, little work has focused on testing the social aspects of these

methods and how they fare in the variability of public space. This article aims to provide more insights into the design of relevant PIDs through a reflection of three prototypes we have worked on. We then synthesise these insights into a set of design patterns to enable PID designers and researchers to create relevance-driven PIDs in the future.

11.4.3 Pattern Language and Design Patterns

The design patterns that are presented in this article follow the definition of pattern languages outlined by Christopher Alexander and his colleagues in their two books: *A Pattern Language* (Alexander, 1977) and *A Timeless Way of Building* (Alexander, 1979). Alexander developed an approach to capture and use design knowledge by establishing an extensive collection of pattern examples to assist architects and engineers in overcoming recurrent design limitations for buildings, towns, and other urban infrastructure. Each pattern is broken down into a description of the issue's context, a problem statement, and a proposed solution that provided practical examples. All of Alexander's patterns follow a similar structure in the attempt to drill down into the core solution to a specific problem, which can also be applied multiple times, without ever doing it the same way twice (Alexander, 1977). The patterns set a benchmark for all stakeholders, including architects, engineers, and everyday people to use a common language for facilitating the design and implementation of a project from its inception to completion.

Pattern languages are well established in the fields of architecture and engineering, however other disciplines, such as information and communication technology (ICT) and human-computer interaction (HCI) have also created pattern languages and design patterns. Schuler (2008) developed a pattern language directed at social change and citizen activism for ICT design and social interaction. A total of 136 patterns were created as an alternative design approach that involves a variety of stakeholders in the decision-making process. Similar to Alexander, Schuler provides a problem, context and solution, however each pattern incorporates detailed explanations through practical examples from previous literature and projects. Fredericks et al. (2017b) developed eight design patterns for designing and implementing digitally augmented pop-up interventions for localised community engagement. Based on the themes highlighted through their research, the patterns were grouped by three categories: 'notification', 'interaction', and 'engagement results'. Further building on Schuler's approach, each pattern specifies a problem, context, discussion, and solution through practical examples provided from their own research experiences and related projects.

In this article we draw on the approaches used by Schuler (2008) and Fredericks et al. (2017b) by providing a set of design patterns that outline the problem, context and solution for designing PIDs through practical examples from our own research projects and literature from previous work.

11.5 Exploring the Design of Relevance-Driven PIDs

To gain further insights into the design of relevance-driven PIDs, we discuss and explore the design of three prototype PIDs (*Public Display with Augmented Reality Assisted Personalisation*, *Transit Public Interactive Display*, and *Height-Aware Public Interactive Display*) and their associated studies. This reflection of PID prototypes informs the themes and design patterns presented in the following section. The prototype systems were evaluated in separate studies and are described below.

11.5.1 Prototype A: *Public Display with Augmented Reality Assisted Personalisation*

In this study we explored how content on a public display could be personalised for individuals through a smartphone app. To avoid the problem of the personalised content being shown on the public display, the app allowed people to have a personalised view of the public display through mobile augmented reality (MAR). Specifically, the prototype system was comprised of two components:

- **Public Display.** The public display essentially acted as a digital community noticeboard, displaying general content targeted towards students. Specifically the content included: local news, university news, local buy and sell advertisements, and property rentals.
- **Mobile Augmented Reality App.** The MAR app allowed users to view personalised content overlaid over the public display through their mobile device. Virtual elements could be interacted with through the smartphone's screen using touch to select a tile and swipe gestures for navigation. To enable AR tracking, the background behind the content on the public display was an AR marker.

The prototype was evaluated in a user study (Parker et al., 2016), where we recruited 10 participants (3 females and 7 males, aged between 19 and 30) to trial the prototype in a university cafeteria. The personalised content featured on the public

display was manually generated by the researchers prior to the study, based on a profile of the user, with the personal information collected through a pre-survey which the participants were asked to complete. The information collected related to their field of study or work, home suburb, and their interests or hobbies. Participants were asked to explore the interface using the MAR app to view personalised content. After participants finished trialling the app, we asked them to participate in an interview, answering questions related to their experience, the relevance of the content, and privacy.

Findings from this study suggested that personalisation should be more responsive and related to the user's current context or objectives. Additionally, the level of privacy offered by a display should adapt based on what the user feels like sharing at the time. We also observed during the study that using an MAR app to view personalised content can at times disturb the flow of the space, as passers-by would avoid walking in front of the user as they thought the user was taking photos. The MAR app also brought attention to the user, particularly when the user was remotely controlling the public display, potentially raising privacy concerns.

The key takeaways from this study are that personalisation should be responsive to a user's current needs, and that MAR, while showing much potential at providing a private view, is not yet intuitive or natural enough to robustly use in a public setting.

Fig. 11.1.: Mobile augmented reality assisted personalisation of a public display.

11.5.2 Prototype B: *Transit Public Interactive Display*

Problems with the smartphone-based personalisation approach are that: (1) it requires an investment of time on the user's part to setup; (2) personalising a PID with information from a personal device can expose the user to security risks, like man in the middle attacks (Sethi et al., 2014), and can also link the content on-screen with the user; and (3) tracking users through their personal devices may negatively impact public sentiment, particularly if consent is not gained (Campbell-Dollaghan, 2013; Savage, 2013).

Therefore, to avoid these problems and to enable a level of personalisation that suits the user's current context or objectives, we implemented and studied a fully functional prototype PID system that implicitly adapted to the goals of the person using it without the need for a personal device (Parker et al., 2018c). The system was designed around the theme of transport, where it would recommend the next bus times from the nearest bus stop depending on the destination suburb selected from the available twelve options - represented by buttons for quick access to suburbs nearby the local area (Figure 11.2A). Depending on the selected suburb, the display showed three information ribbons containing information about the fastest transit options (walking, bus, or train) to the selected suburb at that time (Figure 11.2B). Each information ribbon displayed the bus number or an icon for walking or train, departing time, transit information, and the closest departing stop. The display also showed information, in the lower part of the screen, about the three most highly rated locations of interest in the selected suburb, which could be manually filtered by four categories: restaurants, bars, shopping, and cafes. The information displayed included the name of the place, opening hours, address, and a 5-star scale rating retrieved from Google.

The prototype PID was deployed next to the main entry for the Sydney School of Architecture, Design and Planning building at the University of Sydney - which is a busy thoroughfare for staff, students, and visitors. The PID was left running 24 hours per day for ten days, from Tuesday through to the following Thursday. During the weekdays researchers were present to observe user interactions for one hour in the morning and one hour in the afternoon.

Outside of the observation times the researchers interviewed 12 people (4 females and 8 males), all staff and students at the university. The participants were not pre-recruited and the interviews took place after the participants finished using the PID. The interviews were specifically conducted to gain further understanding of the personalisation feature's usefulness, any privacy concerns with using the PID, and

UI and content design. Data was also collected automatically over the 24 hours as the PID logged the number of sessions, session length, and all interactions.

Findings from the study with this system found that, despite being nearby a bus stop, the information was not useful to participants as the PID was not actually at the bus stop and the information was already available on smartphone apps. Consequently, it seems that PIDs should be positioned where there are likely to be opportunistic interactions, making it more likely someone will use the PID rather than the smartphone as it is faster. Other participants expressed that the PID may also be useful if it displayed information related to events happening in the local area or information for newcomers about what to see.

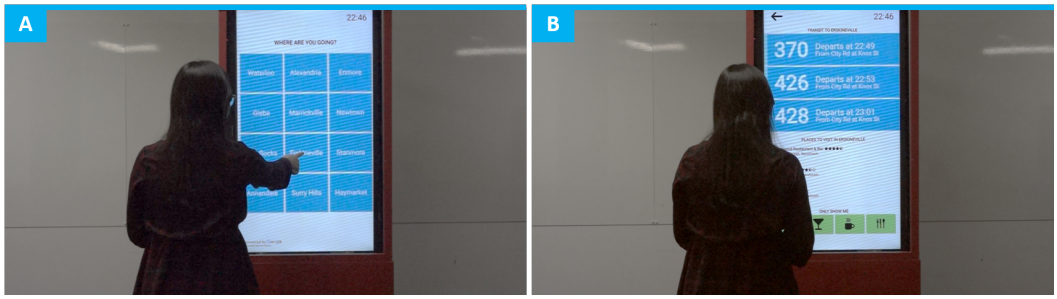

Fig. 11.2.: The two main screens from the Transit public interactive display: (A) suburb selection; and (B) transit information and places to visit.

11.5.3 Prototype C: *Height-aware Public Interactive Display*

In a public space, people of all demographics exist and therefore it is important to cater for diversity in the design of public interfaces. We therefore explored personalisation of a PID based on the physiological traits and characteristics of the user, specifically their height. We designed a semi-functional public display prototype around the playful concept of taking self-portraits. The prototype could respond to a user's height using four different interaction modes: touch interaction (Figure 11.3A), height-sensing through a NFC and Microsoft Kinect (Figure 11.3B), and reaching detection (Figure 11.3C). These were chosen as touch and depth cameras are commonly used for interaction with public displays. The prototype was housed in a custom-made stand, consisting of: (1) a 50-inch touchscreen in portrait orientation; (2) a Mac Mini - running Windows 7 and the PID interface; (3) a webcam for taking selfies; and (4) a dummy Kinect for imagining automatic height detection and assisted reaching, which was mounted on top of the display.

We recruited 10 design experts (4 female) between 24 and 50 years of age as participants in a cognitive walkthrough study (Parker et al., 2017; Parker et al., 2018c). Eight participants were lecturers and tutors in design from The University of Sydney, while the other two were from industry (one web designer and one UX designer). Participants individually interacted with our experience prototype following the set task of taking a selfie in each interaction method while both standing, and sitting in an office chair to simulate the height of wheelchair users. The study followed a counterbalanced design, where each participant used the interaction methods in a different order. Each interaction method was first completed standing, followed by sitting in the mock wheelchair. Participants were asked to think aloud while they were performing the task and all sessions were audio-recorded. After completing all the interaction methods, we interviewed each of the participants, asking them about their experience and an evaluation of the four modes.

The results of the study highlighted that adjustments on PIDs should be subtle and empower the user without impacting on others and bringing attention to their physical capabilities, otherwise there is potential for social embarrassment.

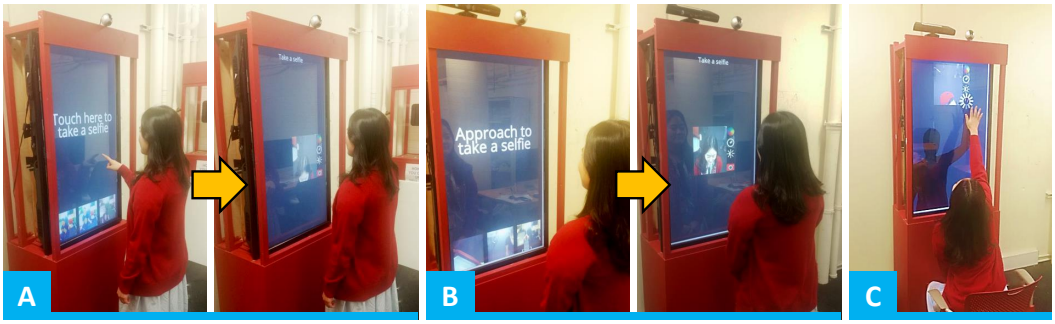

Fig. 11.3.: The height-aware public interactive display had the following height adjustment modes: (A) Touch; (B) Proximity and height sensing; and (C) Reaching detection.

11.5.4 Discussion

In the previous sections, we outlined three of our previous studies to understand how PIDs can be designed so as to be relevant to individual urban dwellers and, consequently, the communities they are located in. The studies gave us the following insights:

- PIDs need to be positioned in areas where opportunistic interactions are likely to occur, such as where people are waiting or nearby the entrance of spaces.

- Content on a PID needs to be related to what is happening in the physical space and community in which the PID is situated.
- User characteristics and current context should be taken into consideration when displaying content and presenting the interface.
- The space and context of the people within it can change over time, therefore, PIDs need to account for variability over time.

From these insights, we identify three broad factors which contribute to PIDs becoming relevant to individuals: *User*, *Locale*, and *Time*. We contextualise these factors within a model we define as the relevance triangle (Figure 11.4), where each factor represents a corner of the triangle. The aim of this model is to provide a way for designers and researchers to reflect on how relevant a PID deployment is against the three factors. These factors are explained in further detail below:

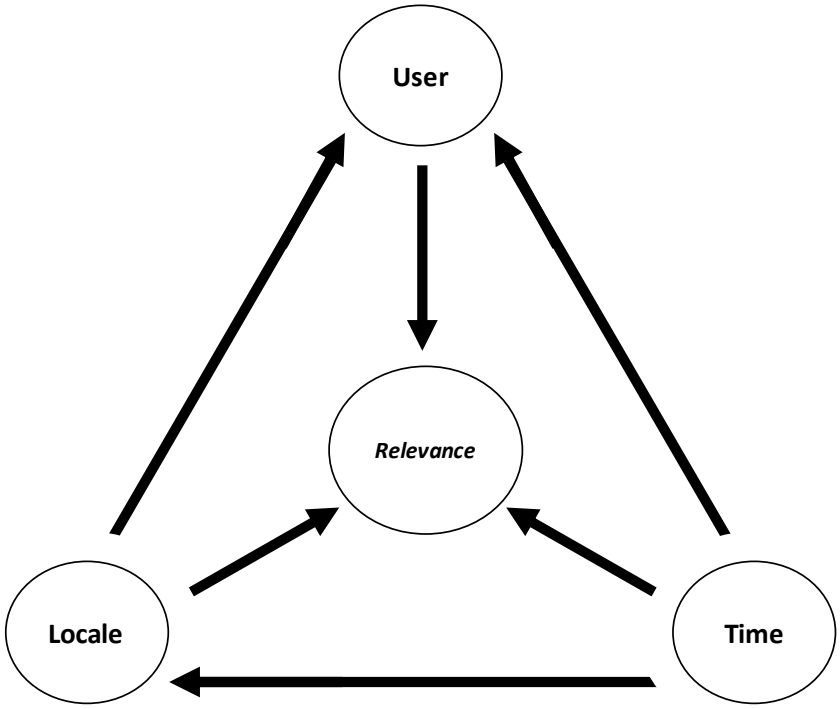

Fig. 11.4.: The relevance triangle model, where each tip refers to one of three different factors that influence the relevance of a PID to individual urban dwellers: User, Locale, and Time.

Users

Users are people that approach and interact with a PID. For a PID to be relevant to individual users, it needs to change its content based on individual differences. These differences can relate to an individual's interactions (Parker et al., 2018c),

behaviour (Wang et al., 2012; Ackad et al., 2013), interests - taken from a user profile (Davies et al., 2014; Parker et al., 2016), and by their physiological traits and characteristics, such as adapting the height of the content based on the user's height for easier reaching (Parker et al., 2017).

The *user* factor is affected by both the *locale* and *time* factors. These factors dictate the type of people present in the space (tourists, workers, etc), which changes over time.

Locale

In the context of this paper, we use the word *locale* as a general term to describe space and place, as these concepts are intertwined and affect each other (Dourish, 2006; Kukka et al., 2014). Specifically, space describes the spatial characteristics of an environment, such as the physical objects and weather (Mäkelä et al., 2017). Place on the other hand, describes the social aspects of a space, such as the people and communities within it (Moere and Wouters, 2012; Parker and Tomitsch, 2017).

The *locale* factor is also inclusive of people other than users in the space, including the paths people walk in the space in relation to the position of the PID, and the effect of passers-by spectating those that are interacting with PIDs. Additionally, the *locale* factor can affect the types of people that use the space and how those people utilise a PID.

Time

Public spaces and the people within them change throughout each day, month, and year (Moere and Wouters, 2012). For a PID to be continually relevant it should adapt over time. For instance, content could change based on the time of day or season (Parker et al., 2018c), or alternatively the PID could power down at certain off-peak times to save energy (Davies et al., 2017). Therefore, the time factor in this model refers to a temporal aspect, such as the current time, day of the week, month, or year, and the PID's reaction to it.

Time affects both the *user* and *locale* factors. In terms of the user, their goals or needs may change over the course of the day, month, year, or season - thus affecting how, and when, they need to interact with a PID. For instance, a user may not have much available time during the week as they need to work, however during the weekend they may have more time to spare (Hespanhol et al., 2015). The *locale* factor is affected as space changes over time, by such things as community-run events, shops

closing, etc.

11.6 Design Patterns

From the discussion of our previous prototypes, seven distinct but closely related design patterns emerged (Table 11.1). These patterns describe how a PID can be relevant to each of the factors defined in the relevance triangle. We set out the design patterns by adopting a similar format as Schuler (2008), Fredericks et al. (2017b), and Lyle et al. (2015). For each design pattern we present a description of the problem the design pattern addresses, the context in which the problem is placed, a discussion to ground the problem, and the solution.

Tab. 11.1.: Design patterns for PIDs that are relevant to individuals.

Theme	Design Pattern	Description
User	1. Awareness of Users' Goals	How can a PID be aware of an individual user's goals? What information is needed?
	2. Reacting to User Traits and Characteristics	How can PIDs be designed so that they can detect and react accordingly to individual users and their specific physiological traits and characteristics?
	3. Privacy and Relevance Trade-offs	Relevance often comes at the cost of privacy, while privacy comes at the cost of relevance. How can these two factors be managed? Furthermore, when should a trade-off be acceptable?
	4. Complementing Smartphone Usage	People in today's society are becoming increasingly hyperconnected through the use personal devices, such as smartphones and smart watches, enabling them to have ubiquitous access to digital information from the internet in any location. Therefore, how does a PID remain relevant to individuals in such societies?
Locale	5. Physical Placement	PIDs can often end up being ignored by urban dwellers due to poor positioning. Therefore, how can the ideal physical placement of a PID be determined?
	6. Awareness of the Community	Communities shape the places and spaces PIDs are deployed in. Therefore, how can PIDs become aware of the community they are situated in and collect up-to-date information about it?
Time	7. Changes Over Time	Certain content may only be relevant at certain times during the day, month, year, or season. Therefore, how should PIDs change over time?

11.6.1 User

Pattern 1: Awareness of Users' Goals

Problem
How can a PID be aware of an individual user's goals? What information is needed?

Context
Individuals in public space all have different goals which change over time. For example, a user's goal could be as simple as walking to the shop to buy milk. Therefore, it is important that PIDs become aware of an individual user's goals, as this can enable the PID to make judgements regarding the type of information that an individual user would be currently interested in.

Discussion
We explored the design of three prototype PIDs (A, B, and C) to test two different approaches for making a PID aware of a user's goals: profile-based and device-free. The profile-based approach implemented in prototype A required the user to connect to a public display through a smartphone app with a pre-filled user profile. The display would then determine the content that would be of interest to an individual, based on their interests and demographic information. The problem with this method is that it may not always be related to a user's current goal and may end up displaying content that is too personal. The other approach, device-free - utilised by both prototypes B and C, tracked a user's explicit interactions and characteristics to recommend content they might be interested in. While this approach does not have detailed information about a user, it can be used to determine the user's current goals, so that this approach has little impact on a user's privacy and less of a barrier for entry as no external devices are required. For instance, prototype B detected a user's goal by their interactions as, depending on the suburb selected, it would implicitly recommend places to visit. On the other hand, prototype C could implicitly detect a user's goals with its reaching mode, where it could detect if the user was trying to reach for an element on-screen and provide assistance with selecting it through an extended "shadow arm".

Solution
Designing a PID that is aware of user goals, and ideally their current goals, should be achieved in a way that includes all potential users. Detection of a user's goals does

not necessarily require detailed information about the user from a profile, much of the information can be implicitly gathered from their interactions, behaviour, and physiological traits and characteristics. By designing PIDs in this way, it ensures that PIDs are open to a broad demographic of potential users, which is inherently what the word 'public' entails.

Pattern 2: Reacting to User Characteristics

Problem
How can PIDs be designed so that they can detect and react accordingly to individual users and their specific physiological traits and characteristics?

Context
Urban environments can have a broad range of people passing through them and are therefore usually designed with affordances built-in to allow everyone access (Clarkson et al., 2013; Evans, 2014). For instance, pedestrian crossing gutter ramps that allow prams and wheelchairs easier and safer passage over gutters while still being accessible to everyone else. Similarly, PIDs need to respond to the unique characteristics of individuals, such as their height, to enable a broader demographic to interact with them.

Discussion
This pattern leads on from the previous one by discussing another aspect relating to the user - their physiological traits and characteristics. To tackle the problem of PIDs responding to different user characteristics, we tested Prototype C - a PID that responds to the height of the user through four different height-aware modes. The main finding from our study that tested Prototype C suggested that height adjustments should be only made to the interface, drawing less attention than hardware adjustments, which could potentially result in social embarrassment for the user. Additionally, another finding from our study on Prototype C indicated that PIDs should avoid using external personal devices or cards to identify users and instead rely on implicit methods, like cameras and interactions.

Solution
PIDs need to be aware of and respond to the physical needs of users. This is becoming increasingly important as screens become larger (Parker et al., 2018d). The

adjustments in response to the physical characteristics of the user need to be subtle, yet empowering, to ensure that attention is not drawn to an individual's physical capabilities. PIDs should also be designed so they implicitly adjust to individual users and this adjustment should be accessible to a broad demographic - covering people of different capabilities.

Pattern 3: Privacy and Relevance Trade-offs

Problem

Relevance often comes at the cost of privacy, while privacy comes at the cost of relevance. How can these two factors be managed? Furthermore, when should a trade-off be acceptable?

Context

This problem applies to patterns 1 and 2, both of which require knowledge about certain aspects of individual users. While it is important to ensure PIDs are relevant to individuals, PIDs need also to be aware of privacy requirements to ensure the PID is not negatively impacting a user's privacy.

Discussion

From our previous studies of the three prototypes (A, B, and C), we found that privacy requirements amongst individuals can differ and change based on certain contexts. For instance, in the case of prototype B, one of the participants mentioned that for the most part they were fine with the content displayed, however, if they were alone at night and they used the PID to find the next bus to their home suburb, they would be concerned about others seeing this information. Other participants commented that the information they give a PID would depend on how legitimate it looked and whether it was from a well known company. Participants that trialled prototype C commented that adjustments to the PID should be subtle and not draw attention to the user.

The prototype PIDs (A and B) both approached making content relevant to individuals differently. Prototype A used a profile-based approach, where it adjusted its content based on user profiles that were transmitted over a smartphone to the PID. Prototype B demonstrated an alternative device-free approach using only the explicit actions of the user to determine their interests and adjust the content accordingly. Both the profile-based and device-free approaches came with their own pros

and cons. For instance, user profiles allow the PID to potentially have access to a broader amount of information about the user, both current and historical. However, this approach has implications for the user's privacy in terms of transferring the information (man in the middle attacks (Sethi et al., 2014)). Additionally, the PID's interpretation of that data and the resulting personalised content displayed may link the user to the PID and show information that the user deems private. The device-free approach on the other hand, utilises a user's explicit interactions to determine what they would potentially be interested in, causing this approach to have less of an impact on their privacy. Despite this, the device-free approach can be limited in that it may not always have a lot of data about the user to draw from, thus limiting inferences the PID can make about the user's interests.

Solution

Designing a PID that is relevant to individual users is a socially complex challenge. The more relevant a PID is to an individual, the less private the experience becomes - which may not be desired in certain contexts, such as busy spaces. Therefore, trade-offs need to be made, with compromises about both the user's privacy preferences and their relevance expectations. An individual's privacy preferences can potentially be discerned from the type of context and the people around them. For instance, a PID in a busy space, such as a shopping centre, should avoid displaying content that specifically identifies where a user lives or their private interests, as it is more likely that there will be onlookers.

An alternative is to explore methods to block onlookers, such as blacking out parts of the screen the user is not looking at (Brudy et al., 2014) or through mobile augmented reality (Baldauf et al., 2012a; Parker et al., 2016). While these methods show potential, more work is needed to test their effectiveness in different real-world contexts, such as busy spaces and different social situations, for example groups of users.

Pattern 4: Complementing Smartphone Usage

Problem

People in today's society are becoming increasingly hyperconnected through the use personal devices, such as smartphones and smart watches, enabling them to have ubiquitous access to digital information from the internet in any location. Therefore, how does a PID remain relevant to individuals in such societies?

Context
The problem of hyperconnectedness primarily applies to countries with a high technology adoption rate[1], such as Australia, Germany, Finland, USA, China, Japan, and South Korea. This pattern highlights the need for PIDs to complement personal devices.

Discussion
Participants from our study of prototype B, a transit PID that implicitly recommended places to visit based on the suburb selected, found that the displayed information was not very relevant to them as they could already find it on their smartphones. Despite this, participants mentioned that the PID might be more relevant than a smartphone in certain contexts, such as in situations where someone is rushing to get somewhere (such as people about to miss their train) as then it might be faster to use the PID than to check their smartphone. Therefore, it is not only important that a PID displays information that cannot be viewed on a smartphone, but it is also imperative that a PID is conveniently located so that it is in the right place at the right time - which is related to pattern 5 in the Locale section.

Solution
Firstly, the content on PIDs needs to be distinct from information that can be accessed on a smartphone. Secondly, PIDs need to be quick and easy to use, so that it is faster to access information on PIDs rather than smartphones. This can be achieved by making clean interfaces that do not require much effort or time to view the desired information. Finally, PIDs need to be positioned so they are conveniently accessible - which links to pattern 5 in the locale section.

11.6.2 Locale

Pattern 5: Physical Placement

Problem
PIDs can often end up being ignored by urban dwellers due to poor positioning. Therefore, how can the ideal physical placement of a PID be determined?

[1] Smartphone ownership worldwide - `https://www.recode.net/2017/10/16/16482168/two-thirds-of-adults-worldwide-will-own-smartphones-next-year`

Context

This pattern can be used to inform the ideal positioning of PIDs and public displays.

Discussion

PID providers need to carefully consider the placement of a PID, aligned with their objectives, and how the physical space is used. Despite the requirement that ensuring PIDs are positioned in a location that gets a lot of traffic being common knowledge in the public display research community (J. R. Williamson and J. Williamson, 2014; E. Huang et al., 2008; Wouters et al., 2016), it is not always followed in practice (Parker et al., 2018d).

Solution

Before deciding on the placement of PIDs, it is important to first survey and observe the space in which the PID will be deployed to see how urban dwellers use that space and move through it. Therefore, the choice of a PID's location should take into consideration the permeability of the space and how this changes over time (Figure 11.5). Additionally, PIDs should be positioned where there is a high likelihood of opportunistic interactions, such as nearby the entrance to the space or in an area where people are waiting, such as near café lines or escalators.

Fig. 11.5.: Positioning a PID nearby the entrance to a space while considering the main paths people take.

Pattern 6: Awareness of the Community

Problem

Communities shape the places and spaces PIDs are deployed in. Therefore, how can PIDs become aware of the community they are situated in and collect up-to-date information about it?

Context

A challenge for PIDs is becoming integrated within the respective communities and gaining relevant information about them, such as local events being held and the demographics of the people that make up the communities. This pattern can be used to inform the design of PIDs that are more attuned to the people within the communities the PID is situated in.

Discussion

From reflecting on our first two prototypes, A and B, it appears that while we had good intentions of making PIDs relevant to individuals, the prototypes lacked a connection to the communities they were situated in, resulting in content that was not always of relevance. Other research has shown that giving citizens control over the content on PIDs can be an effective way to keep content relevant and give people in communities an accessible platform to reach out to one another. For instance, work by Alt et al. (2011) and Schroeter and Foth (2009) tested PIDs that allowed people to post content to them. The content could then be read by other users. What these examples show is that PIDs appropriated by their respective local communities can collect current, natural, and in-depth information about their communities.

Solution

To increase the relevance of a PID and expand the data it can pull from, it needs to be strongly connected to the local communities within the location in which it is situated. Giving members of communities some control enables PIDs to have greater knowledge of the community, giving them a greater pool of data to draw from when tailoring content to individuals, and empowering the people within it. To achieve this, researchers and practitioners could follow a co-design approach (Tomitsch et al., 2018), where stakeholders are actively involved in all stages of the design and development. In the case of PID deployments, co-design needs to be a continuing process before and after the PID is implemented and deployed - this process is referred as "*middle-out design*" (Fredericks et al., 2016a).

11.6.3 Time

Pattern 7: Changes Over Time

Problem
Certain content may only be relevant at certain times during the day, month, year, or season. Therefore, how should PIDs change over time?

Context
Time is an underlying factor that affects the other patterns. Therefore, it is important to understand the impact of time on the physical space and place, the people that use the space, and the community (Parker and Tomitsch, 2017; Moere and Wouters, 2012).

Discussion
Despite the importance of factoring in the time when displaying content, PIDs in the wild generally do not change over time (Parker et al., 2018d). We tested the relevance of changes over time with prototype B. This PID displayed bus times and recommended places of interest that were open at the particular time it was being interacted with. This meant that the PID was always up-to-date and allowed users to access the information at any time. However, the participants that we interviewed during this study mentioned that they would like to have the ability to see content related to things happening in the future, such as events. The reason for this is that users might might already have a set goal or plans in mind. Therefore, it is important for PIDs to have temporal flexibility, where current and future information can be accessed.

Solution
While showing current up-to-date information can be of relevance to people, it is also important for PIDs to have temporal flexibility, where current and future information can be accessed.

Additionally, PIDs need to be aware of a user's time, and adapt according to the time constraints the user has - for instance, if the user needs to be somewhere in a hurry, the PID should optimise speed and present quick snippets of information. Conversely, users with time to spare, such as a traveller or retiree, can probably spend more time with the PID and take in more information.

11.7 Conclusion

In this article we outlined seven design patterns, across three categories, which can be used to guide the design, development, and implementation of PIDs. The patterns were designed to address specific problems and challenges arising from research and those that we encountered during our own deployments. The focus of this work is to provide a set of design patterns to be used as a reference for designers of PIDs in the future. The development of these design patterns contribute to the pervasive displays community by creating a foundation for the design of relevance-driven PIDs and highlights the importance of doing so. As the field is constantly changing due to advances in technology and new methods, these patterns are intended to be dynamic, where they can be continually updated based on these changes.

One of the key insights from this work is in the importance of considering the broader community when creating relevance-driven PIDs. A community can help PIDs become aware of the demographics and needs of people that use the space, and can be a great source of current information that can be displayed to individual users.

Part V

Conclusions

Conclusions 12

12.1 Addressing the Research Questions

In Section 1.2, the core research questions investigated by this research were introduced. The research questions are presented again as separate sections, where the key contributions linked to each research question are outlined and discussed. Table 12.1, which first appeared in section 3.2, outlines the chapters according to the research questions they addressed and the contributions for each research question. The table is updated to also include the answers for each question.

Tab. 12.1.: The research questions, the chapters that address them, and their resulting contributions.

Research Questions (RQ)	Chapters	Contributions	Answers
RQ1 - What is the role of a public interactive display in a hyperconnected society?	4, 5, 6	• Contemporary knowledge of how non-research public interactive displays are used in the wild.	• Public interactive displays need to be a complementary and convenient technology
RQ2 - What are the challenges with making public interactive displays relevant to individuals? And how can they be overcome?	4, 5, 6, 7, 8, 9	• Insights into mitigating privacy concerns when making public interactive displays relevant to individuals. • The factors that drive people to use public interactive displays. • Understanding and overcoming common problems that occur on public interactive displays.	• An individual's privacy and relevance requirements are subjective and change with context • The interaction gulf between users and public interactive displays can be bridged • Public interactive displays need to be adaptive to failure
RQ3 - What factors influence the relevance of a public interactive display to individuals?	7, 8, 9, 10	• The relevance triangle and design patterns for creating relevant public interactive displays for individuals	• The Factors of the Relevance Triangle

12.1.1 Research Question 1: *What is the role of a public interactive display in a hyperconnected society?*

Public interactive displays need to be designed towards being a complementary and convenient technology

- In the wild, public interactive displays are primarily utilised for either displaying advertising or providing general information about an area.

- The role of a public interactive display is affected by smartphone usage, therefore public interactive displays need to display information that complements smartphones and become faster to access.
- Public interactive displays need to be positioned in relation to the permeability of the space so that the chances of gaining opportunistic interactions are increased.
- The purpose of a PID needs to be made clear to passers-by through physical or on-screen signage.

The field observation study of non-research public displays detailed in **Chapter 4** found that the public displays observed were either used for advertising or as information directories. The content was observed to be often quite general and was not specific to any individual. The results from this field observation showed that, for the most part, the insights into public displays provided by E. Huang et al. (2008) still hold. However, we found that there are some differences and new insights that have emerged since their study.

The main PID specific finding is related to the positioning and presentation of PIDs. Firstly, PIDs need to be positioned nearby the main paths within a space, which can be found by observing the permeability of the space over time. While this finding is already well known within the pervasive displays community (J. R. Williamson and J. Williamson, 2014), it appears that it has not yet been picked up in practice (Parker et al., 2018d). Secondly, PIDs should be presented so they stand out and assist passers-by to understand their purpose, through either physical signage or on-screen indicators.

Our study, detailed in **chapters 5** and **10**, revealed that generally, smartphone users did not find the transit and recommended content displayed on prototype B relevant. However, their feedback revealed that in certain contexts a PID might be relevant to them, such as in time critical situations a PID might be faster to access than a smartphone. There are also the cases where a PID might display information not available on a smartphone, such as indoor route maps (such as in shopping centres) and specific information about a local community. Furthermore, large public displays are generally noticed a significant amount even by smartphone users, making large public displays particularly well suited to displaying certain content on a more usable scale than smartphones. This might be useful in collaborative contexts, such as games (Mayer et al., 2018; Müller et al., 2012), planning (Mahyar et al., 2016), digital

placemaking (Schroeter and Foth, 2009), and community engagement (Hespanhol et al., 2015; Fredericks et al., 2017a).

12.1.2 Research Question 2: *What are the challenges with making public interactive displays relevant to individuals? And how can they be overcome?*

An individual's privacy and relevance requirements are subjective and change with context

- An individual's privacy requirements in public space are subjective and variable.
- The challenge of privacy can potentially be overcome with trade-offs between an individual's privacy and relevance requirements, influenced by the context of the of the situation, space, and place.

The core challenge with creating PIDs that are relevant to individuals is that doing so can potentially raise privacy concerns, as the user may not desire their personalised content to be shown in public as it may identify them (Davies et al., 2014; Memarovic and Langheinrich, 2010). To overcome privacy challenges, we built on previous work by Baldauf et al. (2012a) that investigated the privacy of mobile augmented reality (MAR) controlled public displays. In our work we developed Prototype A, a MAR application that provided a personalised view of a public display. We found in the study with this prototype (**Chapter 8**) that while it provided users with a private view of content relevant to their interests on a public display, the content was not always relevant to the user's current context or needs. Additionally, such a system would not be fully inclusive, as it would require users to have a smartphone for the personalisation to work. We also found in this study that holding up a smartphone in public can also be socially awkward and disturbs the flow of people moving through the space. Until augmented reality becomes fully integrated into widely owned consumer devices, handheld MAR may not be the most ideal method.

Bearing in mind the limitations of external personal devices, we decided to explore a more implicit approach without external devices for personalisation. We developed prototype B, which utilised the explicit interactions from a user to implicitly determine their interests. Participants mostly had no concerns about privacy. However, participants raised that the PID could reveal where someone was going, which could be an issue, especially in contexts where the person is alone.

Therefore, Pattern 3 from **Chapter 10** suggests that trade-offs need to be made between an individual's privacy preferences and their relevance requirements. The trade-off may lean more on a particular side depending on the context - for instance, a PID in a busy space should prioritise privacy over relevance.

The interaction gulf between users and public interactive displays can be bridged

- Three factors that have an effect on the utilisation of PIDs are: Position, Content, and Function.

In **Chapter 5**, we further analysed the results of the field observation detailed in **chapter 4** by contrasting the observation results with the results from a field study focusing on Prototype B. The findings from this study outlined three factors that impel passers-by to becoming active participants with a PID: position, content, and function; which are synthesized into key points below.

Position

- Ensure PIDs are eye-level for everyone - this may require implicit sensing on the PID to automatically adjust the on-screen interface and content to allow people of different heights to interact.
- The PID should be positioned near the entrance to a space and in the main path people take, so as to increase the chance of opportunistic interactions occurring.
- The PID should be oriented so that it faces people entering the space.

Content

- The content shown on PIDs should complement the content available on smartphones by providing supplementary information that cannot be easily or quickly accessed using a smartphone.
- Dictation on what content should be shown on PIDs should relate to the space and place the PID is situated in and how that space and place changes over time.

Function

- PIDs should be responsive and quick to use for time-poor citizens.

- The functionality and purpose of a PID needs to be made clear through either information on-screen or through external signage on or around the PID's enclosure.
- The PID should be able to adapt to the characteristics of individual users, such as people that are wheelchair-bound, and their context, including considering the task the user might be performing at that time - for example shopping.

Public interactive displays need to be adaptive to failure

- PIDs, like all digital technologies, can experience failures related to the hardware, software, and interaction.
- A PID is no longer relevant if it is inoperable or does not function as expected, therefore it is important to create PIDs that are adaptive to certain types of failures.

During the field observations of non-research public displays, detailed in **chapter 4**, we observed that some PIDs had noticeable failures that on occasion exposed them to security issues, such as an operating system update window popping up over the interface or interaction methods that did not work. We contextualised these observed failures into a failure matrix, where a failure was either partial or complete. A partial or complete failure can be in relation to the PID's hardware, software, and interaction. Therefore, it is important that providers of PIDs carefully evaluate the types of failures that can occur with the hardware, software, and interactions. It is also important that PID providers ensure that they have appropriate redundancies or mitigation strategies in place to avoid security issues and soften potential failures to reduce their impact. By implementing the strategies defined in **chapter 4**, a PID can continue to provide value despite experiencing most forms of failure.

12.1.3 Research Question 3: *What factors influence the relevance of a public interactive display to individuals?*

The Factors of the Relevance Triangle

- The relevance of a public interactive display towards individuals is influenced by three factors that make up the relevance triangle: User, Locale, and Time.

Chapter 11 draws on previous work by Schuler (2008) and Fredericks et al. (2017b) by synthesising the results from our previous prototype studies (A, B, and C),

detailed in **Chapters 8, 9,** and **10**. From this synthesis, we present a set of design patterns that outline the core problems with making PIDs relevant to individuals and the solutions to them, based on our previous work and research from the pervasive displays community. These patterns are organised by three main factors that influence relevance: User, Locale, and Time. These factors make up the three corners of the relevance triangle and are detailed below.

- *User* - refers to people that interact with a PID and their differentiating physiological characteristics and traits, behaviour, goals, and interests.
- *Locale* - describes the physical space and place, inclusive of the people and things within it.
- *Time* - affects the previous two factors as the needs and goals of a user can change over time. The locale is also affected as the time influences the people within the space, due to working hours, business trading hours, holidays, and seasons.

In summary, a PID needs to be aware of its users' needs and their individual characteristics, the locale - encompassing space and place, and how these factors change over time.

12.2 Evaluation of the Research

This research reported on the findings from a series of studies, conducted as either field observations, field studies, or lab studies. All of these studies, from **parts II** to **IV**, had the focus of understanding the current role of PIDs and how they can be designed so they are relevant to individuals and communities.

As set out in **Chapter 3**, the research in this doctoral thesis followed a research through design approach, utilising action research for the iterative cycles. Each study explored a set of design parameters or problem that generated insights to inform later cycles and the overall research.

In this section, the overall research is reflected upon using questions defined by Zimmerman et al. (2007). These questions are discussed and answered in the sections below.

12.2.1 Process – How well were the methods utilised and was there enough detail to reproduce the process?

In total, three different types of studies were conducted, each exploring a particular aspect of PIDs and their relevance to individuals.

Field observation
For this study (detailed in **chapters 4, 5,** and **6**), we specifically focused on the space the PIDs were deployed in, how each PID was designed, the space and how it changed over time, types of passers-by and their behaviours, and whether people interacted with the PIDs. We decided to not take video or interview people so as to ensure the study was ecologically valid. Instead we took photos, drew sketches, wrote notes, and counted the common behaviours from people walking by each PID. These methods enabled us to gain insights into how the PIDs are currently used and how their usage changes depending on the space they are deployed in and the time. While these methods enabled us to collect ecologically valid data, they were limited in that it could often be hard to tell whether an individual was looking at the PID or something else in the space. However, to overcome this it would have required us to make people wear eye-trackers (N. S. Dalton et al., 2015), or install cameras on the PIDs, which was not feasible as these PIDs were not ours.

Lab Study
In this study, we tested prototype C within our lab at the University of Sydney with pre-recruited participants that were experts in user experience design from both academia and industry. During the study we audio recorded participants, as they were asked to think aloud while they interacted with the prototype. We also interviewed each participant to gain feedback on specific parts of the prototype.

Field Study
We ran two field studies, with prototypes A and B respectively. These studies enabled us to gain more insights into two different personalisation approaches: profile-based and device-free. The first study with prototype A was conducted indoors within a public university cafeteria area with recruited participants, while the second study with prototype B was conducted indoors, next to the main entrance of a university building and, with the researcher asking members of the public to participate in an interview after they finished using the PID. The methods used to collect data from participants in both studies were similar, as recorded interviews were used to ask participants about their experience. In the second study, we also collected the number of times people interacted with the PID throughout a week, 24 hours a day, through log files.

12.2.2 Invention – How does the research contribute to the work already in the research community?

Insights into designing relevant public interactive displays
We explored three methods for using personalisation to make PIDs relevant. Having synthesised the findings of these studies, we outline 7 design patterns for making PIDs that are relevant to individuals based on the user, the locale, and the current time. These patterns address the research gap that was identified in **Chapter 2**, **Section 2.5** by finding the core problems that need to be solved in order to address the gap and presenting potential solutions to these problems based upon knowledge gained from our previous studies and research from the broader pervasive displays community.

An updated understanding of non-research public displays in the wild
Since E. Huang et al. (2008) observations of non-research public displays in 2008, little work has observed public displays in the wild to identify changes. Therefore, we conducted a field observation in Sydney, Australia to gain an updated understanding of PIDs and public displays in the wild - which is detailed in **Chapter 4**. This work made the following contributions:

- Since the study by E. Huang et al. (2008), public displays have become more diversified and ubiquitous.
- The effectiveness of PIDs at attracting users is affected by elements around the display, its position and location, relevance of the content displayed to individuals, and smartphone usage.
- There are opportunities for integrating PIDs into hyperconnected societies by considering their purpose in relation to personal devices, such as smartphones.

12.2.3 Relevance – How is the work relevant and what is the motivation for it?

People in public space are more connected than ever before, through personal technologies, like smartphones. However, if people have ready access to information, what does this mean for PIDs, the purpose of which is to bring digital content into public spaces? Therefore, in this research, we explored the current state of PIDs in the wild (**Chapter 4**) and then designed, developed, and tested three PID prototypes (A, B, and C) to gain a better understanding of how PIDs can be designed to be

relevant towards individuals. This research is relevant in that it provides new and updated insights into PID usage in hyperconnected societies, focusing on what type of information is relevant to individuals and how this information should be accessed within cities.

12.2.4 Extensibility – How can this research be useful for future work in this field?

This doctoral thesis informs future work in the field of pervasive displays in general through a grounded understanding of the current state of public displays in the wild. The thesis also provides a broad understanding of how PIDs can be made relevant to individuals and synthesises this knowledge into a set of design patterns, which can be utilised by researchers and practitioners in the future. The patterns are extensible enough to be built on as technology and research progresses over time.

12.3 Final Reflections

This PhD research covered a broad range of aspects and contributed recommendations and insights into how PIDs can be designed so they are relevant to individuals while also identifying key challenges in doing so. At the same time, further work is needed to gain in-depth insights into the specific aspects of PIDs discussed in this thesis, such as adaptation, personalisation, and privacy. Additionally, the PID deployments featured in this work were all tested over a short period of time. It would be interesting for future work to expand on these and to particularly focus on evaluating the relevance triangle introduced in **Chapter 11** with longer-term PID deployments in varying contexts, such as different cities and countries. Through a replication of the studies in this thesis there is a potential to build towards a practitioner and research community-driven knowledge base of PIDs that could inform international standards relating to the design of PIDs in the future.

12.4 The Way Ahead

Digital technology is improving at a rapid pace and is gradually augmenting spaces within cities. With this, the form of a public display is gradually changing. This is evident from the expanding research on drone displays (Schneegass et al., 2014;

Brock et al., 2018), digital projections (Colley et al., 2018; Hespanhol, 2016), and augmented reality (Parker et al., 2016; Parker and Tomitsch, 2014; G. A. Lee et al., 2012). As technology becomes more accessible and affordable, these types of displays may become a common sight within future cities and no longer a concept commonly only depicted in sci-fi movies and video games. Additionally, the rise of personal devices has caused people to operate within their own media bubbles, only seeing content relevant to them. For example, Keiichi Matsuda[1] shows a future where AR melds digital content such as advertisements and other information into the periphery of ordinary people in a usable and socially acceptable form factor. This vision of holograms and digital content in public space that responds to a user's presence already has the foundations to become a reality. There are also opportunities for the content on public displays to become richer, harnessing big data from the cities they are deployed in. The research in this doctoral thesis has broader implications to the design of these future technologies as it is important they are relevant to individuals and can improve their experience and lives within future cities.

In summary, research on PIDs and public displays in general is still a growing field. However, it is becoming increasingly apparent that there is a major competition for attention between PIDs and the array of personal devices that individuals possess. Therefore, designers and developers need to continue developing and refining PIDs as technology progresses while also constantly re-evaluating the purpose of PIDs. This thesis has laid down multiple frameworks and approaches for this purpose which can be further expanded on and adjusted as PIDs and research progresses in the future.

[1]Hyper-Reality by Keiichi Matsuda - `https://www.youtube.com/watch?v=YJg02ivYzSs`

Terminology

13

13.1 Terminology

Public Display
In the context of this thesis, our definition of a public display has been informed by work within the human-computer interaction (HCI) and pervasive display communities. We define a public display as a term that covers all forms of digital signage that are deployed within an urban or public setting, such as within shopping centres, airports, and universities. This term encompasses known display types that frequently appear in pervasive display literature; like media facades, information displays, and public interactive displays.

Public Interactive Display (PID)
Public displays that accept a form of input, such as touchscreens and mid-air gestures enabled through the Microsoft Kinect. The PID terminology is not inclusive of smaller mundane public technologies (Henderson and Leong, 2017), such as ATMs and parking meters.

Citizen
The term citizen refers to people that reside in cities, suburbia, and rural areas. This term does not include visitors and tourists.

Urban Dweller
This term is more inclusive than citizen, as it refers to all types of people, such as visitors and tourists.

Hyperconnected
This term describes the observation of society becoming increasingly connected and dependant on digital technology and information.

Community
A community is a group of people who share and reside in the same locality. It can also refer to groups of people that share a common culture, heritage, or interest. Communities can also be formed online such as on message boards, Reddit, Facebook groups, etc.

Public Space

The term public space applies to a physical space that is freely available and accessible to everyone. This can include libraries, town squares, parks, playgrounds, etc.

Augmented Reality

A method in which to visualise and interact with digital content in the real-world. Usually this technology requires fiducial markers to enable it to appropriately position content in the real-world. Recent technological advances however, have enabled augmented reality to blend into the physical space without the need for markers, allowing for more advanced applications of this technology.

Mobile Augmented Reality

This is a form of augmented reality that runs on smartphones and tablets. In recent years, particularly since the advent of Pokémon Go, people are more aware of mobile augmented reality. Additionally, companies such as Google and Apple have been increasing their investment into the technology and incorporating it into their respective mobile operating systems (Android and iOS).

Bibliography

Gregory D Abowd, Anind K Dey, Peter J Brown, Nigel Davies, Mark Smith, and Pete Steggles (1999). 'Towards a better understanding of context and context-awareness'. In: *International Symposium on Handheld and Ubiquitous Computing*. Springer, pp. 304–307 (cit. on p. 63).

Christopher Ackad, Martin Tomitsch, and Judy Kay (2016). 'Skeletons and Silhouettes: Comparing User Representations at a Gesture-based Large Display'. In: *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. ACM, pp. 2343–2347 (cit. on pp. 27, 39, 42, 123, 143).

Christopher Ackad, Rainer Wasinger, Richard Gluga, Judy Kay, and Martin Tomitsch (2013). 'Measuring interactivity at an interactive public information display'. In: *Proceedings of the 25th Australian Computer-Human Interaction Conference: Augmentation, Application, Innovation, Collaboration*. ACM, pp. 329–332 (cit. on pp. 95, 97, 160).

Christopher Alexander (1977). *A pattern language: towns, buildings, construction*. Oxford university press (cit. on p. 153).

– (1979). *The timeless way of building*. Vol. 1. New York: Oxford University Press (cit. on p. 153).

Stefano Alletto, Rita Cucchiara, Giuseppe Del Fiore, Luca Mainetti, Vincenzo Mighali, Luigi Patrono, and Giuseppe Serra (2016). 'An indoor location-aware system for an IoT-based smart museum'. In: *IEEE Internet of Things Journal* 3.2, pp. 244–253 (cit. on p. 64).

Florian Alt, Thomas Kubitza, Dominik Bial, Firas Zaidan, Markus Ortel, Björn Zurmaar, Tim Lewen, Alireza Sahami Shirazi, and Albrecht Schmidt (2011). 'Digifieds: insights into deploying digital public notice areas in the wild'. In: *Proceedings of the 10th International Conference on Mobile and Ubiquitous Multimedia*. ACM, pp. 165–174 (cit. on pp. 19, 24, 39, 43, 45, 67, 81, 95, 97, 99, 103, 107, 115, 129, 147, 150, 168).

Florian Alt, Jorg Muller, and Albrecht Schmidt (2012a). 'Advertising on public display networks'. In: *Computer* 45.5, pp. 50–56 (cit. on p. 12).

Florian Alt, Stefan Schneegaß, Albrecht Schmidt, Jörg Müller, and Nemanja Memarovic (2012b). 'How to evaluate public displays'. In: *Proceedings of the 2012 International Symposium on Pervasive Displays*. ACM, p. 17 (cit. on pp. 32, 39, 48, 84).

Florian Alt, Alireza Sahami Shirazi, Thomas Kubitza, and Albrecht Schmidt (2013). 'Interaction techniques for creating and exchanging content with public displays'. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, pp. 1709–1718 (cit. on pp. 23, 45).

Matthias Baldauf, Peter Fröhlich, Jasmin Buchta, and Theresa Stürmer (2013). 'From touchpad to smart lens: A comparative study on smartphone interaction with public displays'. In: *International Journal of Mobile Human Computer Interaction (IJMHCI)* 5.2, pp. 1–20 (cit. on p. 106).

Matthias Baldauf, Katrin Lasinger, and Peter Fröhlich (2012a). 'Private public screens: detached multi-user interaction with large displays through mobile augmented reality'. In: *Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia*. ACM, p. 27 (cit. on pp. 95, 99, 100, 104–107, 131, 165, 174).

– (2012b). 'Real-world drag'n'drop-bidirectional camera-based media transfer between smartphones and large displays'. In: *Proc. International Conference on Pervasive Computing, Newcastle, UK* (cit. on pp. 20, 67, 99, 100).

Matthias Baldauf, Stefan Suette, Peter Fröhlich, and Ulrich Lehner (2014). 'Interactive opinion polls on public displays: studying privacy requirements in the wild'. In: *Proceedings of the 16th international conference on Human-computer interaction with mobile devices & services*. ACM, pp. 495–500 (cit. on pp. 20, 43, 103, 105, 129).

Rafael Ballagas, Michael Rohs, and Jennifer G Sheridan (2005). 'Sweep and point and shoot: phonecam-based interactions for large public displays'. In: *CHI'05 extended abstracts on Human factors in computing systems*. ACM, pp. 1200–1203 (cit. on p. 106).

Till Ballendat, Nicolai Marquardt, and Saul Greenberg (2010). 'Proxemic interaction: designing for a proximity and orientation-aware environment'. In: *ACM International Conference on Interactive Tabletops and Surfaces*. ACM, pp. 121–130 (cit. on p. 63).

Christine Bauer, Paul Dohmen, and Christine Strauss (2011). 'Interactive digital signage-an innovative service and its future strategies'. In: *Emerging Intelligent Data and Web Technologies (EIDWT), 2011 International Conference on*. IEEE, pp. 137–142 (cit. on pp. 23, 45).

Moritz Behrens, Nina Valkanova, Duncan P Brumby, et al. (2014). 'Smart citizen sentiment dashboard: A case study into media architectural interfaces'. In: *Proceedings of The International Symposium on Pervasive Displays*. ACM, p. 19 (cit. on p. 150).

Anabela Berenguer, Jorge Goncalves, Simo Hosio, Denzil Ferreira, Theodoros Anagnostopoulos, and Vassilis Kostakos (2017). 'Are Smartphones Ubiquitous?: An in-depth survey of smartphone adoption by seniors'. In: *IEEE Consumer Electronics Magazine* 6.1, pp. 104–110 (cit. on p. 148).

Gilbert Beyer, Vincent Binder, Nina Jäger, and Andreas Butz (2014). 'The puppeteer display: attracting and actively shaping the audience with an interactive public banner display'. In: *Proceedings of the 2014 conference on Designing interactive systems*. ACM, pp. 935–944 (cit. on p. 42).

Courtney Blackwell, Jeremy Birnholtz, and Charles Abbott (2015). 'Seeing and being seen: Co-situation and impression formation using Grindr, a location-aware gay dating app'. In: *New media & society* 17.7, pp. 1117–1136 (cit. on p. 64).

Sebastian Boring, Dominikus Baur, Andreas Butz, Sean Gustafson, and Patrick Baudisch (2010). 'Touch projector: mobile interaction through video'. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, pp. 2287–2296 (cit. on pp. 106, 113).

Harry Brignull and Yvonne Rogers (2003). 'Enticing people to interact with large public displays in public spaces'. In: *Proceedings of INTERACT*. Vol. 3, pp. 17–24 (cit. on pp. 39, 42, 96, 124).

Anke M Brock, Julia Chatain, Michelle Park, Tommy Fang, Martin Hachet, James A Landay, and Jessica R Cauchard (2018). 'FlyMap: Interacting with Maps Projected from a Drone'. In: *Proceedings of the 7th ACM International Symposium on Pervasive Displays*. ACM, p. 13 (cit. on p. 181).

Frederik Brudy, David Ledo, Saul Greenberg, and Andreas Butz (2014). 'Is Anyone Looking? Mitigating Shoulder Surfing on Public Displays through Awareness and Protection'. In: *Proceedings of The International Symposium on Pervasive Displays*. ACM, p. 1 (cit. on pp. 24, 27, 78, 105, 139, 144, 165).

Glenda Amayo Caldwell and Marcus Foth (2014). 'DIY media architecture: open and participatory approaches to community engagement'. In: *Proceedings of the 2nd Media Architecture Biennale Conference: World Cities*. ACM, pp. 1–10 (cit. on p. 89).

Jorge CS Cardoso and Rui José (2009). 'A framework for context-aware adaptation in public displays'. In: *OTM Confederated International Conferences" On the Move to Meaningful Internet Systems"*. Springer, pp. 118–127 (cit. on pp. 26, 130, 132, 148).

Marcus Carter, Eduardo Velloso, John Downs, Abigail Sellen, Kenton O'Hara, and Frank Vetere (2016). 'Pathsync: Multi-user gestural interaction with touchless rhythmic path mimicry'. In: *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. ACM, pp. 3415–3427 (cit. on p. 19).

Brian Caulfield and Margaret O'Mahony (2009). 'A stated preference analysis of real-time public transit stop information'. In: *Journal of Public Transportation* 12.3, p. 1 (cit. on pp. 77, 137).

Alex Jinsung Choi (2014). 'Internet of things: Evolution towards a hyper-connected society'. In: *Solid-State Circuits Conference (A-SSCC), 2014 IEEE Asian*. IEEE, pp. 5–8 (cit. on pp. 13, 44).

Jorgos Coenen, Sandy Claes, and Andrew Vande Moere (2017). 'The concurrent use of touch and mid-air gestures or floor mat interaction on a public display'. In: *Proceedings of the 6th ACM International Symposium on Pervasive Displays*. ACM, p. 9 (cit. on p. 88).

Dave Colangelo (2016). 'Massive media: when cities become screens'. In: *Proceedings of the 3rd Conference on Media Architecture Biennale*. ACM, p. 9 (cit. on p. 11).

Ashley Colley, Jonna Häkkilä, Meri-Tuulia Forsman, Bastian Pfleging, and Florian Alt (2018). 'Car Exterior Surface Displays: Exploration in a Real-World Context'. In: *Proceedings of the 7th ACM International Symposium on Pervasive Displays*. ACM, p. 7 (cit. on p. 181).

Ashley Colley, Leena Ventä-Olkkonen, Florian Alt, and Jonna Häkkilä (2015). 'Insights from Deploying See-Through Augmented Reality Signage in the Wild'. In: *Proceedings of the 4th International Symposium on Pervasive Displays*. ACM, pp. 179–185 (cit. on p. 39).

Travis Cox, Marcus Carter, and Eduardo Velloso (2016). 'Public display: Social games on interactive public screens'. In: *Proceedings of the 28th Australian Conference on Computer-Human Interaction*. ACM, pp. 371–380 (cit. on p. 19).

John W Creswell and J David Creswell (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications (cit. on p. 31).

Peter Dalsgaard and Kim Halskov (2010). 'Designing urban media façades: cases and challenges'. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, pp. 2277–2286 (cit. on p. 83).

Nicholas S Dalton, Emily Collins, and Paul Marshall (2015). 'Display blindness?: Looking again at the visibility of situated displays using eye-tracking'. In: *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, pp. 3889–3898 (cit. on pp. 39, 41, 43, 48, 65, 71, 81, 178).

Sheep N Dalton, Paul Marshall, and Ruth Conroy Dalton (2010). 'Measuring environments for public displays: A space syntax approach'. In: *CHI'10 Extended Abstracts on Human Factors in Computing Systems*. ACM, pp. 3841–3846 (cit. on p. 78).

Nigel Davies, Sarah Clinch, Mateusz Mikusz, Oliver Bates, Helen Turner, and Adrian Friday (2017). 'Better off: when should pervasive displays be powered down?' In: *Proceedings of the 6th ACM International Symposium on Pervasive Displays*. ACM, p. 19 (cit. on pp. 11, 66, 81, 83, 86, 88, 160).

Nigel Davies, Adrian Friday, Peter Newman, Sarah Rutlidge, and Oliver Storz (2009). 'Using bluetooth device names to support interaction in smart environments'. In: *Proceedings of the 7th international conference on Mobile systems, applications, and services*. ACM, pp. 151–164 (cit. on pp. 25, 27, 43, 119, 121, 130, 148, 152).

Nigel Davies, Marc Langheinrich, Sarah Clinch, Ivan Elhart, Adrian Friday, Thomas Kubitza, and Bholanathsingh Surajbali (2014). 'Personalisation and privacy in future pervasive display networks'. In: *Proceedings of the 32nd annual ACM conference on Human factors in computing systems*. ACM, pp. 2357–2366 (cit. on pp. 12, 14, 25–27, 39, 43, 65, 66, 81, 103–105, 130, 131, 148, 152, 160, 174).

Anind K Dey (2001). 'Understanding and using context'. In: *Personal and ubiquitous computing* 5.1, pp. 4–7 (cit. on pp. 26, 103, 116, 132).

Paul Dourish (2006). 'Re-space-ing place: place and space ten years on'. In: *Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work*. ACM, pp. 299–308 (cit. on p. 160).

– (2016). 'The Internet of Urban Things'. In: *Code and the City, Routledge, London*, pp. 27–46 (cit. on p. 11).

Guiying Du, Auriol Degbelo, and Christian Kray (2017). 'Public displays for public participation in urban settings: a survey'. In: *Proceedings of the 6th ACM International Symposium on Pervasive Displays*. ACM, p. 17 (cit. on pp. 12, 20).

Malin Eiband, Mohamed Khamis, Emanuel von Zezschwitz, Heinrich Hussmann, and Florian Alt (2017). 'Understanding shoulder surfing in the wild: Stories from users and observers'. In: *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, pp. 4254–4265 (cit. on p. 143).

Ivan Elhart, Mateusz Mikusz, Cristian Gomez Mora, Marc Langheinrich, and Nigel Davies (2017). 'Audience monitor: an open source tool for tracking audience mobility in front of pervasive displays'. In: *Proceedings of the 6th ACM International Symposium on Pervasive Displays*. ACM, p. 10 (cit. on p. 44).

Patrick Tobias Fischer and Eva Hornecker (2012). 'Urban HCI: spatial aspects in the design of shared encounters for media facades'. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, pp. 307–316 (cit. on p. 75).

Claude Fortin, Kate Hennessy, and Hughes Sweeney (2014). 'Roles of an interactive media façade in a digital agora'. In: *Proceedings of The International Symposium on Pervasive Displays*. ACM, p. 7 (cit. on pp. 79, 82, 90).

Marcus Foth, Martin Tomitsch, Laura Forlano, M Hank Haeusler, and Christine Satchell (2016). 'Citizens breaking out of filter bubbles: urban screens as civic media'. In: *Proceedings of the 5th ACM International Symposium on Pervasive Displays*. ACM, pp. 140–147 (cit. on p. 20).

Joel Fredericks, Glenda Amayo Caldwell, and Martin Tomitsch (2016a). 'Middle-out design: collaborative community engagement in urban HCI'. In: *Proceedings of the 28th Australian Conference on Computer-Human Interaction*. ACM, pp. 200–204 (cit. on pp. 140, 168).

Joel Fredericks and Marcus Foth (2013). 'Augmenting public participation: enhancing planning outcomes through the use of social media and web 2.0'. In: *Australian planner* 50.3, pp. 244–256 (cit. on p. 148).

Joel Fredericks, Luke Hespanhol, Callum Parker, Dawei Zhou, and Martin Tomitsch (2017a). 'Blending pop-up urbanism and participatory technologies: Challenges and opportunities for inclusive city making'. In: *City, Culture and Society* (cit. on pp. 2, 79, 174).

Joel Fredericks, Luke Hespanhol, and Martin Tomitsch (2016b). 'Not just pretty lights: using digital technologies to inform city making'. In: *Proceedings of the 3rd Conference on Media Architecture Biennale*. ACM, p. 7 (cit. on p. 140).

Joel Fredericks, Martin Tomitsch, Luke Hespanhol, and Ian McArthur (2015). 'Digital Pop-Up: Investigating Bespoke Community Engagement in Public Spaces'. In: *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction*. ACM, pp. 634–642 (cit. on p. 130).

Joel Fredericks, Martin Tomitsch, and Laura Stewart (2017b). 'Design Patterns for Integrating Digitally Augmented Pop-ups with Community Engagement'. In: *International Journal of E-Planning Research (IJEPR)* 6.3, pp. 19–41 (cit. on pp. 146, 148, 153, 154, 161, 176).

Kazjon Grace, Rainer Wasinger, Christopher Ackad, Anthony Collins, Oliver Dawson, Richard Gluga, Judy Kay, and Martin Tomitsch (2013). 'Conveying interactivity at an interactive public information display'. In: *Proceedings of the 2nd ACM International Symposium on Pervasive Displays*. ACM, pp. 19–24 (cit. on pp. 42, 67, 71, 81, 107, 119, 125, 142).

Saul Greenberg, Nicolai Marquardt, Till Ballendat, Rob Diaz-Marino, and Miaosen Wang (2011). 'Proxemic interactions: the new ubicomp?' In: *interactions* 18.1, pp. 42–50 (cit. on pp. 26, 63).

Aniko Hannak, Piotr Sapiezynski, Arash Molavi Kakhki, Balachander Krishnamurthy, David Lazer, Alan Mislove, and Christo Wilson (2013). 'Measuring personalization of web search'. In: *Proceedings of the 22nd international conference on World Wide Web*. ACM, pp. 527–538 (cit. on p. 129).

Tali Hatuka and Eran Toch (2017). 'Being visible in public space: The normalisation of asymmetrical visibility'. In: *Urban Studies* 54.4, pp. 984–998 (cit. on p. 44).

Gillian R Hayes (2011). 'The relationship of action research to human-computer interaction'. In: *ACM Transactions on Computer-Human Interaction (TOCHI)* 18.3, p. 15 (cit. on p. 29).

Hamish Henderson and Tuck Wah Leong (2017). 'Lessons learned: a study on user difficulties with parking meters'. In: *Proceedings of the 29th Australian Conference on Computer-Human Interaction*. ACM, pp. 533–537 (cit. on pp. 16, 182).

Luke Hespanhol (2016). 'Interacting with laughter: a case study on audio-based interactivity of public projections'. In: *Proceedings of the 28th Australian Conference on Computer-Human Interaction*. ACM, pp. 205–214 (cit. on p. 181).

Luke Hespanhol and Martin Tomitsch (2015). 'Strategies for intuitive interaction in public urban spaces'. In: *Interacting with Computers* 27.3, pp. 311–326 (cit. on p. 42).

Luke Hespanhol, Martin Tomitsch, Ian McArthur, Joel Fredericks, Ronald Schroeter, and Marcus Foth (2015). 'Vote as you go: blending interfaces for community engagement into the urban space'. In: *Proceedings of the 7th International Conference on Communities and Technologies*. ACM, pp. 29–37 (cit. on pp. 12, 21, 39, 43, 81, 95, 98, 129, 147, 149, 151, 160, 174).

Marius Hoggenmueller, Martin Tomitsch, and Alexander Wiethoff (2018). 'Understanding Artefact and Process Challenges for Designing Low-Res Lighting Displays'. In: *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, p. 259 (cit. on pp. 11, 65, 83).

Simo Hosio, Jorge Goncalves, Vassilis Kostakos, and Jukka Riekki (2014a). 'Exploring civic engagement on public displays'. In: *User-Centric Technology Design for Nonprofit and Civic Engagements*. Springer, pp. 91–111 (cit. on p. 20).

Simo Hosio, Jorge Goncalves, Hannu Kukka, Alan Chamberlain, and Alessio Malizia (2014b). 'What's in it for me: Exploring the real-world value proposition of pervasive displays'. In: *Proceedings of the international symposium on pervasive displays*. ACM, p. 174 (cit. on p. 26).

Simo Hosio, Marko Jurmu, Hannu Kukka, Jukka Riekki, and Timo Ojala (2010). 'Supporting distributed private and public user interfaces in urban environments'. In: *Proceedings of the Eleventh Workshop on Mobile Computing Systems & Applications*. ACM, pp. 25–30 (cit. on p. 25).

Steven Houben and Christian Weichel (2013). 'Overcoming interaction blindness through curiosity objects'. In: *CHI'13 Extended Abstracts on Human Factors in Computing Systems*. ACM, pp. 1539–1544 (cit. on pp. 46, 66, 67).

Elaine M Huang and Elizabeth D Mynatt (2002). 'Shared displays for small communities: optimizing for privacy and relevance'. In: *Position paper and Invited Presentation for the Workshop on Public, Community, and Situated Displays at the ACM Conference on Computer Supported Cooperative Work (CSCW 2002)* (cit. on p. 152).

Elaine Huang, Anna Koster, and Jan Borchers (2008). 'Overcoming assumptions and uncovering practices: When does the public really look at public displays?' In: *Pervasive Computing*, pp. 228–243 (cit. on pp. 13, 22, 27, 37, 39–41, 43, 45, 46, 49, 61, 63–68, 71, 78, 103, 119, 151, 167, 173, 179).

Ashatu Hussein (2015). 'The use of Triangulation in Social Sciences Research: Can qualitative and quantitative methods be combined?' In: *Journal of comparative social work* 4.1 (cit. on p. 31).

Rui José, Nuno Otero, and Jorge Cardoso (2014). 'Dimensions of situatedness for digital public displays'. In: *Advances in Human-Computer Interaction* 2014, p. 16 (cit. on p. 151).

Judy Kay (1994). *Lies, damned lies and stereotypes: pragmatic approximations of users*. Basser Department of Computer Science, University of Sydney (cit. on p. 152).

Judy Kay, Bob Kummerfeld, and Piers Lauder (2003). 'Managing private user models and shared personas'. In: *UM03 Workshop on User Modeling for Ubiquitous Computing*, pp. 1–11 (cit. on p. 152).

Mohamed Khamis, Regina Hasholzner, Andreas Bulling, and Florian Alt (2017). 'GTmoPass: two-factor authentication on public displays using gaze-touch passwords and personal mobile devices'. In: *Proceedings of the 6th ACM International Symposium on Pervasive Displays*. ACM, p. 8 (cit. on p. 24).

Mohamed Khamis, Ludwig Trotter, Markus Tessmann, Christina Dannhart, Andreas Bulling, and Florian Alt (2016). 'EyeVote in the wild: do users bother correcting system errors on public displays?' In: *Proceedings of the 15th International Conference on Mobile and Ubiquitous Multimedia*. ACM, pp. 57–62 (cit. on p. 90).

Lisa Koeman, Vaiva Kalnikaitė, Yvonne Rogers, and Jon Bird (2014). 'What chalk and tape can tell us: lessons learnt for next generation urban displays'. In: *Proceedings of The International Symposium on Pervasive Displays*. ACM, p. 130 (cit. on p. 78).

Vassilis Kostakos and Timo Ojala (2013). 'Public displays invade urban spaces'. In: *IEEE Pervasive Computing* 12.1, pp. 8–13 (cit. on p. 95).

Thomas Kubitza, Sarah Clinch, Nigel Davies, and Marc Langheinrich (2013). 'Using mobile devices to personalize pervasive displays'. In: *ACM SIGMOBILE Mobile Computing and Communications Review* 16.4, pp. 26–27 (cit. on pp. 26, 130, 131).

Hannu Kukka, Jorge Goncalves, Tommi Heikkinen, Olli-Pekka Suua, Yifei Zuo, Hannu Raappana, Mohamed Abdellatif, Olli Okkonen, Raúl Jiménez, and Timo Ojala (2015). 'Touch OK to Continue: Error Messages and Affective Response on Interactive Public Displays'. In: *Proceedings of the 4th International Symposium on Pervasive Displays*. ACM, pp. 99–105 (cit. on pp. 81, 88).

Hannu Kukka, Jorge Goncalves, Kai Wang, Tommi Puolamaa, Julien Louis, Mounib Mazouzi, and Leire Roa Barco (2016). 'Utilizing audio cues to raise awareness and entice interaction on public displays'. In: *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*. ACM, pp. 807–811 (cit. on p. 71).

Hannu Kukka, Heidi Oja, Vassilis Kostakos, Jorge Gonçalves, and Timo Ojala (2013). 'What makes you click: exploring visual signals to entice interaction on public displays'. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, pp. 1699–1708 (cit. on p. 75).

Hannu Kukka, Johanna Ylipulli, Anna Luusua, and Anind K Dey (2014). 'Urban computing in theory and practice: towards a transdisciplinary approach'. In: *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational*. ACM, pp. 658–667 (cit. on p. 160).

Gun A Lee, Andreas Dünser, Seungwon Kim, and Mark Billinghurst (2012). 'CityViewAR: A mobile outdoor AR application for city visualization'. In: *Mixed and Augmented Reality (ISMAR-AMH), 2012 IEEE International Symposium on*. IEEE, pp. 57–64 (cit. on p. 181).

Jae-Hoon Lee and Woo-Jung Lee (2013). 'A Study on the Impact of Ubiquitous Street Furniture on Human Behavior-Based on Media Poles Installed on Seoul′ s Gangnam Boulevard'. In: *Journal of Asian Architecture and Building Engineering* 12.2, pp. 181–188 (cit. on p. 38).

Kabo Lee, Sarah Clinch, Chris Winstanley, and Nigel Davies (2014). 'I love my display: Combatting display blindness with emotional attachment'. In: *Proceedings of The International Symposium on Pervasive Displays*. ACM, p. 154 (cit. on p. 46).

Diana Lemme, Romina Kühn, Alexandra Funke, and Thomas Schlegel (2014). 'A feasibility study of context-adaptive visualizations in public transport information systems'. In: *Proceedings of the 13th International Conference on Mobile and Ubiquitous Multimedia*. ACM, pp. 262–263 (cit. on p. 132).

C Licoppe and C Levallois-Barth (2011). 'Configuring Commuters' Accessibility to Multimedia Mobile Services: The Case of Bluetooth 'Augmented'Advertising in the Paris Metro'. In: *Mobilities: New Perspectives on Transport and Society*, p. 245 (cit. on p. 130).

Setha Low and Neil Smith (2013). *The politics of public space*. Routledge (cit. on p. 147).

Peter Lyle, Marcus Foth, and Jaz Hee-jeong Choi (2015). 'Design patterns for urban gardening'. In: *Citizen's Right to the Digital City*. Springer, pp. 79–98 (cit. on p. 161).

Mayra Donaji Barrera Machuca, Winyu Chinthammit, Yi Yang, and Henry Duh (2014). '3D mobile interactions for public displays'. In: *SIGGRAPH Asia 2014 Mobile Graphics and Interactive Applications*. ACM, p. 8 (cit. on pp. 103, 106).

Narges Mahyar, Kelly J Burke, Jialiang Ernest Xiang, Siyi Cathy Meng, Kellogg S Booth, Cynthia L Girling, and Ronald W Kellett (2016). 'UD Co-Spaces: A Table-Centred Multi-Display Environment for Public Engagement in Urban Design Charrettes'. In: *Proceedings of the 2016 ACM on Interactive Surfaces and Spaces*. ACM, pp. 109–118 (cit. on p. 173).

Ville Mäkelä, Sumita Sharma, Jaakko Hakulinen, Tomi Heimonen, and Markku Turunen (2017). 'Challenges in Public Display Deployments: A Taxonomy of External Factors'. In: *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, pp. 3426–3475 (cit. on pp. 83, 88, 160).

Lev Manovich (2006). 'The poetics of augmented space'. In: *Visual Communication* 5.2, pp. 219–240 (cit. on pp. 11, 22, 23, 44).

Sven Mayer, Lars Lischke, Jens Emil Grønbæk, Zhanna Sarsenbayeva, Jonas Vogelsang, Pawel W Wozniak, Niels Henze, and Giulio Jacucci (2018). 'Pac-Many: Movement Behavior when Playing Collaborative and Competitive Games on Large Displays'. In: *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, p. 539 (cit. on p. 173).

Nemanja Memarovic, Sarah Clinch, and Florian Alt (2015). 'Understanding display blindness in future display deployments'. In: *Proceedings of the 4th International Symposium on Pervasive Displays*. ACM, pp. 7–14 (cit. on pp. 39, 41, 46, 67, 71).

Nemanja Memarovic and Marc Langheinrich (2010). 'Beyond Web 2.0: Challenges in Personalizing for Networked Public Display Environments'. In: *Pervasive Personalisation Workshop, held in conjunction with Pervasive* (cit. on pp. 12, 14, 43, 104, 107, 130, 148, 152, 174).

Daniel Michelis and Jörg Müller (2011). 'The audience funnel: Observations of gesture based interaction with multiple large displays in a city center'. In: *Intl. Journal of Human–Computer Interaction* 27.6, pp. 562–579 (cit. on pp. 39, 42, 95, 98).

Andrew Vande Moere and Niels Wouters (2012). 'The role of context in media architecture'. In: *Proceedings of the 2012 International Symposium on Pervasive Displays*. ACM, p. 12 (cit. on pp. 47, 151, 160, 169).

John Montgomery (1998). 'Making a city: Urbanity, vitality and urban design'. In: *Journal of Urban Design* 3.1, pp. 93–116 (cit. on pp. 75, 78).

Jörg Müller, Robert Walter, Gilles Bailly, Michael Nischt, and Florian Alt (2012). 'Looking glass: a field study on noticing interactivity of a shop window'. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, pp. 297–306 (cit. on pp. 19, 39, 42, 81, 173).

Jörg Müller, Dennis Wilmsmann, Juliane Exeler, Markus Buzeck, Albrecht Schmidt, Tim Jay, and Antonio Krüger (2009). 'Display blindness: The effect of expectations on attention towards digital signage'. In: *Pervasive Computing*, pp. 1–8 (cit. on pp. 41, 46, 67, 71).

Sean A Munson, Emily Rosengren, and Paul Resnick (2011). 'Thanks and tweets: comparing two public displays'. In: *Proceedings of the ACM 2011 conference on Computer supported cooperative work*. ACM, pp. 331–340 (cit. on pp. 26, 96).

Dietmar Offenhuber and Susanne Seitinger (2014). 'Over the rainbow: Information design for low-resolution urban displays'. In: *Proceedings of the 2nd media architecture biennale conference: World cities*. ACM, pp. 40–47 (cit. on p. 11).

Timo Ojala, Vassilis Kostakos, Hannu Kukka, Tommi Heikkinen, Tomas Linden, Marko Jurmu, Simo Hosio, Fabio Kruger, and Daniele Zanni (2012). 'Multipurpose interactive public displays in the wild: Three years later'. In: *Computer* 45.5, pp. 42–49 (cit. on pp. 46, 71, 150).

Callum Parker (2017). 'Augmenting Public Spaces with Virtual Content'. In: *Media Architecture Compendium: Digital Placemaking*. Ed. by Luke Hespanhol, M. Hank Haeusler, Martin Tomitsch, and Gernot Tscherteu. avedition, pp. 133–135 (cit. on p. 2).

Callum Parker, Joel Fredericks, Judy Kay, and Martin Tomitsch (2018a). 'Design Patterns for Making Public Interactive Displays Relevant in Hyperconnected Societies'. *Under Review* (cit. on pp. 2, 18).

Callum Parker, Joel Fredericks, Martin Tomitsch, and Soojeong Yoo (2017). 'Towards Adaptive Height-Aware Public Interactive Displays'. In: *Adjunct Publication of the 25th Conference on User Modeling, Adaptation and Personalization*. ACM, pp. 257–260 (cit. on pp. 3, 18, 23, 45, 65, 90, 140, 148, 158, 160).

Callum Parker, Marius Hoggenmueller, and Martin Tomitsch (2018b). 'Design Strategies for Overcoming Failures on Public Interactive Displays'. In: *Proceedings of the 7th ACM International Symposium on Pervasive Displays*. ACM (cit. on pp. 3, 17).

Callum Parker, Judy Kay, Matthias Baldauf, and Martin Tomitsch (2016). 'Design implications for interacting with personalised public displays through mobile augmented reality'. In: *Proceedings of the 5th ACM International Symposium on Pervasive Displays*. ACM, pp. 52–58 (cit. on pp. 2, 17, 26, 39, 43, 66, 76, 79, 81, 91, 119, 121, 130, 131, 144, 148, 154, 160, 165, 181).

Callum Parker, Judy Kay, and Martin Tomitsch (2018c). 'Device-free: An Implicit Personalisation Approach for Public Interactive Displays'. In: *ACSW'18: Proceedings of Australasian Computer Science Week 2018*. ACM (cit. on pp. 3, 18, 39, 44, 65, 148, 156, 158–160).

Callum Parker and Martin Tomitsch (2017). 'Bridging the Interaction Gulf: Understanding the Factors that Drive Public Interactive Display Usage'. In: *OzCHI'17: Proceedings of the 29th Australian Conference on Human-Computer Interaction (OZCHI 2017)*. ACM (cit. on pp. 3, 17, 39, 81, 160, 169).

– (2014). 'Data visualisation trends in mobile augmented reality applications'. In: *Proceedings of the 7th International Symposium on Visual Information Communication and Interaction*. ACM, p. 228 (cit. on pp. 2, 181).

Callum Parker, Martin Tomitsch, and Judy Kay (2018d). 'Does the Public Still Look at Public Displays? A Field Observation of Public Displays in the Wild'. In: *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 2.2 (cit. on pp. 2, 17, 84, 148, 151, 163, 167, 169, 173).

Callum Parker, Martin Tomitsch, Judy Kay, and Matthias Baldauf (2015). 'Keeping it private: an augmented reality approach to citizen participation with public displays'. In: *Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers*. ACM, pp. 807–812 (cit. on pp. 3, 17, 43, 72, 104, 106, 107, 139, 148).

Brasilina Passarelli and Alan Cesar Belo Angeluci (2017). 'The Hyperconnected Contemporary Society'. In: *Brazil: Media from the Country of the Future*. Emerald Publishing Limited, pp. 343–362 (cit. on pp. 13, 39, 44).

Charlie Pinder, Jo Vermeulen, Adhi Wicaksono, Russell Beale, and Robert J Hendley (2016). 'If this, then habit: exploring context-aware implementation intentions on smartphones'. In: *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct*. ACM, pp. 690–697 (cit. on p. 132).

Thorsten Prante, Carsten Röcker, Norbert Streitz, Richard Stenzel, Carsten Magerkurth, Daniel Van Alphen, and Daniela Plewe (2003). 'Hello. wall–beyond ambient displays'. In: *Adjunct Proceedings of Ubicomp*. Vol. 2003, pp. 277–278 (cit. on pp. 26, 45, 121, 130, 132, 152).

Md Rahman, SC Wirasinghe, Lina Kattan, et al. (2013). 'Users' views on current and future real-time bus information systems'. In: *Journal of advanced transportation* 47.3, pp. 336–354 (cit. on pp. 77, 137).

Fiona Redhead, Andrew Dekker, and Margot Brereton (2009). 'A Situated Display for Local Community Participation: The Design and Use of Nnub'. In: *Ubiquitous, Autonomic and Trusted Computing, 2009. UIC-ATC'09. Symposia and Workshops on*. IEEE, pp. 102–107 (cit. on p. 150).

Bill N Schilit, Anthony LaMarca, Gaetano Borriello, William G Griswold, David McDonald, Edward Lazowska, Anand Balachandran, Jason Hong, and Vaughn Iverson (2003). 'Challenge: Ubiquitous location-aware computing and the place lab initiative'. In: *Proceedings of the 1st ACM international workshop on Wireless mobile applications and services on WLAN hotspots*. ACM, pp. 29–35 (cit. on p. 64).

Stefan Schneegass, Florian Alt, Jürgen Scheible, Albrecht Schmidt, and Haifeng Su (2014). 'Midair displays: exploring the concept of free-floating public displays'. In: *CHI'14 Extended Abstracts on Human Factors in Computing Systems*. ACM, pp. 2035–2040 (cit. on p. 180).

Ronald Schroeter (2012). 'Engaging new digital locals with interactive urban screens to collaboratively improve the city'. In: *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work*. ACM, pp. 227–236 (cit. on pp. 130, 148).

Ronald Schroeter and Marcus Foth (2009). 'Discussions in space'. In: *Proceedings of the 21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group: Design: Open 24/7*. ACM, pp. 381–384 (cit. on pp. 12, 21, 24, 39, 43, 45, 66, 81, 99, 106, 148, 150, 168, 174).

Ronald Schroeter, Marcus Foth, and Christine Satchell (2012). 'People, content, location: sweet spotting urban screens for situated engagement'. In: *Proceedings of the Designing Interactive Systems Conference*. ACM, pp. 146–155 (cit. on p. 151).

Douglas Schuler (2008). *Liberating voices: A pattern language for communication revolution*. MIT Press (cit. on pp. 146, 153, 154, 161, 176).

Mohit Sethi, Elena Oat, Mario Di Francesco, and Tuomas Aura (2014). 'Secure bootstrapping of cloud-managed ubiquitous displays'. In: *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. ACM, pp. 739–750 (cit. on pp. 156, 165).

Matthew Sharifi, Terry Payne, and Esther David (2006). 'Public display advertising based on bluetooth device presence'. In: *Mobile Interaction with the Real World (MIRW 2006)* 52 (cit. on pp. 12, 104, 131, 152).

Garth Shoemaker, Anthony Tang, and Kellogg S Booth (2007). 'Shadow reaching: a new perspective on interaction for large displays'. In: *Proceedings of the 20th annual ACM symposium on User interface software and technology*. ACM, pp. 53–56 (cit. on p. 122).

Fabius Steinberger, Marcus Foth, and Florian Alt (2014). 'Vote with your feet: Local community polling on urban screens'. In: *Proceedings of The International Symposium on Pervasive Displays*. ACM, p. 44 (cit. on pp. 12, 21, 43, 81, 97, 129, 147, 149, 150).

Martin Tomitsch (2018). *Making Cities Smarter: Designing Interactive Urban Applications. Designing Interactive Urban Applications*. Jovis Verlag GmbH, Berlin (cit. on pp. 11, 82, 88).

Martin Tomitsch, Christopher Ackad, Oliver Dawson, Luke Hespanhol, and Judy Kay (2014). 'Who cares about the content? An analysis of playful behaviour at a public display'. In: *Proceedings of the International Symposium on Pervasive Displays*. ACM, p. 160 (cit. on pp. 19, 21, 26, 39, 78, 81, 97, 98, 105, 126, 132, 150, 151).

Martin Tomitsch, Cara Wrigley, Madeleine Borthwick, Naseem Ahmadpour, Jessica Frawley, Baki Kocaballi, Claudia Nunez-Pacheco, Karla Straker, and Lian Loke (2018). *Design. Think. Make. Break. Repeat. A handbook of methods*. BIS Publishers (cit. on p. 168).

Elias Z Tragos, Henrich C Pöhls, Ralf C Staudemeyer, Daniel Slamanig, Adam Kapovits, Santiago Suppan, Alexandros Fragkiadakis, Gianmarco Baldini, Ricardo Neisse, Peter Langendörfer, et al. (2015). 'Securing the internet of things—security and privacy in a hyperconnected world'. In: *Building the hyperconnected society-internet of things research and innovation value chains, ecosystems and markets. River Publishers Series of Communications*, pp. 189–219 (cit. on pp. 13, 44).

Nina Valkanova, Robert Walter, Andrew Vande Moere, and Jörg Müller (2014). 'MyPosition: sparking civic discourse by a public interactive poll visualization'. In: *Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing*. ACM, pp. 1323–1332 (cit. on pp. 21, 98, 99, 149).

Mettina Veenstra, Niels Wouters, Marije Kanis, Stephan Brandenburg, Kevin te Raa, Bart Wigger, and Andrew Vande Moere (2015). 'Should public displays be interactive? Evaluating the impact of interactivity on audience engagement'. In: *Proceedings of the 4th International Symposium on Pervasive Displays*. ACM, pp. 15–21 (cit. on pp. 42, 103).

Daniel Vogel and Ravin Balakrishnan (2004). 'Interactive public ambient displays: transitioning from implicit to explicit, public to personal, interaction with multiple users'. In: *Proceedings of the 17th annual ACM symposium on User interface software and technology*. ACM, pp. 137–146 (cit. on p. 26).

Miaosen Wang, Sebastian Boring, and Saul Greenberg (2012). 'Proxemic peddler: a public advertising display that captures and preserves the attention of a passerby'. In: *Proceedings of the 2012 international symposium on pervasive displays*. ACM, p. 3 (cit. on pp. 27, 39, 44, 63, 81, 119, 132, 148, 152, 160).

Mark Weiser (1991). 'The Computer for the 21 st Century'. In: *Scientific american* 265.3, pp. 94–105 (cit. on p. 64).

Julie R Williamson and John Williamson (2014). 'Analysing pedestrian traffic around public displays'. In: *Proceedings of The International Symposium on Pervasive Displays*. ACM, p. 13 (cit. on pp. 78, 167, 173).

– (2017). 'Understanding Public Evaluation: Quantifying Experimenter Intervention'. In: *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, pp. 3414–3425 (cit. on pp. 48, 84).

Niels Wouters, Sandy Claes, and Andrew Vande Moere (2015a). 'Investigating the Role of Situated Public Displays and Hyperlocal Content on Place-Making.' In: *IxD&A* 25, pp. 60–72 (cit. on p. 12).

Niels Wouters, John Downs, Marcus Carter, and V Moere (2015b). 'Masquerade: Social influence of full-body game interaction on public displays'. In: *Proceedings of DiGRAA Digital Games Research Association* (cit. on p. 19).

Niels Wouters, John Downs, Mitchell Harrop, Travis Cox, Eduardo Oliveira, Sarah Webber, Frank Vetere, and Andrew Vande Moere (2016). 'Uncovering the honeypot effect: How audiences engage with public interactive systems'. In: *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*. ACM, pp. 5–16 (cit. on pp. 39, 42, 71, 167).

Niels Wouters, Jonathan Huyghe, and Andrew Vande Moere (2014). 'StreetTalk: participative design of situated public displays for urban neighborhood interaction'. In: *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational*. ACM, pp. 747–756 (cit. on pp. 12, 39, 79).

Johanna Ylipulli, Anna Luusua, Hannu Kukka, and Timo Ojala (2014). 'Winter is coming: introducing climate sensitive urban computing'. In: *Proceedings of the 2014 conference on Designing interactive systems*. ACM, pp. 647–656 (cit. on pp. 83, 88).

Soojeong Yoo and Callum Parker (2015). 'Controller-less interaction methods for Google cardboard'. In: *Proceedings of the 3rd ACM Symposium on Spatial User Interaction*. ACM, pp. 127–127 (cit. on p. 3).

Soojeong Yoo, Callum Parker, and Judy Kay (2017). 'Designing a Personalized VR Exergame'. In: *Adjunct Publication of the 25th Conference on User Modeling, Adaptation and Personalization*. ACM, pp. 431–435 (cit. on p. 3).

Soojeong Yoo, Callum Parker, Judy Kay, and Martin Tomitsch (2015). 'To Dwell or Not to Dwell: An Evaluation of Mid-Air Gestures for Large Information Displays'. In: *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction*. ACM, pp. 187–191 (cit. on pp. 2, 88, 119, 120).

Oren Eli Zamir, Jeffrey L Korn, Andrew B Fikes, and Stephen R Lawrence (2010). *Personalization of placed content ordering in search results*. US Patent 7,693,827 (cit. on p. 103).

John Zimmerman, Jodi Forlizzi, and Shelley Evenson (2007). 'Research through design as a method for interaction design research in HCI'. In: *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, pp. 493–502 (cit. on pp. 29, 177).

Webpages

The Outdoor Media Association (2017). *OMA Digital Guideline*. URL: http://oma.org.au/__data/assets/pdf_file/0019/13447/OMA_Digital_Guideline_2016.pdf (visited on Apr. 16, 2017) (cit. on p. 120).

Kelsey Campbell-Dollaghan (2013). *Brave New Garbage: London's Rubbish Bins Track You Using Your Smartphone*. URL: http://www.gizmodo.com.au/2013/08/brave-new-garbage-londons-trash-cans-track-you-using-your-smartphone/ (visited on Jan. 18, 2017) (cit. on pp. 130, 156).

Ericsson (2017). *Ericsson Mobility Report*. URL: https://www.ericsson.com/en/mobility-report (visited on Aug. 16, 2017) (cit. on pp. 79, 137).

Nelson Granados (2016). *How Facebook Biases Your News Feed*. URL: https://www.forbes.com/sites/nelsongranados/2016/06/30/how-facebook-biases-your-news-feed/#47802fe11d51 (visited on Sept. 11, 2017) (cit. on p. 130).

Jeff Hastings (2018). *Digital signage adoption continues to surge forward*. URL: https://www.digitalsignagetoday.com/blogs/digital-signage-adoption-continues-to-surge-forward (visited on Mar. 15, 2018) (cit. on p. 11).

Department of Justice (2010). *2010 ADA Standards for Accessible Design*. URL: https://www.ada.gov/regs2010/2010ADAStandards/2010ADAstandards.htm (visited on Apr. 21, 2017) (cit. on p. 120).

Patrick Lion (2016). *Red faces all round after video advertising billboard accidentally shows pornographic film to passing motorists during rush hour*. URL: http://www.mirror.co.uk/news/world-news/video-billboard-shows-pornographic-film-8951516 (visited on Jan. 12, 2018) (cit. on p. 89).

Julian Luk (2016). *Porn is played in public outside a Chinese shopping mall after screen tester connects personal computer to the device and leaves it on autoplay*. URL: http://www.dailymail.co.uk/news/peoplesdaily/article-4072876/Porn-played-public-outside-Chinese-shopping-mall-screen-tester-connects-personal-computer-device-leaves-autoplay (visited on Jan. 12, 2018) (cit. on p. 89).

Michael Passingham (2013). *City of London bans data-collecting WiFi smart bins*. URL: https://www.v3.co.uk/v3-uk/news/2288299/city-of-london-bans-datacollecting-wifi-smart-bins (visited on June 19, 2017) (cit. on pp. 26, 106).

PwC (2017). *Out-of-home advertising*. URL: http://www.pwc.com/gx/en/industries/entertainment-media/outlook/segment-insights/out-of-home-advertising.html (visited on Mar. 25, 2017) (cit. on p. 39).

JCDecaux Media Release (2016). *JCDecaux's Live Touch screens see strong growth*. URL: http://oma.org.au/media2/latest-news/archive-items/jcdecauxs-live-touch-screens-see-strong-growth (visited on Mar. 25, 2017) (cit. on p. 38).

John Riccio (2016). *Report: Rapid adoption of wearables, 2016*. URL: https://www.digitalpulse.pwc.com.au/2016-wearable-statistics-report (visited on Sept. 21, 2017) (cit. on p. 131).

Rachel Savage (2013). *Snooping Garbage Bins in City of London Ordered to Be Disabled*. URL: https://www.bloomberg.com/news/articles/2013-08-12/snooping-garbage-bins-in-city-of-london-ordered-to-be-disabled (visited on Jan. 18, 2017) (cit. on pp. 130, 156).

Robert Triggs (2015). *Samsung Pay transport card service launches in South Korea*. URL: https://www.androidauthority.com/samsung-pay-transport-card-korea-660816/ (visited on Jan. 22, 2018) (cit. on p. 23).

Fred Vogelstein (2017). *Inside Apple's 6-Month Race to Make the First IPhone a Reality*. URL: https://www.wired.com/story/iphone-history-dogfight/ (visited on Jan. 11, 2018) (cit. on p. 39).

Vuforia (2017). *Image Targets*. URL: https://library.vuforia.com/articles/Training/Image-Target-Guide (visited on June 19, 2017) (cit. on p. 100).

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Appendix A

A.1 Study Documents for Field Observation

Observation Notes Structure Guide

Observation notes

Type of Display
- *Kiosk, ATM, TV Displays, Large, Cinema, Projection, etc.*
- *Description of the size and orientation*
- *How is it mounted?*
- *Where is it placed?*

Description
- *What is displayed on the screen?*
- *What does it do?*
- *How can it be interacted with?*

Location
- *Where was this display exactly?*
- *Level of building and the map coords. The map will either be created or sourced from online and a grid will be applied to make it easier to locate points of interest.*

Time
- *What date and time did the observation occur?*

Environment
- *What was around?*
  - *Such as other screens, music, lights, special events, etc.*
- *Who was around?*
  - *Do people congregate in this space?*
  - *Is this a local hangout?*
- *Thoroughfare/destination*

Behaviour
- *What did people do at the display?*
  - *How did they interact?*
- *Phenomena observed*
  - *Queueing*
  - *Bystanders*
  - *Did the screen create conversation?*
  - *Time spent in front of display*

Description of people engaging with the display
- *Characteristic of people, such as gender and age group (child, teen, young adult, middle aged, senior).*
- *Number of people.*

Visual references
- *Photos of the display.*
- *Sketches of the space and behaviours observed.*

A Taxonomy of Digital Public Displays
Version 1.0 – 15/11/2016

Safety Protocol

THE UNIVERSITY OF SYDNEY

A/Prof Martin Tomitsch
Director of Bachelor of Design Computing
Faculty of Architecture, Design and Planning

Wednesday, 26 October 2016

Safety protocol for HREC project number <number goes here>

Supervisor: A/Prof Martin Tomitsch
Researcher: Callum Parker

Supervisor and student agree to the following terms:

1. The research involves observing people in public spaces that in some cases may be off-campus. The researcher will be conducting the observations alone. However his supervisor considers that the safeguards provided in this safety protocol are sufficient to manage the safety risks.
2. Risk management strategies have been discussed between the researcher and his supervisor, and both parties are clear as to procedure. The researcher will have a trial observation in the University campus and discuss with the supervisor after completing it.
3. The researcher agrees to communicate the time and location of the observations to his supervisor prior to commencing them. The researcher will communicate about his experience after the observations are completed.
4. The researcher will carry a mobile phone at all times while being at a research site and will communicate the number of the phone to the supervisor prior to commencing the interview.
5. The supervisor will communicate his phone number, under which he will be reachable while the researcher is conducting his research off-campus, to the researcher.
6. Should anything untoward happen, or the researcher becomes uneasy for any reason, the observations will be terminated immediately. The supervisor will be contacted as soon as practically possible.
7. Where possible, observations will be conducted in daylight hours or in the early evening.
8. Transport to and from the observation locations will be by public transport.

Version 1.0 – 10/10/2016

9. This safety protocol has been agreed and accepted by the researcher and the supervisor.

10. The researcher will dress appropriate to the research context.

11. The researcher will wear a university name tag where appropriate.

A/Prof Martin Tomitsch
Supervisor

Callum Parker
Researcher

A.2 Study Documents for Field Study in Chapter 8

Consent Form

THE UNIVERSITY OF SYDNEY

Faculty of Architecture, Design and Planning
Design Lab

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Web: http://www.sydney.edu.au/

Designing for personalised interactive experiences at digital public displays through mobile augmented reality

PARTICIPANT CONSENT FORM

I, ... [PRINT NAME], agree to take part in this research study.

In giving my consent I state that:

- ✓ I understand the purpose of the study, what I will be asked to do, and any risks/benefits involved.
- ✓ I have read the Participant Information Statement and have been able to discuss my involvement in the study with the researchers if I wished to do so.
- ✓ The researchers have answered any questions that I had about the study and I am happy with the answers.
- ✓ I understand that being in this study is completely voluntary and I do not have to take part. My decision whether to be in the study will not affect my relationship with the researchers or anyone else at the University of Sydney now or in the future.
- ✓ I understand that I can withdraw from the study at any time.
- ✓ I understand that I may stop the interview at any time if I do not wish to continue, and that unless I indicate otherwise any recordings will then be erased and the information provided will not be included in the study. I also understand that I may refuse to answer any questions I don't wish to answer.
- ✓ I understand that personal information about me that is collected over the course of this project will be stored securely and will only be used for purposes that I have agreed to. I understand that information about me will only be told to others with my permission, except as required by law.

I understand that the results of this study may be published, but these publications will not contain my name or any identifiable information about me unless I consent to being identified using the "Yes" checkbox below.

☐ Yes, I am happy to be identified.

☐ No, I don't want to be identified. Please keep my identity anonymous.

I consent to:

- **Audio-recording** YES ☐ NO ☐
- **Video-recording** YES ☐ NO ☐

Would you like to receive feedback about the overall results of this study?

YES ☐ **NO** ☐

If you answered **YES**, please indicate your preferred form of feedback and address:

☐ Postal: _____

_____

☐ Email: _____

.....
Signature

.....
PRINT name

.....
Date

Designing for personalised interactive experiences at digital public displays through mobile augmented reality

Version 1.0 15 July 2014

Participant Information Statement

THE UNIVERSITY OF SYDNEY

Faculty of Architecture, Design and Planning
Design Lab

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Designing for personalised interactive experiences at digital public displays through mobile augmented reality

PARTICIPANT INFORMATION STATEMENT
Field Study

(1) What is this study about?

You are invited to take part in a research study with the aim of personalising large public displays to make the content more relevant to individuals while retaining privacy. Additionally, we aim to understand preferences of people that interact with a large public display using a smartphone device so that we can potentially find a solid usable design. Therefore, a prototype public display system has been created to test our design, which will be refined from the feedback generated from this study.

This Participant Information Statement tells you about the research study. Knowing what is involved will help you decide if you want to take part in the research. Please read this sheet carefully and ask questions about anything that you don't understand or want to know more about.

Participation in this research study is voluntary. So it's up to you whether you wish to take part or not.

By giving your consent to take part in this study you are telling us that you:
- ✓ Understand what you have read
- ✓ Agree to take part in the research study as outlined below
- ✓ Agree to the use of your personal information as described.

You will be given a copy of this Participant Information Statement to keep.

(2) Who is running the study?

The study is being carried out by the following researchers:

- Dr. Martin Tomitsch, Lecturer in Design Computing, University of Sydney.
- Callum Parker, MPhil Candidate, University of Sydney.

Callum Parker is conducting this study as the basis for the degree of Master of Philosophy (Architecture) at The University of Sydney. This will take place under the supervision of Dr. Martin Tomitsch.

(3) What will the study involve for me?

You have been using the public display system that was created by researchers at the Design Lab in the University of Sydney.

You may opt into a completely voluntary interview after interacting with the public display. To participate in an interview, simply see one of the researchers who are standing nearby. However, you are under no obligation to have an interview.

If you choose to proceed with the interview, you will be recorded via audio and video. These recordings will not be shared or published in any form and will only be used by the researchers for their observations. No personal data will be collected and data about your usage of the public display installation and smartphone application will not be shared with anyone else.

(4) How much of my time will the study take?

The interview time will take 5-10 minutes.

(5) Who can take part in the study?

Anyone that is 18 years or older.

(6) Do I have to be in the study? Can I withdraw from the study once I've started?

Being in this study is completely voluntary and you do not have to take part. Your decision whether to participate will not affect your current or future relationship with the researchers or anyone else at the University of Sydney.

If you decide to take part in the study and then change your mind later, you are free to withdraw at any time. You can do this by notifying either researchers via the contact details provided on page 1.

If you decide to withdraw from the study, we will not collect any more information from you. Please let us know at the time when you withdraw what you would like us to do with the information we have collected about you up to that point. If you wish your information will be removed from our study records and will not be included in the study results, up to the point that we have analysed and published the results.

You are free to stop the interview at any time. Unless you say that you want us to keep them, any recordings will be erased and the information you have provided will not be included in the study results. You may also refuse to answer any questions that you do not wish to answer during the interview.

(7) Are there any risks or costs associated with being in the study?

Aside from giving up your time, we do not expect that there will be any risks or costs associated with taking part in this study.

(8) Are there any benefits associated with being in the study?

We cannot guarantee or promise that you will receive any direct benefits from being in the study.

(9) What will happen to information about me that is collected during the study?

By providing your consent, you are agreeing to us collecting personal information about you for the purposes of this research study. Your information will only be used for the purposes outlined in this Participant Information Statement, unless you consent otherwise.

Your information will be stored securely and your identity/information will be kept strictly confidential, except as required by law. Study findings may be published, but you will not be individually identifiable in these publications. Any images taken while you are using the display will have the faces blurred out before being included in a publication, to ensure you are not identified.

The information collected will only be used to help guide our system's design. The video and audio recordings will be used for observational purposes only and will not be publically broadcasted or distributed.

(10) Can I tell other people about the study?

Yes, you are welcome to tell other people about the study.

(11) What if I would like further information about the study?

When you have read this information, Callum Parker will be available to discuss it with you further and answer any questions you may have. If you would like to know more at any stage during the study, please feel free to contact Callum Parker via email (cpar9842@uni.sydney.edu.au) or Dr Martin Tomitsch via phone (02 9351 4610) or email (martin.tomitsch@sydney.edu.au).

(12) Will I be told the results of the study?

You have a right to receive feedback about the overall results of this study. You can tell us that you wish to receive feedback by ticking the receive feedback box on the consent form. This feedback will be in the form of a one page summary via email. You will receive this feedback after the study is finished.

(13) What if I have a complaint or any concerns about the study?

Research involving humans in Australia is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). The ethical aspects of this study have been approved by the HREC of the University of Sydney 2014/795. As part of this process, we have agreed to carry out the study according to the *National Statement on Ethical Conduct in Human Research (2007).* This statement has been developed to protect people who agree to take part in research studies.

If you are concerned about the way this study is being conducted or you wish to make a complaint to someone independent from the study, please contact the university using the details outlined below. Please quote the study title and protocol number.

The Manager, Ethics Administration, University of Sydney:

- **Telephone:** +61 2 8627 8176
- **Email:** ro.humanethics@sydney.edu.au
- **Fax:** +61 2 8627 8177 (Facsimile)

This information sheet is for you to keep

Interview Questions

THE UNIVERSITY OF SYDNEY

Faculty of Architecture, Design and Planning
Design Lab

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LAB STUDIES INTERVIEW QUESTIONS

Background Information

1. How old are you?
2. What is your current occupation?
3. Have you used augmented reality on a mobile device before using this system?

Usability

4. Did you find the system useful? How?
5. How difficult was the system to use?
6. How quickly did it take you to realise the function of each menu item?
7. How easy were menu and interface buttons to find?
8. Which buttons (if any) did not function in the way you expected?
9. Did the system overall respond in the way you expected it to? Why/Why not?

Design

10. How effective is the system at conveying what to do?
11. Do you have any criticisms of the aesthetic design of the interface?

Privacy

12. How did you feel about your privacy when using the system?
13. What level is your trust in this system?

Content

14. Do you feel that the system would allow you to contribute to the public space? Why/Why not?

Evaluation

15. What is your overall opinion about the public display with mobile interaction?
16. What improvements are necessary to deliver a better experience?
17. Do you have any other comments about your experience with the system?

Designing for personalised interactive experiences at digital public displays through mobile augmented reality

Version 1.0 30 June 2014

A.3 Study Documents for Lab and Field Studies in Chapters 5, 9, and 10

Participant Information Statement

THE UNIVERSITY OF SYDNEY

Faculty of Architecture, Design & Planning

ABN 15 211 513 464

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Chief Investigator (Supervisor)
Senior Lecturer in Design Computing

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Enhancing Community Engagement for Urban Planning through the use of Ubiquitous Computing Technologies

PARTICIPANT INFORMATION STATEMENT - INTERVIEWS

(1) What is this study about?

You are invited to take part in a research study that investigates the use of a community engagement application. Community engagement seeks feedback from the local community on proposed projects in public spaces, such as the construction of new bicycle lanes. Specifically, this study will explore how existing digital computing technologies can be tailored and customised as additional tools for community engagement in urban planning. The aim is to provide citizens with alternative options to be involved in urban planning decisions within their community.

You have been invited to participate in this study to provide information on your experience of using the community engagement application. This Participant Information Statement tells you about the research study. Knowing what is involved will help you decide if you want to take part in the research. Please read this sheet carefully and ask questions about anything that you don't understand or want to know more about.

Participation in this research study is voluntary. So it's up to you whether you wish to take part or not.

By giving your consent to take part in this study you are telling us that you:
- ✓ Understand what you have read
- ✓ Agree to take part in the research study as outlined below
- ✓ Agree to the use of your personal information as described.

You will be given a copy of this Participant Information Statement to keep.

(2) Who is running the study?

The study is being carried out by the following researchers:

- Dr Martin Tomitsch (Senior Lecturer)
- Joel Fredericks (PhD Candidate)

The study is being conducted by Joel Fredericks (PhD Candidate) and will form the basis for the PhD in Architecture at The University of Sydney under the supervision of Dr Martin Tomitsch (Senior Lecturer).

(3) What will the study involve for me?

Interviews will take place after you have used the community engagement application, to obtain feedback on your experience. You will be asked a series of questions about using the application, how you found the experience and how you would like your input to be used for urban planning. Interviews will be audio and video recorded. These recordings will be used to document information only and will not be shared or published in any form. Some demographic information will also be asked, for example, age groups, gender and suburb of residence. Personal information will not be shared or published in any form.

(4) How much of my time will the study take?

Interviews will take 5 minutes to complete. Joel Fredericks will explain the purpose of the questions and will undertake the interview. A total of 5 minutes would be required.

(5) Do I have to be in the study? Can I withdraw from the study once I've started?

Being in this study is completely voluntary and you do not have to take part. Your decision whether to participate will not affect your current or future relationship with the researchers or anyone else at the University of Sydney any other individuals or organisations related to this study.

If you decide to take part in the study and then change your mind later, you are free to withdraw at any time. You can do this by informing Joel Fredericks that you no longer wish to participate.

You are free to stop the interview at any time. Unless you say that you want us to keep them, any recordings will be erased and the information you have provided will not be included in the study results. You may also refuse to answer any questions that you do not wish to answer during the interview.

(6) Are there any risks or costs associated with being in the study?

Aside from giving up your time, we do not expect that there will be any risks or costs associated with taking part in this study.

(7) Are there any benefits associated with being in the study?

We cannot guarantee or promise that you will receive any direct benefits from being in the study.

(8) What will happen to information about me that is collected during the study?

Some personal information will be asked of you, for example, age group, suburb location and your mode of transport. Video and audio recordings will be used for interpretation and analysis only. A transcription service may be employed to transcribe interviews, however, your personal information will be kept confidential.

All aspects of the study, including the results, will be strictly confidential and only the researchers will have access to information on participants. The results of the study will be published in Joel Fredericks' PhD thesis, journal publications and conference papers. Material collected in the course of the research will be kept in a locked storage box at Room 276, G04 'Wilkinson Building', 148 City Road, The University of Sydney, NSW 2006.

By providing your consent, you are agreeing to us collecting personal information about you for the purposes of this research study. Your information will only be used for the purposes outlined in this Participant Information Statement, unless you consent otherwise.

Your information will be stored securely and your identity/information will only be disclosed with your permission, except as required by law. Study findings may be published, but you will not be identified in these publications unless you agree to this using the tick box on the consent form.

(9) Can I tell other people about the study?

Yes, you are welcome to tell other people about the study.

(10) What if I would like further information about the study?

When you have read this information, Joel Fredericks will be available to discuss it with you further and answer any questions you may have. If you would like to know more at any stage during the study, please feel free to contact Joel Fredericks (PhD Candidate) email: jfre8867@uni.sydney.edu.au phone: 0418 250 380.

(11) Will I be told the results of the study?

You have a right to receive feedback about the overall results of this study. You can tell us that you wish to receive feedback by indicating on the participant consent form. This feedback will be in the form of one page summary. You will receive this feedback after the study is finished.

(12) What if I have a complaint or any concerns about the study?

Research involving humans in Australia is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). The ethical aspects of this study have been approved by the HREC of the University of Sydney *[INSERT* protocol number once approval is obtained*].* As part of this process, we have agreed to carry out the study according to the *National Statement on Ethical Conduct in Human Research (2007).* This statement has been developed to protect people who agree to take part in research studies.

If you are concerned about the way this study is being conducted or you wish to make a complaint to someone independent from the study, please contact the university using the details outlined below. Please quote the study title and protocol number.

The Manager, Ethics Administration, University of Sydney:

- **Telephone:** +61 2 8627 8176
- **Email:** ro.humanethics@sydney.edu.au
- **Fax:** +61 2 8627 8177 (Facsimile)

This information sheet is for you to keep

Participant Consent Form

THE UNIVERSITY OF SYDNEY

Faculty of Architecture, Design & Planning

ABN 15 211 513 464

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Senior Lecturer in Design Computing

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Enhancing Community Engagement for Urban Planning through the use of Ubiquitous Computing Technologies

PARTICIPANT CONSENT FORM

I, ... [PRINT NAME], agree to take part in this research study.

In giving my consent I state that:

- ✓ I understand the purpose of the study, what I will be asked to do, and any risks/benefits involved.
- ✓ I have read the Participant Information Statement and have been able to discuss my involvement in the study with the researchers if I wished to do so.
- ✓ The researchers have answered any questions that I had about the study and I am happy with the answers.
- ✓ I understand that being in this study is completely voluntary and I do not have to take part. My decision whether to be in the study will not affect my relationship with the researchers or anyone else at the University of Sydney now or in the future.
- ✓ I understand that I can withdraw from the study at any time.
- ✓ I understand that I may leave the focus group at any time if I do not wish to continue. I also understand that it will not be possible to withdraw my comments once the group has started as it is a group discussion.
- ✓ I understand that personal information about me that is collected over the course of this project will be stored securely and will only be used for purposes that I have agreed to. I understand that information about me will only be told to others with my permission, except as required by law.

I understand that the results of this study may be published, and that publications will not contain my name or any identifiable information about me.

I consent to:

- **Audio-recording** YES ☐ NO ☐
- **Video-recording** YES ☐ NO ☐
- **Photographs** YES ☐ NO ☐
- **Reviewing transcripts** YES ☐ NO ☐
- **Being contacted about future studies** YES ☐ NO ☐
- **Receiving feedback about my personal results** YES ☐ NO ☐

Would you like to receive feedback about the overall results of this study?

YES ☐ **NO** ☐

If you answered **YES**, please indicate your preferred form of feedback and address:

☐ Postal: _____

_____

☐ Email: _____

.....
Signature

.....
PRINT name

.....
Date

Interview Questions

THE UNIVERSITY OF SYDNEY

Faculty of Architecture, Design & Planning

ABN 15 211 513 464

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Chief Investigator (Supervisor)
Head of the Design Lab

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INTERVIEW QUESTIONS

Background Information

1. What is your age group?

18-24 25-34 35-44 45-54 55-64 65-74 75 +

2. What is your gender?
3. What is your suburb of residence?
4. What is your current occupation?

Community Engagement Applications

5. How was your experience using the community engagement applications?
6. What did you like or dislike about the community engagement applications?
7. How would you improve them?
8. In what situations do you think you would use the community engagement applications?

Personalisation

9. What content was relevant to you?
10. How could the content be more relevant?
11. What would you like to happen with your responses?

Privacy

12. How do you feel about your privacy when using the community engagement applications?
13. How concerned were you about your surroundings? Such as onlookers?
14. What personal information would you be comfortable displaying in public?
15. What personal information would you be comfortable supplying to personalise the content?

Other

16. What did you like or dislike about the community engagement kiosk?
17. How would you improve it?

18. Have you attended any community engagement events? If yes, why did you attend? If no, why didn't you attend?
19. Do you have any other comments you would like to make?