Supporting Public Participation through Interactive Immersive Public Displays

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November 19, 2018

GEOINFORMATICS

Supporting Public Participation through Interactive Immersive Public Displays

Inaugural dissertation in fulfillment of the academic degree of

Doctor of Natural Sciences (Dr. rer. nat.)

in the Department of Geosciences
of the Faculty of Mathematics and Natural Sciences
of the Westfälische Wilhelms-Universität Münster

Submitted by
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from Shandong, China

- 2018 -

European Joint Doctorate in Geoinformatics: Enabling Open Cities
Marie Skłodowska-Curie Action (ITN-EJD)

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Day of defence: 15th, Nov, 2018
Day of promotion: 31st, August, 2018

Abstract

Citizen participation as a key priority of open cities, gives citizens the chance to influence public decision-making. Effectively engaging broader types of citizens into high participation levels has long been an issue due to various situational and technical constrains. Traditional public participation technologies (e.g. public hearing) usually are blame for low accessibility by the general public. The development of Information Communication Technology brings new methods to engage a broader spectrum of citizens in deeper participation level during urban planning processes. Interactive public displays as a public communication medium, hold some key advantages in comparison to other media. Compared to personal devices, public displays make public spaces into sociable places, where social communication and interaction can be enriched without intentionally or unintentionally excluding some groups' opinions. Public displays can increase the visibility of public events while it is more flexible and up-to-date regarding showing information. Besides, they can also foster a collective awareness and support group behavioral changes. Moreover, due to the public nature of public displays, they provide broad accessibility to different groups of citizens.

Public displays have a great potential in bringing new opportunities to facilitate public participation in an urban planning process. In the light of previous work on public displays, the research goal is to investigate a relatively new form of citizen participation known as Public Display Participation. This participation form refers to the use of public displays for citizen participation in the context of urban planning. The main research question of the thesis is how public displays can be used for facilitating citizen consultation in an urban planning process. First, a systematic literature review is done to get an understanding of the current achievements and gaps of research on public displays for public participation. Second, an elicitation study has been conducted to design end user centered interactions with public displays for citizens' consulting activities. Finally, we run a usability to evaluate the usability of public displays for citizen consultation and their user experience.

The main contributions of this thesis can be summarized as: (1) the identification of key challenges and opportunities for future research in using public displays for public participation in urban contexts; (2) two sets of user-defined gestures for two sets of user-defined phone gestures and hand gestures for performing eleven consulting activities, which are about examining the urban planning designs and giving feedback related to design alternatives, are also identified. (3) a new approach for using public displays for voting and commenting in urban planning, and a multi-level evaluation of a prototypical system implementing the proposed approach. Designers and researchers can use the contributions of this thesis, to create interactive public displays for supporting higher public participation, i.e. citizen collaboration and empowerment.

Acknowledgement

First of all, I would like to thank my supervisor Christian Kray for giving me the opportunity to work on this topic, guiding me to try different ideas, always being available for questions and discussions. Similarly, I want to express my thanks to our postdoc Auriol Degbelo. Both of them did a great job. They gave me a lot of invaluable help on structuring my thoughts, focusing on the main points of my research, and keeping me making progress on my research. This work would not have been possible without them. I would also like to thank my second supervisor Marco Painho for hosting me in NOVA IMS, discussing ideas with me, and helping me to improve my papers. I appreciate my third supervisor Oscar Belmonte Fernández, who gave helpful guidance to my research proposal and quarterly reports of my Phd study.

I have greatly enjoyed working at the situated computing and interaction lab with a great group of people: Anita, Max, Mehrnaz, Samuel, Holger, Matthias, Champika, and Markus, whose knowledge and experiences broadened my views. There are also warm thanks I want to send: to our student assistants, Nicholas, Albert, Lasse for their assisting work on running studies, and programming parts of the prototype presented in this thesis; to Jakub for his valuable guidance and discussion on designing my user studies; to Karsten and Heike, who are always so nice and helpful. I would especially thank Meng, who encouraged me a lot during my Phd study.

Finally, I owe a lot of thanks to my family for their unconditional love and support as always. Whenever I need them, they are always there. I would also like to thank my friends for their priceless friendship, and I hope they will understand that I could not list all of them here by name.

This dissertation is funded by the European Commission within the Marie Skłodowska-Curie Actions (ITN-EJD). Grant Agreement num. 642332 - GEO-C - H2020-MSCA-ITN-2014.

List of Papers

The core chapters of this thesis consist of following manuscripts:

1. **Public displays for public participation in urban settings: a survey**
   Du, Guiying, Auriol Degbelo, and Christian Kray. Proceedings of the 6th ACM international symposium on pervasive displays. ACM, 2017.

2. **Gestural Interaction with 3D Objects Shown on Public Displays: an Elicitation Study**
   Du, Guiying, Auriol Degbelo, Christian Kray, and Marco Painho. Interaction Design and Architecture(s) Journal (IxDA).*Accepted*

3. **User-generated Gestures for Voting and Commenting on Immersive Displays in Urban Planning**
   Du, Guiying, Auriol Degbelo, and Christian Kray. Submitted to the 2019 ACM CHI Conference on Human Factors in Computing System

4. **Interactive Immersive Public Displays as Facilitators for Deeper Participation in Urban Planning**
   Du, Guiying, Christian Kray, and Auriol Degbelo. Submitted to International Journal of Human–Computer Interaction.

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1 Introduction

Digital signage provides dynamic real-time, near-real-time, or non-real-time information that may be individually adapted to the location, time, situation, and who is actually watching the screen. Using simultaneous screen elements such as regions, layers and tickers (or "crawlers"), several messages, originating from different sources (and places), may be combined on one single screen. Though providing information in a fully automated way, the medium also allows for interaction with the viewer, using touch screens or other means of user control.

—Lars-Ingemar Lundstrom, author, Digital Signage Broadcasting: Broadcasting, Content Management, and Distribution Techniques, by NAB-Focal Press

1.1 Motivation

When we try to introduce the research of public displays to non-experts, the first question most people ask is "what is it". Public displays are everywhere in our daily lives. In shopping malls or streets, public displays are used for advertising, which is a major application domain for public displays (Davies, Clinch, et al., 2014). Another major use of public displays is as information boards, e.g. in the airports or train stations, public displays are showing arrival and departure information. Street signs are another kind of public displays, on which nationally or internationally agreed on symbols are shown to remind drivers of the speed limits or road hazards. People also use public displays for art and entertainment purposes, e.g. artists made public displays as an innovative use of showing art information or during the 2018 World Cup[1], during which big screens were particularly popular for large groups of people to watch football matches at city locations together.

However, as a still relatively new, undeveloped, and untested branch of computer science (Davies, Clinch, et al., 2014), public displays lack a standard definition to describe their features and capabilities adequately. According to the Oxford

[1] `https://www.st-christophers.co.uk/travel-tips/blogs/2017/where-to-watch-the-football-world-cup-2018-in-berlin` (last accessed: July 31th, 2018).

English Dictionary [2], a terminological definition of pervasive displays is described as: “electronic devices for visual presentation” (displays) which "spreading widely throughout an area or a group of people" (pervasive). But to acquire a more accurate understanding of public displays for readers, in our thesis, a public display is a sub-segment of electronic signage in public space that is "centrally managed and individually addressable for display of text, animated or video messages for advertising, information, entertainment, and merchandising to targeted audiences" (Schaeffler, 2012). It’s worth pointing out that, due to diverse research communities working on public displays from the outset, there is a number of different terms for the same concept, in this thesis, digital signage, pervasive displays, and public displays are used interchangeably to mean the same thing, i.e. "collections of digital displays deployed in public or semi-public spaces" (Davies, Clinch, et al., 2014).

As we described in the first paragraph, advertising, information presentation, signature or entertainment are four major application domains for all existing public displays. However, the key challenge for designers of future public displays is more about creating innovative new systems that deliver real value to people (Davies, Clinch, et al., 2014). This encourages us to explore the possibility of expanding the use of public displays to citizen participation in the urban planning domain.

1.1.1 Citizen Engagement in Urban Planning Processes

The realisation of a smart city vision calls for empowering citizens to enable them to participate and benefit from the city (Degbelo et al., 2016). Citizen participation aims to incorporate concerns, needs, and values from the public (e.g. citizens and communities) into the governmental decision-making processes. Implementing public participation in governmental decision-making process is thought to be vitally important to reflect public interests, manage conflicts, and achieve better decision-making results (Pateman, 1970; Fagence, 2014; Berry et al., 2002). With citizen participation, decisions might be more realistically rooted in citizen interests, the public might become more sympathetic partners to reveal hidden facts for tough decisions, and the improved support from the public might improve the quality of decisions. Though incorporating citizens into decision-making process needs effort, the potential benefits from the political, social, and economic perspectives give essential reasons to initiate citizen participation in decision-making processes (Pateman, 1970; Fagence, 2014; Berry et al., 2002). In the thesis, we follow the definition of citizen engagement from Sheedy et al. (2008), "Above all, citizen engagement values the right of citizens to have an informed say in the decisions that affect their lives". This definition emphasises the right of citizens, i.e. to be informed and heard to finally influence the decisions, which is consistent with

[2] https://en.oxforddictionaries.com/definition/pervasive

our understanding of the citizen engagement in this thesis. The term of citizen participation and citizen engagement are sometimes interchangeably used in the thesis.

A critical part of public participation theory is redistribution of power among different stakeholders, e.g. government, institutions, communities, and citizens. The concept of public participation is, however, too broad, leaving room for diverse interpretations, for the reason that citizens may be involved in a number of levels. Sherry Arnstein's ladder of citizen participation (Arnstein, 1969)is one of the most well-known theories in citizen engagement research. As a typology, his theory suggests how much power citizens get at five different participation levels. Another related public engagement typology was proposed by Rowe and Frewer (2005). This typology identified three public engagement levels, which were defined based on the direction of the information flow and the nature of information. However, we are going to use the public participation spectrum [3] from the International Association for Public Participation (IPA2), which defines five levels of realizing citizen participation: informing, consulting, involving, collaborating with, and empowering citizens. Our reasons for this decision are as follows: first, compared to other public participation theories, each of public engagement levels in the spectrum has an obvious goal and promise for the public. It provides our research with useful guidance for us to study public displays for facilitating public participation from the low level to higher levels in an urban planning process. Second, as Fechner (2016) describe in his work, the spectrum is actively referenced in the literature (Sheedy et al., 2008; Head, 2007; Creighton, 2005) and commonly used in the open government context. It is in line with the scope of the thesis, which focuses on public participation in open cities, i.e. "smart cities that are open to all citizens and facilitate participation on all level" [4].

Since the 1950s empowering citizens in decision-making processes has been intensively proposed with rapid development of participation theories and models (Arnstein, 1969; Godschalk et al., 1994; Innes, 1996; Forester, 1999; Straus, 1999; Wondolleck and Yaffee, 2000). As an important part of decision-making, public participation is also demanded in spatial urban planning, such as regional development, transport and mobility, design and use of open spaces in a city/community. Planners have also published a vast number of theories, models and case studies in the past decades (Lowry et al., 1997; Innes and Booher, 2004). Citizens usually acquire knowledge about planning projects from information in situated scene with certain circumstances (Healy, 2009). Fostering high-quality information flow among citizens and other stakeholders is one essential part to achieve a successful public participation (Rowe and Frewer, 2005; Gudowsky and Bechtold, 2013). The

[3] `https://sustainingcommunity.wordpress.com/2017/02/14/spectrum-of-public-participation/` (last accessed: July 20th, 2018).
[4] `http://www.geo-c.eu/goals` (last accessed: July 20th, 2018).

scoping of this thesis focuses on citizen participation in Germany, which is a typical example of democratic countries. In Germany, a typical urban planning project usually involves two kinds of public participation: formal participation and informal participation. Formal participation is mandatory and encompasses "all forms of legal and usual possibilities of influence and decision-making. They differ depending on current forms of democracy" (E. Müller et al., 2011). Informal participation permits and allows for "the inclusion, on certain issues, of groups who cannot (e.g. migrants) or are not yet able (e.g. children and teenagers) to formally take part in decision-making processes. It also enables interest groups or persons concerned to contribute, depending on the issue or problem" (E. Müller et al., 2011). Our research in this thesis intends to support both formal participation and informal participation for showing urban planning design alternatives to citizens and collecting feedback from them through public displays.

Citizens conventionally contribute their information in verbal or written form during specific events that are organised by local governments or planning institutions such as public hearing, workshops, and face-to-face dialogues (Sanoff, 2000; Creighton, 2005). In practice, though it is vital to integrate citizens, the cost of participation, e.g. the cost of educating oneself about the issue sufficiently, seems a severe barrier drawing citizens back from participation (Krek, 2005). The development of Information Communication Technology brings new methods to facilitate public participation in urban planning. These new possibilities are introduced in the next section.

1.1.2 Enhancing Citizen Engagement through ICT

Since it is no longer a question whether public participation is needed in urban planning processes or not (Irvin and Stansbury, 2004), the question is when and how to involve citizens. Traditional public participation technologies (e.g. public hearing) usually are blamed for low accessibility by the general public (Conroy and Evans-Cowley, 2006). For many reasons, such as work pressure and family responsibilities, citizens who are willing to participate in the urban planning process may not be able to participate. Furthermore, an important measure to ensure the success of an urban planning project is to involve a broad range of citizens in the process; which is also a major challenge (Münster et al., 2017). By traditional public participation technologies, usually only a subset of the potentially affected citizens can be reached. Further, for those who do become involved, their level of participation is often very low. Besides, Howard and Gaborit (2007) pointed out that key roadblocks to generating public interest in deeper public involvement, i.e. citizen consultation in urban planning, were three limitations: lack of interactivity; lack of a feeling of immersion; the comments are limited.

In recent years, people are trying to use Information and Communication Technologies (ICT) to deal with the challenges of traditional public participation methods and align citizen participation with the society's changes. Therefore, the notion of electronic participation (eParticipation) has been proposed and developed. Among these ICT technology forms, main attentions were put on opportunities offered by mobile technologies and computer technologies for engaging citizens in the urban planning process and overcoming the barriers and challenges of traditional public participation (Houghton et al., 2014). As each coin has two sides, technologies not only provide new opportunities for enhancing public participation, but also build potential barriers. These barriers may occur due to a lack of facilities or devices (e.g. no internet connection or no smartphone) and the complexity of technologies themselves, as stated by Gordon and Koo (2008). Besides, due the quick development of various ICT, we are in an era of information explosion. That means how to help people quickly get informed what happened without losing in the vast information ocean is another challenge. So it can be an opportunity for ICT to be useful to show selected information to citizens.

1.1.3 Public Displays for Citizen Engagement

The great civic potential of public displays has been increasingly explored by various academic communities, such as the urban planning community. For instance, Hosio and his colleagues (Hosio, Goncalves, Kostakos, and Riekki, 2015) argued that public displays, and especially interactive public displays, have great importance in gathering and diffusing information to support civic engagement in the urban planning process. Nowadays, public displays become commonly seen in public or semi-public spaces. They are getting more and more attention as a promising communication medium (Davies, Langheinrich, et al., 2012). They often serve as ambient information providers in shopping malls, schools, museums, airports, train stations and stadiums. More and more networked and interactive displays are developed and deployed (J. Müller, Alt, et al., 2010). Public displays are thought to be able to change current city life dramatically (Kuikkaniemi et al., 2011). The unique characteristics of public displays (Kuikkaniemi et al., 2011) make themselves have amazing potentials to become powerful citizen engagement tools for overcoming barriers and challenges of traditional public participation methods in the planning process.

Public displays can make public spaces into sociable places (Kuikkaniemi et al., 2011), where social communication and interaction can be enriched without intentionally or unintentionally excluding some groups' opinions. With the rapid development of computer and mobile technologies, people's social life has undergone profound changes in the last ten years. The place, such as cafes or bars, where "homes away from home, where unrelated people relate" (Oldenburg, 1999), were quintessential third places. These third places provide "neutral spaces in which diverse people with divergent views can serendipitously encounter and engage with one another". However, the prevalence of mobile or computer technologies makes those places “physically inhabited but psychologically evacuated" (Fakhry, 1973). People, especially young people, become more and more having communications with their families, friends, or even strangers via digital communication, such as Facebook, Whatsapp, and Wechat. The kind of digital communication makes analogue interaction with strangers, which helps people hear other opinions, get rarer. It is also not helpful in providing "the full spectrum of local humanity" (Memarovic and Langheinrich, 2010), creating opportunities for connecting people with different backgrounds and interest. Public displays offer an opportunity to show that digital media can not only separate people but, quite the opposite, bring people together. McCarthy et al. (2009) presented the CoCollage system, which was designed to promote community conversation in a café. Their study showed that the situated public display improved sense of community over time. Both Rubegni et al. (2011) and Wouters, Huyghe, and Vande Moere (2013)’s research revealed that public displays could act as conversation starters between both strangers and acquaintance. Moreover, Memarovic and Langheinrich (2010) illustrated the great potential of public displays for enhancing community interaction through four short scenarios. Later, they (Memarovic, Langheinrich, and Alt, 2012) presented their effort on creating the Interacting Places Framework for networked public displays aiming for promoting community interaction and place awareness. Besides, social spaces created by public displays offer the inclusive sociability and ease of association, which benefits the whole community by enabling people to participate in public decision-making process McCarthy et al. (2009).

Public displays can foster a collective awareness and support group behavioural changes. As we described above, in the context of citizen engagement, some researchers put public displays as a communication channel within groups of people. Under this research scenario, public displays even became a collaboration device, by which people constantly adapted their behaviours by observing other people’s behaviours or through feedback they received (Drochtert et al., 2015). For instance, Rogers and Brignull (2002) observed a honeypot effect around public displays. They built and placed a shared display, known as Opinionizer, which acted as the magnet drawing people together and enable them to be communally changed from being onlookers to interactors and back again. As large public displays become more affordable, more and more research effort are put on them for studying group collaboration and behaviors. Moraveji et al. (2009) found that the shared display performed better than the private display on a collaborative learning task in two science classes. To explore how people use large public displays, Peltonen et al. (2008) developed and deployed CityWall, a large interactive public display. By they observed its usage over one month, they found that people were attracted to begin using it by watching other people using it. Furthermore, a collection of models was proposed to analyse user behaviour around a public display. Examples are multi-user interaction models and 'Audience Funnel' (Ju et al., 2008; Memarovic, Langheinrich, Alt, et al., 2012; Wang et al., 2012). Memarovic, Gehring, et al. (2015) reviewed these models by examining the relationship between different interaction types and locations around public displays.

Public displays can act as a feedback channel, which supports behaviour change by providing persistent feedback about users' behaviours. This can be explained by Green Cloud [5], which is a city-scale display. By showing the city's electricity consumption level, the display helped people make some public decision, such as cutting electricity consumption. Hosio, Goncalves, Kostakos, and Riekki (2015) also found that getting feedback from groups of users is often easier than from individuals. Besides, public displays also have the potential of encouraging civic discourse and discussion (Ananny, Strohecker, and Biddick, 2004). Schroeter et al. (2012) developed an application 'DIS' to collect citizens' ideas about local topics in Melbourne. TexTales (Ananny and Strohecker, 2009) was designed to encourage European young people to share photos and SMS annotation of daily city events or discussion on controversial public issues. Similarly, Hosio, Kostakos, et al. (2012) presented Ubinion, a service that utilises large public interactive displays to enable young people to give personalised comments on municipal issues to local youth workers. Their field trials illustrated the effectiveness of public displays in collecting comments in youth.

Public displays can increase events visibility. During 2018 World Cup this summer, university canteens, pubs, and even churches across Germany are screening matches to bring people flocking. For hundreds of thousands of people in Germany, 2018 was very much a communal experience. People chose this way to participate in such significant events happened in another side of the world. Large public displays are commonly used as an extended stage in large concerts or other kinds of public events to make events visibility. Public displays can also make smaller events more visible by their everywhere deployments and their public nature, i.e. public displays can be easily accessible and available for the full spectrum of local humanity. For instance, public displays sometimes have been deployed in semi-public spaces, such as working places, to broadcast institution news or notification. Paper-based posters have the similar function as digital displays, but one advantage of public displays is that public displays can be interactive so the content shown on the displays could be easily updated. Even the manipulation of changing contents on public displays can be done remotely (Davies, Clinch, et al., 2014).

[5] `http://hehe.org2.free.fr/?language=en` (last accessed: July 20th, 2018).

As can be seen from previous work, the growing attention has been placed on using public displays for citizen participation in urban scenarios. However, little research has deeply investigated this topic from citizen participation theory perspectives. More research should be needed to fill this gap.

1.2 Objectives

The previous section mainly presented the motivation that drives this thesis. This chapter consists of two parts: the first part presents the main research questions and the corresponding sub-questions. The second part describes the scope of this thesis into details.

1.2.1 Research questions

The thesis investigates how public displays can be used for supporting citizen participation in urban planning processes. We break down the whole research into three parts, which make the research more manageable. The first part discusses the challenges and opportunities in the research of using public displays for citizen participation. The second part focus on designing interactions with public displays for citizen consultation in urban planning. The third part is concerned with the design and evaluation of the prototype of realising the public display consultation, i.e. voting and commenting. Hence research questions are phrased as follows:

RQ1: What are the main challenges and opportunities of using public displays to support citizen participation in urban settings? (chapter 3)

RQ2: How to design interactions with public displays for citizens' consulting activities in urban planning processes?

- How do citizens envision interacting with public displays to scrutinize urban planning designs? (chapters 4)
- How do citizens envision interacting with public displays to give their voting and commenting? (chapter 5)

RQ3: How to enable citizen consultation using interactive public displays in urban planning? (chapter 6)

Two sub-questions are proposed to give a comprehensive understanding of RQ2. They together contribute the completed answer to RQ2. The final results obtained from these research questions indicates the contributions, which will be presented in 6.3.1, 6.

1.2.2 Scope

This thesis explores the use of public displays for citizen consultation in urban planning scenario. To make our research manageable in three yearsthe scopes of the thesis have to be limited.

A large body of research are available that investigate the public participation from different viewpoints, the scope of which is quite broad. The public participation theory we have followed in our research is from the International Association for Public Participation (IAP2). IAP2 developed the spectrum including five different levels of public participation to help groups define the public's role in any public participation process. Compared to the other public participation theories, this typology defines clear public participation goals for each public participation level. Moreover, it sets out the promise being made to the public at each participation level. Hence, we chose this typology to be in line with our research purpose: using public displays to achieve higher levels of public participation, i.e. Consult, in urban planning processes through public displays.

In terms of urban planning, firstly we need to point out that our focus of the thesis is the urban planning process in Germany involving both informal participation and formal participation (E. Müller et al., 2011), which is our working country. But we believe the obtained results of our research should be adaptable insights, since open cities are supposed to be open to all citizens and facilitate participation on all level. For instance, we found Austria has almost the same public participation system of the urban planning as Germany (Arbter et al., 2007). Secondly, urban planning is a quite a big and complicated topic, as it is defined as "technical and political process concerned with the development and use of land, protection and use of the environment, public welfare, and the design of the urban environment, including air, water, and the infrastructure passing into and out of urban areas such as transportation, communications, and distribution networks" [6]. To make the research more manageable in the research context of urban planning, in this thesis, the urban planning scenarios are used with a focus on the design and use of open spaces in the city of Muenster in North Rhinge-Westphalia of Germany in particular.

[6] `https://mcgill.ca/urbanplanning/planning` (last accessed: August 22, 2018).

1.3 Methodology

Research motivation and objectives were described in previous chapters. This section firstly provides an overview of the research methodology of this thesis, then describes how the research methods should be applied to each sub research question with the justification about the applied methods. In all aforementioned research questions, public displays and the human are two common threads. As public displays can be grouped to one kind of designed artefacts or machines, which are used by the human, we position our research in the research area of Human-Computer Interaction with a focus on the urban planning scenarios.

Alt, Schneegaß, et al. (2012) reviewed study types for evaluating public displays and they found descriptive, relational, and experimental studies are three principal types of research for evaluating public displays. Since the relationships between different dependent variables in our research are not our primary research interest, the relational research has not been applied in this thesis. To answer the second research question, we investigated two interaction modalities to see which one would be more suitable for interacting with the large immersive public display in our study. Alt, Schneegaß, et al. (2012) pointed out that experimental research "aims at determining causality, i.e., that one variable directly influences another variable". Thus, we chose the experimental research as the approach for getting the answer to the second research question. The descriptive research was applied to answer the third research question in our thesis. The justification for choosing this study type is that, as Alt, Schneegaß, et al. (2012) note, "descriptive research is the only of the three types of where variables do not need to variate, e.g. multiple prototypes to be compared are not needed". Moreover, we applied multiple methods, i.e. interviews, questionnaires, observations, and logging, for data collection in this thesis. In the remainder of this section, we will give a detailed explanation of how these approaches and methods are used in our research.

The first research question is concerned with identifying the challenges and opportunities of using public displays for public participation in urban settings. The answer to this question is based on a literature review drawing and combining multiple research areas, public displays, citizen engagement/public participation, and urban planning. We categorised previous work along eight dimensions, as described in Chapter 2, to gather insights on the topic of this survey, i.e. public displays for public participation in urban settings. Based on the results from our analysis, we identified two key challenges and opportunities for future research in using public displays for public participation in urban contexts. Especially, we found that current research on public displays is targeting the low level of public participation, i.e. addressing the *inform* level of the IPA2'S public participation spectrum. Involving citizens at higher levels of participation has so far received little attention. The literature review provides an understanding of the current achievements and gaps of research on public displays for public participation,

The second research question is answered in part and informed by each sub research question. By these two sub-questions, we want to explore from end users' perspective, how they envision their interactions with public displays to support their consultation activities during an urban planning process. To find the answers for them, we conducted an elicitation study which belongs to the experimental study mentioned in the second paragraph of the chapter. The user-elicitation study incorporates citizens into the design process, which is a specific type of participatory design (Schuler and Namioka, 1993). This kind of user-elicitation study is used for designing two interaction interface types in this thesisnamely phone gestures and hand gestures. We want to use this methodology to produce gestures preferred by citizens, rather than gestures designed by HCI professionals who are not end-users. During the study, we used questionnaires and automated observations for collecting data during the study. The questionnaires are customised and used to ask users their background information and their personal views about two different interaction modalities. Automated observations are observed by two cameras from different views to record users' behaviours when they are performing all tasks. For analyzing the video footage data, two taxonomies are respectively applied for user-centred phone gestures and user-centred hand gestures.

Finally, the third research question strives to design and evaluate the public display prototype for citizen consultation, i.e. voting and commenting. A usability study has been designed to find the answer for this question. The study aims to validate a large interactive public display prototype, i.e. an interactive immersive video environment consisting of a mobile application plus the immersive video environment, evaluating its usability to explore how it can be improved for citizen consultation. Both qualitative data and quantitative data are collected in the study. There are also two questionnaires being used in the study, one of which is customised questionnaire collecting users' background information, and the other one is the questionnaire Usefulness, Satisfaction and Ease of Use (USE). The USE questionnaire has been developed by Arnie Lund (Lund, 2001), including 30 questions with seven-point Likert scales. All the questions are split in 4 groups: Usefulness, Satisfaction, Ease of Learning, and Ease of Use. We believe these four factors are the most important for our prototype, the aim of which is supporting citizens with diverse backgrounds and technology experience in the consulting process of the urban planning. Besides, the user interactions are also logged, e.g. time to perform the task, their specific votes and comments during the study. These log files are post-study analyzed. A semi-structured interview has also been conducted at the end of the study to investigate their perceptions of specific features of the interactive public display.

1.4 Thesis Outline

Chapter 2

Chapter 2 reviews the current research state of using public displays for public participation in urban settings. The main opportunities and challenges of using public displays for public participation are identified. Especially, one of the key challenges is that current research on public displays is targeting low levels of public participation. The first research question is answered in this chapter.

Chapter 3

Chapter 3 is more specific about exploring suitable interaction methods from users' perspective for the large public display. A study for eliciting user-defined gestural interactions is introduced. Two interaction modalities, smartphone and hands, for supporting examining urban planning materials are explored in this study. Two user-defined sets of gestures are identified, the consistency and user acceptance of which are also assessed. This chapter provides the answer to the first subquestion of the second research question.

Chapter 4

Chapter 4 provides the other part of the answer to the second research question. This part of research continually investigates the same two interaction modalities mentioned in chapter 3, for voting and commenting. Similarly, two user-defined sets of interactions with hands and smartphone, respectively, are also identified. Chapter 3 and chapter 4 together presented a study case of using user-centred approach to decide the suitable interaction method for the large public display supporting a specific public participation level, i.e. citizen consultation, in urban planning.

Chapter 5

Chapter 5 presents an usability study of a public display participation prototype with smartphone interactions. The study evaluates if the general public would be able to use it for public consultation in urban planning processes. This study also investigates user perceptions on the features of the prototype.

Chapter 6

Chapter 6 reviews the main findings of the thesis and reflects on the significance of the findings. The contributions, limitations, and the aspects of future works are discussed.

2 Public Displays for Public Participation in Urban Settings: a Survey

This chapter reviews the current research state of using public displays for public participation in urban settings. It has been published in preparation for the 6th ACM international symposium on pervasive displays as Du, Guiying, 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

Abstract. Public displays can be used to support public participation in urban settings. This article provides a survey of the use of public displays for public participation in an urban context, covering articles on this topic published between 2012 and 2016. 36 papers were selected and analysed along eight dimensions: type of political context, type of scientific contribution, standalone displays vs displays with a device, single vs multi-purpose displays, shape of displays, lab vs field study, deployment in public vs semi-public space, and the level of public participation addressed. Our analysis revealed a number of trends regarding public displays and public participation in urban settings. Inspecting these articles also led to the observation that current research on public displays is mainly targeting lower levels of public participation and that the evaluation of public displays for public participation in urban settings remains a challenge.

2.1 Introduction

Nowadays a wide range of online technologies are available for public participation, such as e-mail, web forums, chat rooms and bulletin boards (Coleman and Gøtze, 2002). However, due to the private nature of these tools, parts of the population may become marginalized if facts and information about urban life were only delivered through these channels. Public displays are a technology that has the potential to transform our urban environments and to dramatically change current city life (Kostakos and Ojala, 2013; Urban et al., 2011). Specifically, they can be used to encourage local participation by informing citizens about available opportunities

– in their immediate vicinity – to contribute to the urban life. As Goncalves et al. (2014) pointed out, public displays are useful in generating interest in a particular topic, and in channeling respondents to other mediums. There is already some research exploring a variety of ways to stimulate public participation amongst certain communities, e.g., through a sentiment dashboard that gives citizens the opportunity to express their mood about local challenges (Moritz Behrens, Valkanova, Schieck, et al., 2014), by collecting citizens' feedback via voting systems (Claes, Slegers, and Vande Moere, 2016; Schiavo et al., 2013) or by using tangible interaction to explore different forms of community engagement (Claes and Vande Moere, 2015). Public displays as pervasive technologies have the potential to reach a broader group of stakeholders. The well-known honeypot effect (Brignull and Rogers, 2003) is one factor that public displays can use to draw more attention from potential participants. However, up to now there has been comparatively little research looking into how public displays are used for public participation in urban settings. This is the main motivation for the present work as it reports on a systematic literature survey on this topic.

Public participation can be defined in different ways. Throughout this article, we will use the definition from the European Institute for Public Participation (European Institute for Public Participation (EIPP), 2009), which defines public participation as: "the deliberative process by which interested or affected citizens, civil society organizations, and government actors are involved in policy-making before a political decision is taken. By deliberation we mean a process of thoughtful discussion based on the giving and taking of reasons for choices". This definition emphasizes the involvement of stakeholders to come to a shared understanding of issues and solutions. While public participation can bring great value to all stakeholders, more efforts are needed to facilitate public participation and realize its full potential. Developing and emerging information technologies have great potential to support citizen participation in decision-making processes (Hanzl, 2007). As one kind of information technology, public displays have proven to be able to facilitate participation opportunities for citizens through interactions such as questionnaires, voting, and discussion via simple text entry (Hosio, Goncalves, Kostakos, and Riekki, 2014; Steinberger et al., 2014; Moritz Behrens, Valkanova, Schieck, et al., 2014).

In this paper, we report on a survey on the current development of public displays for supporting public participation in urban environments. We focus on studies published on the ACM digital library between 2012 to 2016, and try to give a thorough analysis of the papers surveyed to give some inspiration for future research on public displays in this context. Our contribution is two-fold. First, we provide a review of recent research progress of using public displays for public participation in urban settings by analysing various research dimensions of public displays in these papers. Second, we summarise the challenges and opportunities for future studies on achieving higher levels of public participation by using public displays.

The paper is organized as follows. We first briefly review related work on surveying research in the public display field. We then describe our data collection process in detail, including the inclusion criteria we used for selecting papers from ACM digital library. The main part of the paper reports on the analysis of the collected papers, points out current research trends, challenges and opportunities, and reflects on the limitations of our work. The paper concludes by briefly summarizing our main contributions.

2.2 Related Work

An early survey[1] on large high-resolution displays was carried out by (Tao Ni et al., 2006). The survey covered aspects such as hardware configurations, rendering, steaming, as well as application areas of large high-resolution displays. Tao Ni et al. (2006) mentioned several challenges with respect to research on large displays. These included overcoming variations of color and luminosity which may easily break the illusion of a single seamless display; building large-scale, high-resolution headtracked stereoscopic displays; creating displays that can easily be reconfigured and support diverse form factors (e.g., flat, curved); the development of effective interaction techniques for large public displays; and presenting empirical evidence as to the benefits and limitations of large high resolution for a range of tasks.

Surveys focusing specifically on interaction techniques for large displays were presented in (Bierz, 2006; Khan, 2011). In his article, Bierz (2006) discussed gaze tracking, head tracking, body tracking and gesture interfaces as possible interaction techniques. Khan (2011) listed at least four means of conveying information to, and receiving information from a large display: speech, tracking, gestures and haptics.

Ardito et al. (2015)'s comprehensive survey was concerned with the evolution of the use of interactive large displays over the years. Ardito et al. (2015) proposed five classification dimensions for previous research on public display: visualization technology (e.g., projection or monitor), display setup (e.g., horizontal, vertical, diagonal, or floor display), interaction modality (e.g., external devices, touch or other body movements), application purpose (e.g., productivity, entertainment, social interaction, gaming and advertising), and location (e.g., city, office, university/school, conference).

[1] 'Survey' in this section refers to academic writings on public displays (i.e., overview of work done in the field), not to survey research (i.e., data collection about a group of people through interviews or questionnaires).

According to their findings, before 2004, both projections and monitors were used. Since 2004, however, projections have been more frequent than monitors. In addition, the vertical setup is still the most popular and currently trailed by the horizontal setup. There are commercial solutions available for the vertical and horizontal setup, but all other setups are still in an experimental phase. As for interaction modalities, touch-based interaction is the oldest and still most used modality, but there is a growing number of systems tracking the users' body movements to realize interaction with large displays. Most public displays are designed to provide a specific utility to their users (i.e., they are designed for productivity). Regarding location, installations of displays in offices prevailed in the earlier years. However, as Ardito et al. (2015) observed, systems are increasingly installed in cities, universities, schools, and sites of cultural interest in recent years. Challenges for large displays that were mentioned in (Ardito et al., 2015) include blended interaction in ubiquitous environments, better understanding the potential of large displays to foster collaboration, making public displays accessible to disabled people, and the evaluation of public display research.

As this section illustrates, previous surveys looked at various aspects, produced a set of different insights and identified a series of challenges revolving around public displays research. None of them has however specifically looked at the benefits and challenges of utilizing public displays for public participation in urban settings. This paper aims to fill that gap.

2.3 Data Collection

In order to ensure the analysis of relevant papers in our survey, we organized the selection process by steps as described in this section. At the beginning, we defined inclusion criteria of the papers to be surveyed: the main criteria for including a paper in our survey were (a)the paper uses public displays as an object of study; (b) the paper is related to public participation; and (c) the context of the paper is related to urban space. Next, keywords were selected.

We screened all the papers from the PerDis conference from 2012 to 2016 manually. We read all the papers' abstracts, the introduction and conclusion, while applying our inclusion criteria. After this step, 12 papers were selected. After reading these 12 papers carefully, 10 papers were kept which really fit our purpose. We analysed the author keywords of these 10 papers using Wordclouds[2]. It turned out that authors publishing at PerDis use the keyword "engagement" (instead of "participation") as Figure 2.1 shows. Based on this, we used two groups of keywords to search for

[2] `http://www.wordclouds.com/` (last accessed: February 2, 2017).

Fig. 2.1: Author keywords of relevant papers from PerDis on public participation in an urban context.

relevant papers in the ACM digital library: (public display, urban, participation) and (public display, urban, engagement). The time frame was limited to 2012-2016 to catch the most recent trends since the PerDis conference series started. The search on the ACM digital library was performed in January 2017.

This keyword searches returned 40 papers from various outlets as raw materials for our review. After a thorough reading, a total of 36 papers were identified as falling within the scope of the study, namely using public displays in urban settings for public participation (or citizen engagement). In Table 2.1, we sketch the distribution of all the papers over conferences and journals. Additionally, we built an online repository that is publicly available[3] and also contains the meta-data of the selected papers. The meta-data includes the paper title, publication year, and the conference or journal informations. The data collected was organized along the following dimensions:

Type of political context: as indicated in (European Institute for Public Participation (EIPP), 2009), "any approach to understand the use of public participation must take into account the cultural and political context". Therefore, special attention

[3] `https://github.com/robinhood747/Papers-list`

Outlets	***Frequency***	***Percentage***
ACM International Symposium on Pervasive Displays (PerDis)	11	30.5%
ACM CHI Conference on Human Factors in Computing Systems (CHI)	5	13.9%
Media Architecture Biennale (MAB)	4	11.1%
ACM Conference on Computer-Supported Cooperative Work and Social Computing (CSCW)	2	5.5%
ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp)	2	5.5%
International Conference on Communities and Technologies (C&T)	2	5.5%
International Conference on Mobile and Ubiquitous Multimedia (MUM)	2	5.5%
Nordic Conference on Human-Computer Interaction (NordiCHI)	2	5.5%
ACM International Conference on Interactive Surfaces and Spaces (ACM ISS)	1	2.8%
Australian Conference on Human-Computer Interaction (OzCHI)	1	2.8%
British Human Computer Interaction Conference (British HCI)	1	2.8%
Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI)	1	2.8%
Participatory Design Conference (PDC)	1	2.8%
Personal and Ubiquitous Computing (JPUC)	1	2.8%
Total	***36***	***99.8%***

Tab. 2.1: Selected outlets and paper frequencies

was given to the countries where the studies presented in the papers surveyed were conducted.

Type of scientific contribution: Jacob O. Wobbrock and Kientz (2016) proposed seven research contribution for the field of Human Computer Interaction (HCI) which are re-used in this article. These are (1) empirical (i.e., they provide new knowledge through findings based on observation and data gathering), (2) artifact (i.e., prototypes which reveal new possibilities and facilitate new insights), (3) methodological (new knowledge that informs how research is carried out), (4) theoretical (i.e., improved concepts, definitions, models, principles, or frameworks), (5) dataset (i.e., useful corpora for the research community), (6) surveys (i.e., synthesis of work done on a research topic with the goal of exposing trends and gaps), and (7) opinion (i.e., essays which seek to change the mind of the reader through persuasion).

Type of public display: Buerger (2011) distinguished between two types of interactive public displays: "standalone public display" (where no additional device is required to interact with the screen) and "public displays in combination with mobile devices" (where mobile phones are used to interact with the display). This distinction, with some slight change, was adopted for the classification. Instead of "public displays in combination with mobile devices" (which is restriced to mobile phones), "public displays in combination with additional devices" was chosen as a dimension to include devices such as tablets, physical push buttons, physical cursors, microphones, tangible user interfaces and mouse devices.

Single-purpose vs multi-purpose displays: according to previous work (Katsanos et al., 2014), if a public display just provides one single "application" or interface, it can be understood as a single-purpose display. In contrast, a multi-purpose public display is a display that provides multiple types of applications or services (e.g., information browsing, games, galleries, and polls) concurrently (Katsanos et al., 2014). The essential difference between single-purpose and multi-purpose public displays is the number of applications on public displays (Kostakos and Ojala, 2013).

Shape of the display: the shape of a public display can vary between the most common shape (a single rectangular and flat shape) to unconventional shapes (e.g. circular or 3D displays). The display shape can influence the design of interaction and visualization methods of a public display.

Type of space where the display has been deployed: two types of spaces are considered, namely public and semi-public. Semi-public spaces are defined after (Bødker et al., 2014) as "spaces that are owned and controlled by a private entity or institution, but open for the public (e.g., a café, a train, a movie theatre)". Public spaces are in contrast, owned and controlled by the government or local authorities.

study vs field study: to denote whether the study was conducted in a laboratory or in the real world. In the context of public participation, there is arguably a very big difference in terms of ecological validity between the two options.

Level of public participation addressed: While Arnstein's eight rungs on the ladder of citizen participation (Arnstein, 1969) are a common approach to describe the levels of citizens engagement, this paper uses the International Association for Public Participation (IPA2)'s Public Participation Spectrum[4]. This spectrum defines five types of engagement with stakeholders and communities: *inform, consult, involve, collaborate*, and *empower*. The spectrum has been developed from the perspective of the government, and the five types of participations should be considered from that perspective. According to the IPA2, *inform* refers to transmitting information from the government to the public; *consult* means giving the public the possibility to give feedback on the information provided; *involve* denotes working directly with the public throughout the decision process to ensure that public concerns and aspirations are consistently understood and considered; *collaborate* refers to partnering with the public in each aspect of a decision, including the development of alternatives and the identification of a preferred position; and *empower* means that the goverment places the final decision-making into the hands of the public.

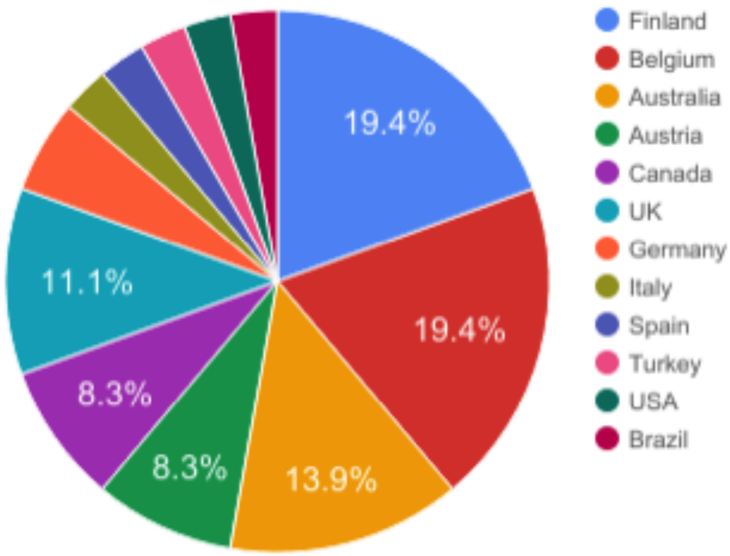

Fig. 2.2: Distribution of the studies according to countries.

[4] `http://bit.ly/2kkPFAM` (last accessed: January 31, 2017).

Main research contribution (s)	(1)	(1) & (2)	(1) & (3)	(1) & (4)	(3)
Frequency	18	13	2	2	1
Percentage	50.0%	36.1%	5.6%	5.6%	2.7%

Tab. 2.2: Types of the main research contributions of the papers surveyed.

2.4 Analysis

Using the dimensions detailed in the previous section, we analysed the papers we collected to gather insights on the topic of this survey, i.e. public displays for public participation in urban settings. This analysis yielded a number of insights and trends that we report on in the following.

Type of political context: as Figure 2.2 illustrates, the overwhelming majority of the papers surveyed report on research done in developed regions of the world (i.e., Europe, North America, Australia). Lessons learned about deployments of public displays in other regions of the world, e.g., Asia and Africa, are rare. This suggests that research on public displays for public participation still needs to expand to embrace a wider audience, and a greater diversity of political contexts. HCI4D (HCI for development, see Dell and Kumar (2016)) already has documented studies in Asia, Africa, as well as Central and South America.

Type of scientific contribution: The main contributions of the surveyed papers are summarised in Table 2.2. The collected papers show the fundamental role of empirical studies for the topic of interest in this paper. HCI as a research field has an inclination towards empirical contributions (see for example (Oulasvirta and Hornbæk, 2016)), and research on public displays for public participation seems to be no exception. In order to broaden the existing body of knowledge, it would be desirable to see more theoretical, methodological, artifact, opinion and survey contributions. In addition, though artifacts are "often accompanied by empirical studies but do not have to be, and sometimes should not be" (Jacob O. Wobbrock and Kientz, 2016), there seems to be a close association between artifact and empirical contributions with respect to public participation.

Type of public display: among the 36 papers surveyed, three were about exploring people's awareness of public displays, about their use for e-participation through a workshop (Thiel, 2015), about presenting arguments by analyzing works empirically grounded in field observations and design research (Foth et al., 2016), and about focusing on describing certain participatory design methods (Baumann et al., 2016). Since these did not specifically study public display as artifact, they are not included in the current discussion. In the remaining 33 papers, the number of studies on the two types of public displays (standalone and with device) were approximately equal. This may indicate that both types are equally relevant for public participation. The dataset did not allow to infer clear trends over time in this respect. In addition, touch, air gestures and body gestures were the most common interaction methods used for standalone public displays. Different kinds of physical buttons and handheld devices were the most common additional devices that were combined with public displays.

Single vs multi-purpose displays: Table 2.3 shows that there is currently little research on multi-purpose public displays. Compared to public displays with a single purpose (e.g., supporting citizen voting in (Schiavo et al., 2013)), few papers dealt with multi-purpose public displays. A notable exception is Jurmu et al. (2013), who implemented two different services for different purposes. One service is a slot machine application, which provides shopping information, while the other one displays recent tweets around the display in a map-based view. Hosio, Goncalves, Kostakos, and Riekki (2014) pointed out that multi-purpose public displays (MPDs) – which can be "customized to offer something for everyone" – are envisioned to be popular in the future. The potential of MPDs is to "offer something for everyone", which could be an attractive feature in an urban context. They can indeed be calibrated to offer participation opportunities to diverse user groups. Deploying MPDs for public participation might come at a price though: as Hosio, Goncalves, and Kostakos (2013) observed, popular applications on MPDs proportionately attract fewer targeted users. The data collected (Table 2.3) does not give enough evidence to claim that the apparent tension between popularity and target users' attraction is the reason for the very low number of studies on MDPs for public participation. It rather suggests that this tension could benefit from further investigations. Future studies should also shed light on the respective effectiveness of both types of displays (single and multi-purpose) for citizen engagement.

Shape of the display: according to our analysis, most previous studies (25) have dealt with public displays with rectangular shape. Still, there were a few unconventional shapes such as different appearances of lightings (Luke Hespanhol and Tomitsch, 2012), chained public displays (Sodangi et al., 2013), or a large multi-dimensional media facade (Moritz Behrens, Valkanova, Schieck, et al., 2014). Ten Koppel et al. (2012) performed a field study comparing three types of chained displays: flat, concave, and hexagonal. They observed that flat displays created the strongest honeypot effect and attributed this to the users being able to see manipulations and effects of actions at the same time.

Type of space: Table 2.3 shows that several investigations were conducted in public spaces while few studies took place in semi-public spaces or in both places together. For instance, one paper (Memarovic, Langheinrich, Alt, et al., 2012) reported two field studies conducted in a main library and the center of the city at the same time.

Another group (Koeman et al., 2015) deployed their voting system in coffee shops but visualized the voting results outside the shops. According to Fortin et al. (2014), the type of space can invite different degrees of public participation. We analyzed the numbers of participants involved, and the duration of studies in the different types of space. The majority of field studies in public spaces lasted more than 5 working days (sometimes up to 12 weeks) while most of field studies in semi-public spaces took less than 5 days. The small sample of papers arguably puts some limits on generalizability, but this observation remains a trend to watch out for in the future. In addition, the number of participants involved in the majority of studies in public spaces was bigger than the number of participants involved in studies in semi-public space. This trend also needs further confirmation through larger sample sizes.

Lab vs field study: the data collected shows that nearly all papers used field studies to test their ideas. Only one paper (Mahyar et al., 2016) mentioned the use of laboratory studies, but did not provide enough detail as to the why, the benefits and the drawbacks. Our survey provides additional evidence for the point that ecological validity is being prioritized over internal and external validity (Alt, Schneegass, Schmidt, et al., 2012). In addition, few papers (Claes and Vande Moere, 2015; Claes, Wouters, et al., 2015) emphasized using "controlled in-the-wild studies" as a viable alternative in evaluating more complex interaction methods in public spaces. The controlled in-the-wild study could be valuable if researchers want to reduce the practical effort of involving participants in real-life contexts while preserving some features of the field study. Furthermore, the deployment duration of public displays in the field varies from study to study, and no specific pattern (e.g., a recurrent minimum/maximum/average field study duration) emerged from the papers we examined.

Level of public participation addressed: most of the research emphasized community awareness, interaction, discussion for the purpose of citizen engagement or public participation in urban environments. Voting applications, mainly related to local issues, were also common. Comparing the focus of selected studies to the level of public participation as defined above, we found that most studies address the level of *inform*. At this level, there is no expectation of receiving feedback from the citizens (and of course the level of the public impact is rather low). The studies surveyed used different kinds of visualizations on public displays (e.g., lights, text, picture or voice) to show information to communities, and explore how community awareness should be enacted. Besides, there are few papers which focus on deploying voting applications on public displays and on providing real-time voting results. Overall, very few projects currently address the level of *consult* and even fewer operate on the *collaborate* level. This was the case for the work presented by Mahyar et al. (2016)

Dimension	*2012*	*2013*	*2014*	*2015*	*2016*	*Total*
Standalone	3	5	3	4	1	16
With a device	1	3	5	4	4	17
Public space	2	7	6	6	3	24
Semi-public space	0	1	2	1	1	5
Semi-public & public space	2	0	0	1	0	3
Semi-public & Lab space	0	0	0	0	1	1
Multi-purpose	1	1	0	0	0	2
Single-purpose	3	7	8	8	5	31

Tab. 2.3: Papers surveyed according to the types of public displays examined, their purpose, and the type of space where they are studied.

who worked towards engaging citizens and professionals in the complex process of collaborative urban design. *Empower* was not tackled by any the papers examined.

2.5 Discussion

Based on the results reported on in the previous section, we identifed two key challenges/opportunities for future research in using public displays for public participation in urban contexts. In the following we discuss those and also briefly reflect on limitations of our study.

Current research on public displays is targeting low levels of public participation. As mentioned above, current research has, by and large, addressed the *inform* level of the IPA2's public participation spectrum. Involving citizens at higher levels of participation has so far received little attention. Moving up on the spectrum of public participation is challenging, but is generally desirable and also constitutes a research opportunity. Higher levels of public participation mean greater involvement of the public in public decision making processes. As Milakovich (2010) indicated: "efforts to increase citizen participation result in better governmental decisions that involve larger numbers of citizens and are, therefore, more acceptable and legitimate to the majority of people".

Achieving higher levels of public participation is challenging for several reasons. Considering urban planning as one example area where this would be desirable, Rittel and Webber (1973) indicated that it is "a field with confronting social problems that needs to balance the concerns of a wide range of stakeholders to reach solutions". This applies to other application areas for public participation in urban context as well. Current research has mainly focused on citizens. Embracing additional stakeholders such as civil society organisations and governments actors poses the question of designing displays which supports smooth communication between the different parties. For example, future research may put a focus on visualizing different kinds of urban planning information in a way which could be easily understood by regular citizens. Also designing new interactions for and with such urban planning information offers interesting avenues for future work.

Evaluating public displays for public participation is a challenge. This applies both to the evaluation methods to use as well as to evaluating various aspects of relevance in this context. As we mentioned above, the types of space where public displays are deployed can invite different degrees of public participation. Here, it would be desirable to establish both methods to evaluate these aspects and a basic understanding of the relationship between space and partcipation. Similar research questions emerge in relationship to the impact of different interaction techniques on citizen engagement and the influence of the type of public display (standalone, with device, single purpose, multi-purpose) on public participation. Finally, a central open question is: how to evaluate the effectiveness of public displays in supporting higher levels of public participation in general? This calls for an evaluation framework which helps to assess public displays with respect to their achievements regarding higher levels of public participation.

Limitations of the study: Since 36 is a relatively small number of papers to analyze, this limits the generalisability of the results of our survey. Moreover, the keywords used might have limited the number of papers retrieved. For example, some additional keywords (e.g., community involvement, urban screens or public screens) might have produced a larger set of papers to analyze. Besides, the focus of the survey was on recent trends (i.e., 2012 onwards), but it is worth mentioning that there is a rich history before 2012 on exploring the use of public displays for community interaction in different settings, e.g., BigBoard (Maunder et al., 2011) deployed for sharing informations within communities in a township in a developing world; TexTales (Ananny and Strohecker, 2009) collecting public expressions in different developed countries; and the Urban Screens conferences which began to explore the potential use of screens for urban society in 2005.

The study is also limited by the number of outlets that we considered. The ACM digital library indexes many important outlets in the HCI field (including the PerDis proceedings) and we therefore considered it to be a suitable source to collect relevant papers from. By extending the survey to include other electronic libraries (e.g., Science Direct, IEEE Xplore Digital Library, ISIWeb of Knowledge and Springer Link), a more comprehensive overview of work done on public displays for public participation could have been produced. In addition, "increasing citizen participation" was essentially discussed through the lens of reaching higher levels of the IPA2's public participation spectrum. Increasing citizen participation might involve further aspects.

For instance, exploring alternative ways of enabling participation (e.g., art, play) and promoting them might also contribute to pushing current public participation forward. Finally, though we carried out a thorough analysis, we did not contact the authors of the surveyed papers directly regarding the characteristics of their work. It is thus possible that our study might have misrepresented some aspects as the classification of the papers is based on our understanding of what the authors did. Consequently, future work could include data from additional outlets and involve authors in the classification process of their papers along the dimensions introduced we proposed.

2.6 Conclusion

In this paper we reported on a study exploring the use of public displays for supporting public participation in urban settings. We presented a snapshot of research done from 2012 to 2016 based on papers indexed in the ACM digital library and analyzed current trends regarding different dimensions: political contexts, scientific contribution, type of public displays, single purpose vs multi-purpose displays, shape of public displays, lab vs field study,type of space, the levels of public participation addressed. We observed that the current research on public displays lacks diversity of political contexts and that beyond empirical contributions more types of scientific contributions would be desirable to add diversity to the existing body of knowledge. We also identified a gap of research regarding the respective effectiveness of single purpose displays and multi-purpose displays in achieving public participation. Rectangular shapes of displays were most common, and most research emphasized community awareness, interaction and discussion for the purpose of public participation. Finally, we identified two challenges/opportunities: designing public displays which support higher levels of public participation and evaluating them in the context of public participation.

3 Gestural Interaction with 3D Objects Shown on Public Displays: an Elicitation Study

This chapter investigates the suitable interaction methods about how people examine urban planning designs on public displays. The chapter has been accepted in Interaction Design and Architecture(s) Journal (IxDA) as Du, Guiying, Auriol Degbelo, Christian Kray, and Marco Painho. (2018). "Gestural Interaction with 3D Objects Shown on Public Displays: an Elicitation Study"

Abstract. Public displays have the potential to reach a broad group of stakeholders and stimulate learning, particularly when they are interactive. Therefore, we investigated how people interact with 3D objects shown on public displays in the context of an urban planning scenario. We report on an elicitation study, in which participants were asked to perform seven tasks in an urban planning scenario using spontaneously produced hand gestures (with their hands) and phone gestures (with a smartphone). Our contributions are as follows: (i) We identify two sets of user-defined gestures for how people interact with 3D objects shown on public displays; (ii) we assess their consistency and user acceptance; and (iii) we give insights into interface design for people interacting with 3D objects shown on public displays. These contributions can help interaction designers and developers create systems that facilitate public interaction with 3D objects shown on public displays (e.g. urban planning material).

3.1 Introduction

An important measure to ensure the success of an urban planning project is to involve a broad range of citizens in the process; however, this is also a major challenge (Münster et al., 2017). First, usually only a subset of the potentially affected citizens can be reached. Further, for those who do become involved, their level of participation is often very low. Key roadblocks to generating public involvement relate to how information about participation opportunities are distributed, what media are chosen to disseminate information, and other barriers that affect citizens' capability and willingness to actively take part. In this context, one way to potentially improve citizen participation is to use public displays (Brignull and Rogers, 2003; Memarovic, Langheinrich, Alt, et al., 2012). Public displays have become ubiquitous, and they are now found in many public or semi-public spaces such as shopping malls, transportation hubs, plazas, museums and various other urban settings. They can lower the barriers for citizens' who want to take part in public decision-making processes such as urban planning in two ways: these public displays can make information available at locations that are frequently visited, and they can enable everyone to participate actively, regardless of their age, background, or experience.

In addition to providing easy access to urban planning materials and facilitating in-situ interaction, public displays also have the potential to stimulate learning. Interacting with public displays significantly increases recall (Alt, Schneegass, Girgis, et al., 2013), and Barth and W. Müller (2017) also reported positive feedback from users regarding the use of public displays for learning. In another study, Giovannella et al. (2013) implemented a mid-air gesture interface integrating smart learning and tourism by Kinect, which resulted in a very rapid learning curve. Nevertheless, there has been limited use of such displays (and displays that connect with mobile devices) for tracking and visualizing data in a learning context (Verbert et al., 2014). Recent work (Du, Degbelo, et al., 2017) has also highlighted the need for further research on the promising combination between urban planning and interactive public displays: current research has indicated that public displays usually involve only low levels of public participation (displays focus on informing citizens rather than enabling them to voice opinions or make suggestions). The goal of this article is to address the following question: *How do users envision interacting with public displays - using mobile phones and gestures to scrutinize urban planning material, i.e. 3D objects*? By answering this question, we aim to contribute insights into how public display designers can engage a broader range of citizens to more actively participate in urban planning projects.

In the following, we report on an elicitation study for determining the hand and phone gestures people make in the context of interacting with 3D objects shown on public displays. We asked participants to spontaneously perform gestures to accomplish tasks in the context of actively participating in urban planning. Our main contributions are as follows: (i) We identify two user-defined gesture sets that participants produced using their hands or using a mobile phone when performing several examination tasks with the 3D objects shown on a large public display; (ii) we assess the two gesture sets regarding their consistency and user acceptance; and (iii) we derive several implications for the design of interactive public displays in the context of interacting with 3D objects. Our contributions can help designers select suitable interaction modalities for citizen consultations via public displays (e.g. in the context of urban planning). In addition, our findings pave the way for the design of smart learning ecosystems (Giovannella, 2014) by connecting a network of citizens, urban planning materials, and public display technology in order to facilitate active citizen participation in urban planning processes.

In the following sections, we first review work related to using public displays for public participation and gesture interaction. We then describe the elicitation study we conducted, and then we report our key results and discuss their implications for system design and gestural interaction for public displays. Finally, we conclude our research by summarizing our main contributions and outlining future work.

3.2 Related Work

Since the aim of the current work is to gain insights into participants' perceptions about and needs for interacting with 3D objects shown on public displays, this section reviews previous research that has been done on two relevant topics: public displays for public participation and gestural interaction.

3.2.1 Public Displays for Public Participation

The International Association for Public Participation (IPA2)'s Public Participation Spectrum [1] defines five levels of realizing citizen participation: informing, consulting, involving, collaborating with, and empowering citizens. To engage such citizen participation, studies have explored using a variety of online technologies (Zolotov et al., 2017), and various means have also been explored for encouraging citizen participation specifically with public displays. For instance, some public displays have included voting applications (Claes, Slegers, and Vande Moere, 2016; Schiavo et al., 2013) regarding local issues. In another study, (Hosio, Goncalves, Kostakos, and Riekki, 2014) used applications on public displays to disseminate information about the construction of a long-term renovation project and to enable citizens to provide in situ feedback to the institution responsible for the renovation project. Taking another view, Goncalves et al. (2014) observed that public displays are instrumental in generating interest, but this interest comes at the price of noisy feedback. In another study, Moritz Behrens, Valkanova, Brumby, et al. (2014) gave citizens the opportunity to express their feelings about local urban challenges on media façades through tangible artifacts. Despite these participation-invoking efforts, Du, Degbelo, et al. (2017)'s survey found that current research on public displays in urban settings still mainly targets low levels of participation. They observed that most research on public displays for public participation just address the *inform* level of IPA2's

[1]https://sustainingcommunity.wordpress.com/2017/02/14/spectrum-of-public-participation/ (last accessed: July 20th, 2018).

public participation spectrum. Further research efforts are thus needed to achieve higher levels of citizen participation, which may then result in “better governmental decisions that involve larger numbers of citizens and are, therefore, more acceptable and legitimate to the majority of people” (Milakovich, 2010).

The increasing use of large public displays in urban public life brings new challenges and opportunities for both designers and users, especially regarding how to provide suitable interaction modalities to retrieve information from or perform useful tasks for citizens in different scenarios. In addition, citizens are very diverse in their age, background, and experience with technology. Looking at current research on large interactive displays, there are four main interaction modalities for large public displays: touch, tangible objects, external devices, and body (Ardito et al., 2015). However, while the modalities of touch and tangible objects have been used more frequently for horizontal displays (Rogers, Lim, et al., 2006; Dohse et al., 2008), they may be unsuitable for large vertical displays, e.g. if displays are very large or unreachable. In this research, we want to make large displays accessible to a broader group of people. For this reason, in this article we focus on gestural interaction, i.e. hand gestures and phone gestures.

3.2.2 Gestural Interaction

Since gestures are considered to be an intuitive method of interaction, it is not surprising that much research has been done in this area for a broad range of applications. For instance, Medrano et al. (2017) looked into remote pointing when using mobile devices, and they identified three categories of pointing gesture interactions, namely free-hand pointing, see-through pointing and device pointing. Rovelo Ruiz et al. (2014) examined gestures for interacting with 360° panoramic recordings, both for an individual and collocated usage. Further,Kray et al. (2010) studied how people use gestures on mobile phones to interact with other types of devices (i.e. another phone, a tabletop, and public display). They reported that the concept of phone gestures was very easy to understand and to put into practice; their participants indicated that phone gestures would work well for interacting with public displays. Jacob O Wobbrock, Morris, et al. (2009) stressed the importance of involving users in coming up with gestures for a given task, reporting that “three experts cannot generate the scope of gestures that 20 participants can”. Further outcomes from previous studies include a gesture set for 3D manipulations of distant objects (Liang et al., 2012), a gesture set for the exploration of large datasets through active tokens (Valdes et al., 2014), and insights from sign language interpreters about hand gestures that are most comfortable when performed repeatedly (Rempel et al., 2014).

Example work specifically directed towards gestural interaction with public displays include the following studies (Fikkert, Van Der Vet, et al., 2009; Nancel et al., 2011; Walter, Bailly, Valkanova, et al., 2014): Fikkert, Van Der Vet, et al. (2009) identified a set of gestures through which commands (e.g. panning and zooming) can be issued to a large interactive display 'with ease'. Panning and zooming were also the focus of a study by Nancel et al. (2011), though they looked closely into the performances of the different types of gestures used for these two tasks. They found that two-handed gestures were faster than one-handed ones and that linear gestures are generally faster than circular ones Nancel et al. (2011). Walter, Bailly, Valkanova, et al. (2014) investigated the usability of a system that allows people to vote on a given topic, and they concluded that people (if provided no hint) use pointing and dwelling gestures to successfully select items. As the studies mentioned above illustrate, gestural interaction is a vibrant area of research and has the promise of immediate usability (when implemented appropriately). The study presented in the next sections aims at exploring gestures that are helpful (and natural) to people when it comes to interacting with 3D objects.

3.3 User Study

User-centered design is an approach that puts the user in the center to elicit input from them when interacting with technologies and allowing them to define intuitive and easy interactions (Obaid, Kistler, Kasparavičiūtė, et al., 2016). In the spirit of participatory design, one aim of our elicitation study is to explore user-defined hand gestures and phone gestures to interact with 3D objects shown on large public displays. The motivation for the study, as mentioned in Section 1, is that public displays hold great potential for providing a broad set of citizens with access to urban planning material and that higher interactivity with displays can lead to higher information recall (Alt, Schneegass, Girgis, et al., 2013). We focus only on *enabling users to examine the 3D objects shown on public displays*, and in particular on tasks such as *showing the back/right/left side, repositioning, resizing (bigger/smaller) and selecting a building*.

3.3.1 Overview and Rationale

Immersive technologies have been employed in urban planning processes for decades, either for experts or for different groups of stakeholders. In our study, we represented urban planning material as 3D objects integrated into panoramic video footage, which was projected on three large screens in a room. This setting is also known as an Immersive Video Environment (IVE). IVE is a type of audiovisual simulation that provides a feeling of immersion, where users are immersed in panoramic video footage to provide them with a strong sense of being at the real-world site depicted in the video. This immersion can promote user engagement (Drettakis et al., 2007). 3D objects are increasingly used when presenting urban planning projects to citizens and can be combined with the IVE. While 3D objects provide a realistic and intuitively understandable view of what is planned, they also, however, introduce new challenges regarding how they can be examined more closely. These are two reasons why we had participants interact with 3D objects. We chose to investigate the use of both hand gestures and phone gestures, because they are two representative interaction modalities (Ardito et al., 2015). In addition, hand gestures can lead to a more immersive user experience (Ren et al., 2013) because they do not require any external device. Furthermore, many people are very familiar with smartphones, and using these devices helps to solve some privacy problems: people can input personal data without worrying about it being visible for third parties.

As one goal of our study was to elicit user-defined hand and phone gestures, we did not want the participants' behaviors to be influenced by technical issues such as gesture recognition issues or smartphone sensor technologies. No feedback from the system, i.e. IVE was provided during their performance. We also provided the participants with a transparent mockup prototype phone (as shown in Figure 3.1) instead of a real phone. All participants were encouraged to disregard any gesture recognition or sensor technologies issues, and we asked them think of the mockup prototype as a futuristic smartphone. They were told that the mockup prototype could have any features they wished for and that it would be capable of understanding and recognizing all the gestures they would perform. In this way, we followed the same principles as followed by previous research (Medrano et al., 2017; Jacob O Wobbrock, Morris, et al., 2009; Ruiz et al., 2011). In addition, we wanted to remove the gulf of execution (Hutchins et al., 1985) from the user-device dialogue to make sure our observation of users' unrevised behavior was not influenced by the gesture recognition issue or the sensor technologies.

All the tasks that participants performed were played back to them as audio messages generated via a free online text-to-speech service [2]. Two additional questions for evaluating the ease and appropriateness of each gesture were also played by audio message after each task. The rationale behind this was to avoid users' misunderstanding of the tasks because of English pronunciation problems and to ensure consistent delivery of the instructions. All participants were video-recorded during the whole study session. Our study followed a within-group design. We used two panoramic videos spanning all three screens, which were captured from two different sites of our city. As said above, we focused on how participants examined 3D objects.

[2] `http://www.fromtexttospeech.com/` (last accessed: July 20th, 2018).

3.3.2 Selection of Tasks

According to IPA2, two key goals for citizen consultation are to keep the public informed and to obtain public feedback. To choose the suitable interaction activities for realizing these goals, we determined which tasks to include in our study by first classifying tasks into two categories: examining urban planning material, i.e. 3D objects, and giving feedback on it. Since existing research has explored providing feedback via public displays various ways, such as through entering text or voting (Steinberger et al., 2014; Cheverst et al., 2003), we focused mainly on the first category: examining 3D objects. In doing so, we also followed the typology of general interactivity (Crampton, 2002) for geographic visualization. The selected tasks are representative of typical tasks that can be used in the scenario of examining 3D objects shown on large public displays. In total, we asked each participant 14 questions, seven for each gesture type, using the following two templates: *Which hand gesture would you use to do ACTION?* and: How would you use your smartphone to do ACTION?, where ACTION stands for:

- Show the back side of the building?
- Show the right side of the building?
- Show the left side of the building?
- Move the building from its location to another location?
- Make the building smaller?
- Make the building bigger?
- Select the building?

3.3.3 Apparatus and Materials

We conducted the study in a lab environment. The two panoramic videos overlaid with 3D buildings were displayed in the IVE consisting of three big screens connected to a single PC running Windows 7. A MacBook Pro was used to play all the audio message questions during the whole study. The 3D building objects used in our study were downloaded from the 3D Warehouse [3]. One 3D model [4] was a model of

[3] `https://3dwarehouse.sketchup.com/` (last accessed: July 20th, 2018).
[4] `https://3dwarehouse.sketchup.com/model/fec488ae8cbf0c8035d6a087b4694131/Meijer-Supermarket` (last accessed: July 20th, 2018).

supermarket and another one [5] was a skateboard shop. We used Sketchup Pro 2017 [6] to export the pictures of each model to PNG format with transparent backgrounds, which were then overlaid over the videos by Final Cut Pro X. We used two cameras in our study. One Canon EOS 550D [7] camera was put beside participants on a tripod to view them from the side . Another GoPro Hero4 camera was situated on the top of the front section of the IVE to view them from the front. There was a moderator sitting close to the Canon EOS 550D camera throughout the study session. With this setup, we attempted to capture all the details when participants were performing surface gestures on the phone. All the participants were guided to stand in the same location of the room in front of the IVE. The location was marked by a white paper with two footprints. Figure 3.1 depicts the study settings and also shows the transparent mockup prototype used in the phone-gesture condition.

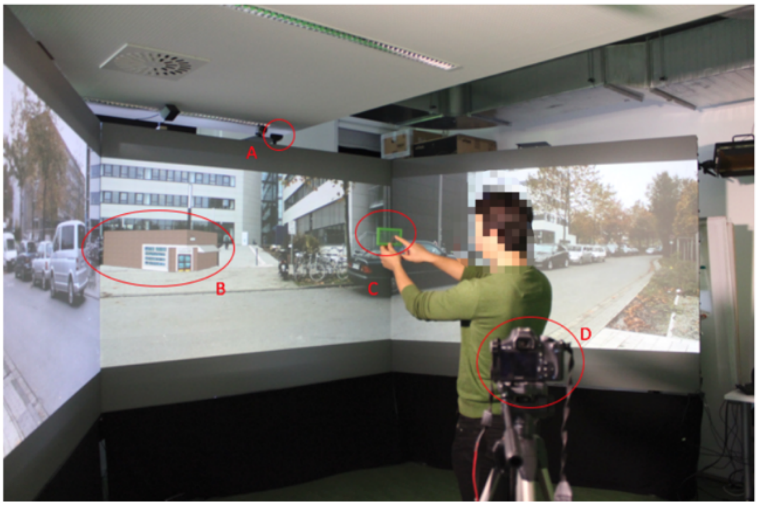

Fig. 3.1: Study setup: The participant with the transparent mockup prototype (C) stood on the footprint mark in front of the IVE showing the 3D objects (B), while the GoPro Hero4 camera (A) and the Canon camera (D) recorded the participant's behaviors.

3.3.4 Participants

Twenty-eight participants, twenty-one males and seven females, between the ages of 22-39 (mean=28, SD=4.9) were recruited for our study. They had different professional backgrounds. Most of them had lived in Germany for the last two years, but some participants had primarily lived in other European countries, American countries or Asian countries over last two years. There were no special requirements about participants' age or prior experience regarding participation in urban planning processes. All participants had a moderate level of English. Recruitment was done

[5] `https://3dwarehouse.sketchup.com/model/76e9d3b5554893e272396bc529d8c9c/Small-Time-Skates` (last accessed: July 20th, 2018).
[6] `https://www.sketchup.com/download/all` (last accessed: July 20th, 2018).
[7] `https://www.canon.de/for_home/product_finder/cameras/digital_slr/eos_550d` (last accessed: July 20th, 2018).

through emails, flyers, Facebook, and word of mouth. Each participant received 10 EUR as a reward at the end of the study.

3.3.5 Procedure

At the beginning of the study, each participant was given a brief explanation of the objective and the procedure. After they read and understood the study, they were asked to sign the consent form. Then the moderator guided each participant to stand at a marked position in front of the large display. Before starting the main part of the study, the moderator spent several minutes introducing the IVE and the tasks in the study. The moderator encouraged participants to ask any question regarding the study. The moderator also told participants that they could think aloud when performing the tasks. The main part of the study started when participants were clear about what was going to happen and what they should do.

After the setup, the moderator gave an urban planning story to each stimulus, i.e. the panoramic video with the 3D objects overlaid. Then each participant was given about one minute to become familiar with the IVE and the stimuli. The audio message describing the task was played next, and participants began to perform the task. After each task, the participants were asked how easy/how appropriate it was to come up with an action for the particular task. The order of exposure to each of the interaction modalities, i.e. the hand and the smartphone, was counterbalanced. For each condition, the order of tasks and videos were randomized across conditions and participants.

Once the two scenarios were finished, each participant was given two questionnaires. The first one asked for participants' background information, and the second aimed to get general feedback and attitudes about the hand-gesture and phone-gesture interactions. Finally, the moderator wrapped up the session and handed out their reward. The duration of each study was about 45 minutes.

3.4 Results

In the following section, the results of our study will be presented. The section starts with a brief introduction of the taxonomies for hand gestures and phone gestures used during the analysis, and it goes on to describe the hand- and phone-gesture sets obtained in the study, the agreement scores between participants, and their subjective ratings.

3.4.1 Taxonomy used in the analysis

Studdert-Kennedy (1994) described that gestures consist of four stages: preparation, stroke, hold, retraction. The stroke phase describes the step of performing the gesture, so we firstly extracted this phase of all proposed gestures. The gestures were further analyzed by the taxonomies. Inspired by relevant work about classification of gestures (Jacob O Wobbrock, Morris, et al., 2009; Obaid, Kistler, Kasparavičiūtė, et al., 2016; Ruiz et al., 2011; Obaid, Kistler, Häring, et al., 2014), we then derived our taxonomies for further analyzing users' hand gestures and phone gestures. In order to analyze the gestures in as much detail as possible, we made changes to previous taxonomies. The taxonomy for user-defined hand gestures was modified and extended from Obaid, Kistler, Kasparavičiūtė, et al. (2016) and Obaid, Kistler, Häring, et al. (2014) and Ruiz et al. (2011). The taxonomy for user-defined phone gestures was modified and extended from Obaid, Kistler, Kasparavičiūtė, et al. (2016) and Obaid, Kistler, Häring, et al. (2014), Ruiz et al. (2011), and Jacob O Wobbrock, Morris, et al. (2009). We analysed the hand gestures according to five dimensions: form, nature, body parts, temporal, and complexity dimensions. Each dimension consists of multiple categories, as shown in Table 3.1. The phone gestures were analyzed along seven dimensions (Table 3.2): form, nature, touch-fingers, temporal, complexity, spatial, and type of gestures dimensions.

The form dimension in the air-hand gesture taxonomy was adopted from Obaid, Kistler, Kasparavičiūtė, et al. (2016) and Obaid, Kistler, Häring, et al. (2014) without changes. In the phone gesture taxonomy, we combined the form of surface gestures (Jacob O Wobbrock, Morris, et al., 2009) and the form of motion gestures (Ruiz et al., 2011) into the form dimension. We modified the categories of the body-parts dimension from Obaid, Kistler, Kasparavičiūtė, et al. (2016) and Obaid, Kistler, Häring, et al. (2014), because we were eliciting air-hand gestures that only involved hands but no other body parts. In the taxonomy of the phone gestures, we replaced this dimension by the touch-fingers dimension, which describes the number of fingers involved in performing gestures.

We extended the nature dimension originally from (Obaid, Kistler, Kasparavičiūtė, et al., 2016) according to the research presented by Jacob O Wobbrock, Morris, et al. (2009). The categories of our nature dimension include deictic, iconic, metaphorical, abstract and symbolic gestures. The temporal dimension is also adopted from Jacob O Wobbrock, Morris, et al. (2009) to show whether the ongoing recognition of gestures is needed or not. The complexity dimension adopted from Ruiz et al. (2011) aims to capture as how complicated a gesture is perceived to be.

Regarding the spatial dimension, we got inspiration from (Medrano et al., 2017). Some participants preferred to perform gestures by looking through the transparent

Dimension	*Sub-category*	*Description*
Form	static	A static body posture is held after a registration phase
	dynamic	The gesture contains the movement of one or more body parts during the stroke phase
Nature	deictic	The gesture is indicating a position or direction
	iconic	The gesture visually depicts an icon and directly represents a real-world property
	metaphoric	The gesture visually depicts an icon and describes a real-world property in an abstract way
	abstract	Gesture-referent mapping is arbitrary
	symbolic	The gesture is an artificial symbol that does not represent a real-world property but represents a meaning that needs to be learned and is often culture specific
Body parts	right hand only	The gesture is performed with the right hand only
	left hand only	The gesture is performed with the left hand only
	two hands	The gesture is performed with two hands
Temporal	discrete	Action occurs after completion of gesture
	continuous	Action occurs during gesture
Complexity	simple	Gesture consists of a single gesture
	compound	Gesture can be decomposed into simple gestures

Tab. 3.1: Taxonomy for user-defined hand gestures.

screen of the mockup device. These gestures were classified as 'see-through' (ST) gestures. Some participants also used the mockup device as an extension of their arms or remote control. These gestures were labelled as 'device-pointing' (DP) gestures. We also found that some participants designed gestures that mimicked actions occurring during normal use of smartphones. These gestures were categorized as 'standard smartphone-use' (SSU).

A total of 196 hand gestures were collected. As shown in the overall taxonomy distribution of the hand gestures (see Figure 3.2), these gestures tended to be simple dynamic gestures which were performed involving the right hand and which required continuous recognition and real-time feedback. The overall taxonomy distribution of the phone gestures illustrates the breakdown of the 196 phone gestures observed in our study. As shown in Figure 3.3, more surface gestures were found than motion gestures, and more than 90% of gestures were performed by one or two fingers. Similar to the hand gestures, most of phone gestures were simple gestures and required continuous recognition and real-time feedback.

Dimension	*Sub-category*	*Description*
Types of gestures	surface gesture	Deliberate movements of the device by end-users to invoke commands
	motion gesture	Two-dimensional gestures using the touchscreen of the smartphone as a mobile surface computer
	mixed gesture	Combine the surface and motion gesture
Form	static pose	Hand pose is held in one position
	dynamic pose	Hand pose changes in one position
	static pose and path	Hand pose is held as hand moves
	dynamic pose and path	Hand pose changes as hand moves
	Single-Axis motion	Phone-Motion occurs around a single axis
	Tri-Axis motion	Phone-Motion involves either transnational or rotational motion, not both
	Six-Axis	Motion occurs around both rotational and transnational axis
Temporal	discrete	Action occurs after completion of gesture
	continuous	Action occurs during gestu
Spatial	ST	Perform the gesture while looking through the transparent screen of the device
	DP	Device was used an extension of their arm or remote control
	SSU	Device was used as current smartphone and held on one of the hands
Touch-fingers	One finger	The gesture is performed with one finger only
	two fingers	The gesture is performed with two fingers
	multi-fingers	The gesture is performed with more than two fingers
Complexity	simple	Gesture consists of a single gesture
	compound	Gesture can be decomposed into simple gestures
Nature	deictic	The gesture is indicating a position or direction
	iconic	The gesture visually depicts an icon and directly represents a real-world property
	metaphoric	The gesture visually depicts an icon and describes a real-world property in an abstract way
	abstract	Gesture mapping is arbitrary
	symbolic	Gesture visually depicts a symbol

Tab. 3.2: Taxonomy for user-defined phone gestures.

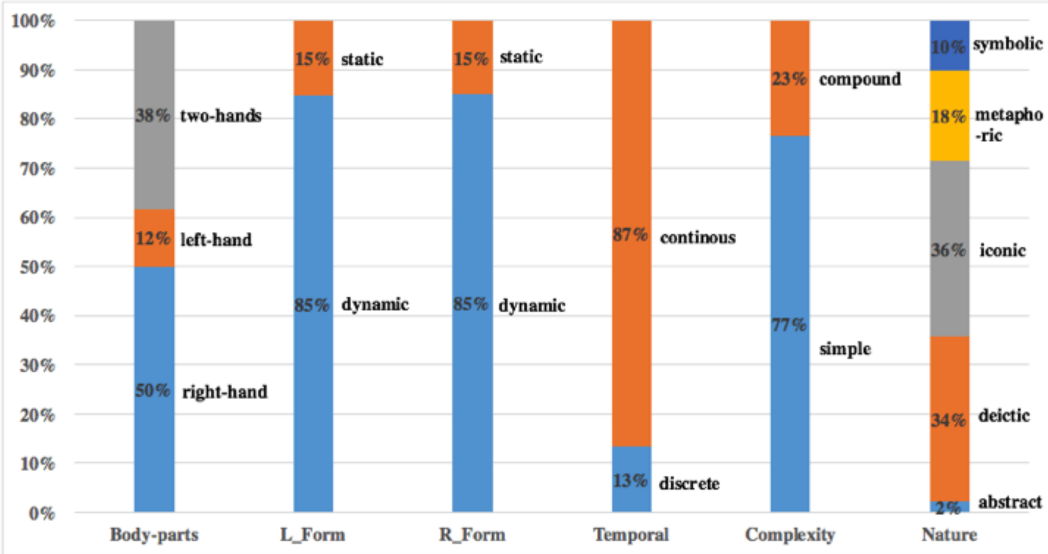

Fig. 3.2: The overall taxonomy distribution for all the elicited hand gestures.

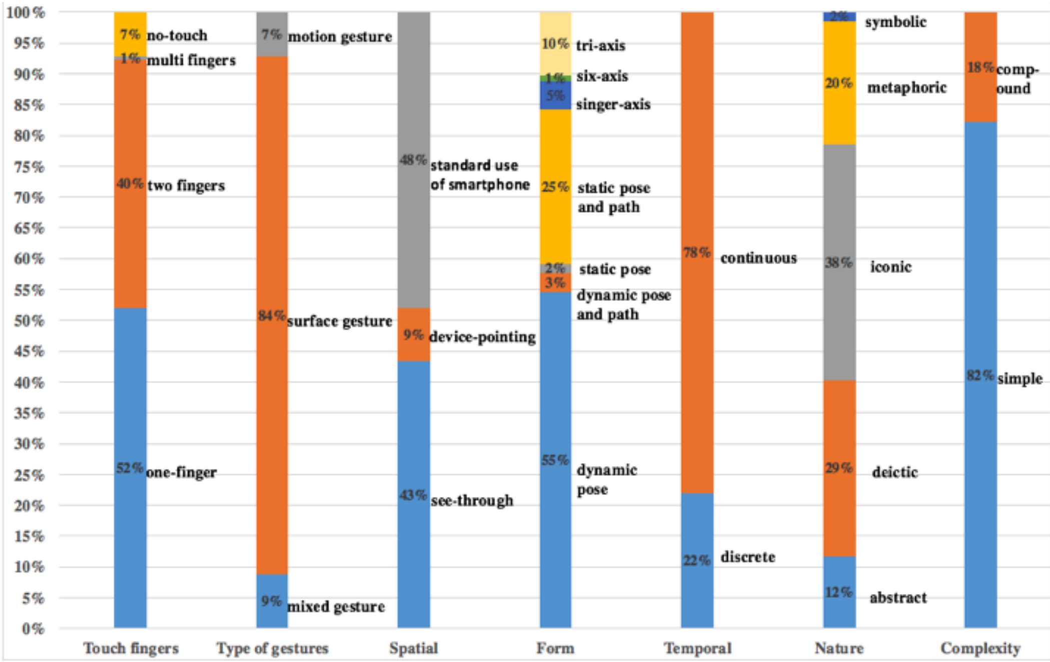

Fig. 3.3: The overall taxonomy distribution for all the elicited phone gestures.

3.4.2 User-Defined Gesture Sets and Agreement Scores

The core of our study aim is to generate user-defined gesture sets. This process was structured as follows: firstly, for one task t, all gestures produced were grouped into a set $P(t)$; then we classified all gestures in $P(t)$ into subsets, which contain identical gestures $P_i(t)$, with i$\in$ 1, 2. . . n, and n is the value of the total number of identified subsets for task t. The subset $P_i(t)$ with the largest size was then chosen as the representative gesture for the task t for our user-defined set. We also checked if there was more than one gesture candidate for a task. Second or third gesture candidates were only chosen when they were accounted for at least half of the first gesture candidate. However, if the representative gestures for different tasks were the same, then a conflict occurred. That is because one gesture cannot result in two or more outcomes. To resolve the conflict, we assigned the gesture to the task that was associated with that gesture the most often. Also if the first gesture candidate of one task was the second or the third gesture candidate of another task, we removed this gesture as the alternative gesture for the other task. Table 3.3, Table 3.4, and Table 3.5 show all the gesture candidates for each of the seven tasks in the two conditions, how often the participants performed each task with the gesture candidate, and all the gesture candidates' taxonomies. Our process of generating user-defined gestures can be traced back to previous work (Jacob O Wobbrock, Morris, et al., 2009; Obaid, Kistler, Kasparavičiūtė, et al., 2016; Ruiz et al., 2011; Obaid, Kistler, Häring, et al., 2014). In our study, the first candidate gesture of *Show back* conflicts with that of *Show right* and *Show left* in both conditions. Compared with the other two actions, the action *show back* did not have the largest group, so we moved the second candidate gesture as the first candidate gesture for that action.

To evaluate the degree of consensus among participants with the proposed gesture, we use the formula as used by Jacob O Wobbrock, Morris, et al. (2009). They calculate an agreement score $AS(t)$ for each task t, where:

$$AS(t) = \sum_{i=1}^{n} \left(\frac{P_i(t)}{P(t)} \right)^2$$

The range of $AS(t)$ is $[P_i(t)^{-1}, 1]$, and $P_i(t)^{-1}$ corresponds to all the participants choosing different gestures for task t, while 1 means all the participants performed the same gesture for task t. So we can say if there is a high agreement score for task t, then all the participants have a similar understanding of how to perform the task by gesture. But when there is a low agreement score for task t, participants found it difficult to think of a similar appropriate gesture for task t. Figure 3.4 shows agreement levels for hand gestures and phone gestures.

3.4.3 Subjective Ratings

After each action, the participants answered the two following questions using a 5-point Likert scale:

- How easy was it for you to produce this gesture? Answers were given on a scale from 1 = "quite hard" to 5 = "quite easy".

Action	*Candidates*	*Occurrences*	*Form*	*Nature*	*Body-parts*	*Temporal*	*Complexity*
Show right	Swipe left	35%	Dynamic	Deictic	One hand	Continuous	Simple
Show left	Swipe right	35%	Dynamic	Deictic	One hand	Continuous	Simple
Select	One hand air-point	52%	Static	Deictic	One hand	Continuous	Simple
Resize smaller	Move two hands linearly closer	75%	Iconic	Deictic	Two hands	Continuous	Simple
Resize bigger	Move two hands linearly spread	75%	Iconic	Deictic	Two hands	Continuous	Simple
Reposition	Hand-point to the building, then move the hand to another location, then loosen hand	68%	Dynamic	Deictic	One hand	Continuous	Compound
Show back	Two hands perform clockwise motion along Y-axis	18%	Dynamic	Metaphoric	Two hands	Continuous	Simple

Tab. 3.3: Gesture candidates for performing the seven tasks by hands.

Action	*Candidates*	*Occurrences*	*Types of gestures*	*Form*
Show right	Swipe right/left	46%	Surface	Static pose and path
Show left	Swipe right	43%	Surface	Static pose and path
Select	Tap	68%	Surface	Dynamic pose
Resize smaller	Pinch to zoom out	96%	Surface	Dynamic pose
Resize bigger	Pinch to zoom out	96%	Surface	Dynamic pose
Reposition	Keep on pressing the building on the smartphone, move the smartphone to another location and then release the finger; Drag the building on the smartphone	43% 39%	Mixed Surface	Tri-Axis motion Static pose and path
Show back	Move fingers around each other on the building	18%	Surface	Dynamic pose

Tab. 3.4: Gesture candidates for performing the seven tasks by smartphone (First part).

Action	*Touch fingers*	*Temporal*	*Complexity*	*Nature*	*Spatial*
Show right	One finger 77% Two fingers 23%	Continuous	Simple	Deictic	SSU 46% ST 54%
Show left	One finger 75% Two fingers 25%	Continuous	Simple	Deictic	SSU 42% ST 58%
Select	One finger 95% Two fingers 5%	Discrete	Simple	Abstract	SSU 47% ST 53%
Resize smaller	Two fingers	Continuous	Simple	Iconic	SSU 48% ST 52%
Resize bigger	Two fingers	Continuous	Simple	Iconic	SSU 48% ST 52%
Reposition	One finger 92% Two fingers 8% One finger 91% Two fingers 9%	Continuous Continuous	Simple Simple	Metaphoric Iconic	DP 25% ST 58% SSU 17% ST 36% SSU 64%
Show back	Two fingers 80% Multi-fingers 20%	Continuous	Simple	Metaphoric	SSU 80% ST 20%

Tab. 3.5: Gesture candidates for performing the seven tasks by smartphone (Second part).

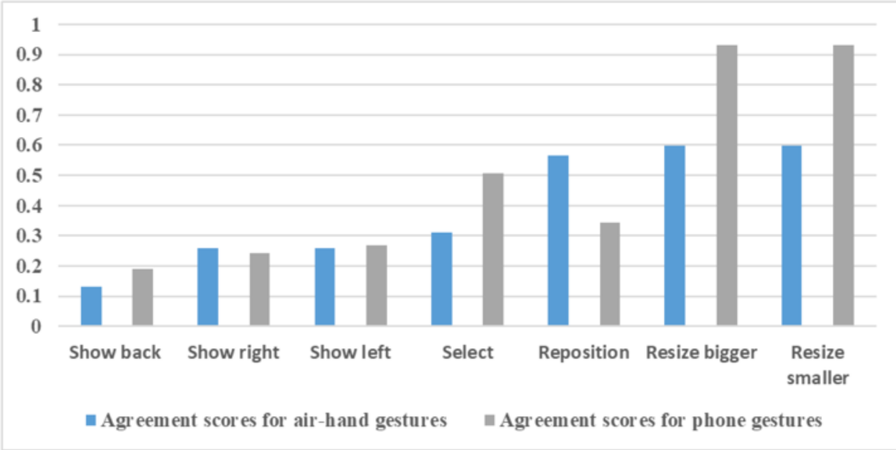

Fig. 3.4: Agreement scores for user-defined gestures.

- How would you rate the appropriateness of your gesture/action to the task? Answers were given on a scale from 1 = "quite inappropriate" to 5 = "quite appropriate".

Figure 3.5 and Figure 3.6 show the mean values for users' ratings of easiness and appropriateness of the hand gestures and phone gestures, respectively. We applied a two-way repeated ANOVA and found that neither the means of the ratings for ease nor appropriateness differed significantly with the interaction modalities, i.e. hand and smartphone. However, they did differ significantly with the tasks, F (6) =2.9225, $P < 0.05$ but not as a function of both tasks and interaction modalities. A one-way repeated measures ANOVA revealed that the means of rated appropriateness differed significantly between the actions, with F (6) = 3.231, $P < 0.01$ for all the phone gestures. The task *show back* received significantly lower ratings of the appropriateness than the other actions, while the tasks *resize bigger, resize smaller, select* had significantly higher ratings for appropriateness than other actions. No significant difference of the means of the rated easiness of gestures were found for hand gestures or phone gestures. The means of the rated appropriateness also did not differ with tasks for phone gestures.

3.5 Discussion

In this section, we discuss the user-defined gestures we observed in our study as well as the implications of our results for system design and interface design.

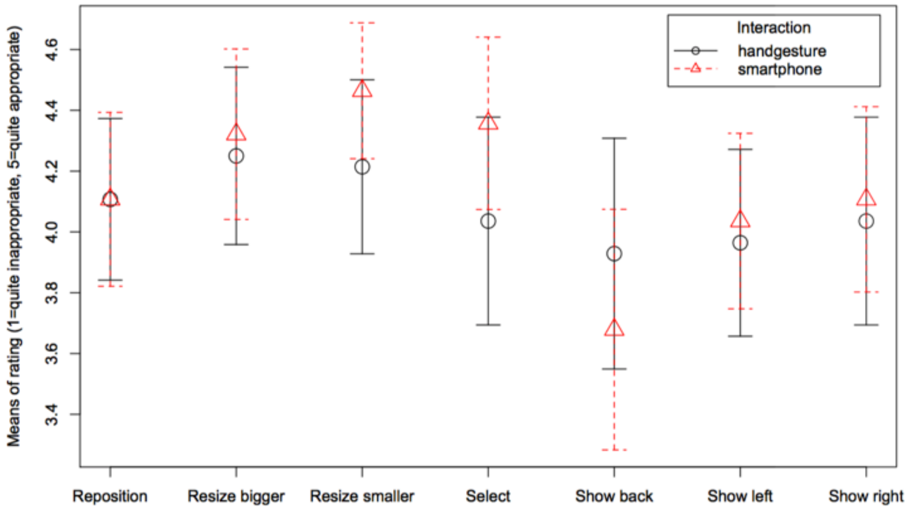

Fig. 3.5: User ratings for the appropriateness of the proposed gestures for the seven tasks.

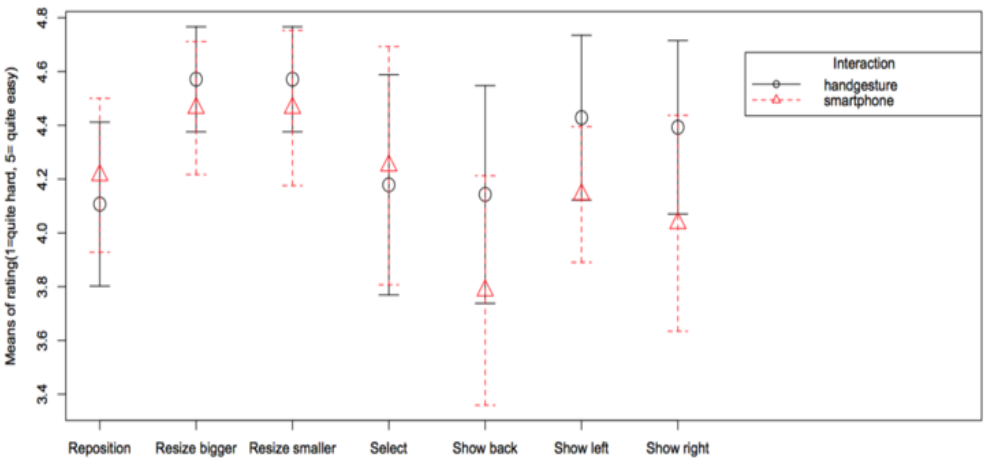

Fig. 3.6: User ratings for the easiness of the proposed gestures for the seven tasks.

3.5.1 User-Defined Gestures

The distributions of hand gestures and phone gestures reveal some common characteristics. Both types of user-defined gestures tend to be simple and continuous. There is a similar distribution for user-defined hand gestures (iconic and deictic; 70%) and user-defined phone gestures (iconic and deictic; 67%). This suggests that users expect gestural interaction to provide immediate responses and continuous control regarding the urban planning information by means of simple gestures. It also indicates that users prefer to have their actions directly and visually depicted on the 3D objects when examining them in the IVE. People found the task *show back* hard to understand as indicated by the low scores for agreement and appropriateness. This indicates no common concept exists among people for this task. Consequently, it may make sense to remove this task and to instead rely on performing *show left/right* twice.

Dynamic right-hand gestures were most preferred according to the taxonomy distribution of the elicited hand gestures, both for left-hand gestures and right-hand gestures (dynamic; 85%). Even though recognizing dynamic gestures is technically more challenging than static postures, this finding implies future gestural interfaces for 3D objects might require the former.

According to the taxonomy distribution of phone gestures, one finger (52%) and two fingers (40%) touch were most popular among the participants. It may make sense to not distinguish between one-point touch and two-point touch for supporting interactions with 3D objects by a smartphone. This observation is similar to what we observed for hand gestures. During our study, we found people usually did not consider the number of fingers when performing the tasks by hands. For example, when performing the gesture *hand point*, some participants pointed to the display while bending all the fingers resulting in a fist, while some others pointed to it by using one finger or more fingers. We also observed that more surface gestures (84%) were generated than motion gestures (9%), although participants were well aware that they could imagine that the mockup phone supports any type of technology or function they wished. This may be the result of our participants having extensive smartphone experience, since more than 90% of them frequently used smartphones. Medrano et al. (2017) showed in a previous study that user preferences were influenced by the technology experience of the participants.

3.5.2 Implications for System Design

Regarding the system design for the two user-defined gesture sets, we can point out several challenges. Except the gesture candidate for the task select, the other gesture candidates in the user-defined hand gesture set are dynamic and continuous. Developers should consider that users will not all be the same height, may stand at different locations in front of a large public display, and may expect immediate responses during the gestures. Hence, it is important to find a suitable recognition system that provides a wider tracking range and facilitates synchronous responses. Most of the gesture candidates in the user-defined set are of the deictic type, but there are also some iconic and metaphoric types. This suggests that the recognition system needs to be able to recognize both types. A suitable recognition system should also meet the requirement of recognizing one-handed or two-handed gestures while ignoring the number of fingers.

In the case of the user-defined phone gesture set, we observed a strong need for surface recognition technology. There are iconic, deictic, metaphoric, and abstract types of gestures with different forms. This means the sensor should be sensitive enough to recognize diverse patterns and forms of surface gestures. It was very common for the same gesture candidate to be performed by users but with different numbers of fingers. Developers could provide a choice for users to decide the number of fingers involved or decide to ignore the number of fingers while focusing on the shape, location and dynamics of the gesture. Another challenge is the mixture of motion gesture and surface gesture for one task. To support this type of gesture, different sensor technologies have to be integrated during the system design. In addition, a major trend that emerged was that people preferred to hold the smartphone with the screen facing the 3D objects with one hand, while performing surface gestures with the other hand. They imagined that there should be a synchronous response to their gestures from the urban planning materials (i.e. 3D objects) both on the smartphone and the large public display. This case may necessitate technologies like a rear-mounted camera and low-latency connectivity to support communicating the data and interaction events between the smartphone and the large display. A related challenge is to quickly and reliably compute the geometric mapping between the smartphone image and the display, which is known as display registration (Pears et al., 2009).

3.5.3 Implications for User Interface Design

The high agreement scores regarding the resizing tasks imply that user interfaces for interacting with 3D objects shown on public displays may readily implement the gesture set identified in this work. The lower agreement between participants for other tasks suggests, on the contrary, that user interface designs may have to accommodate the variety of options expressed by the participants. In addition, with the exception of the task *reposition*, the degree of the consensus among the participants regarding the elicited phone gestures was higher than the degree of consensus for the hand gestures. People rated phone gestures as more appropriate than hand gestures, although they commented in general that phone gestures were less intuitive to recall than hand gestures. Participants found it particularly hard to come up with an appropriate phone gesture for the task *show back*. The higher degree of consensus for phones gestures than for hand gestures may be explained through participants' general familiarity with phone usage.

Qualitative feedback collected from our participants suggests some implications for the design of interfaces based on hand gestures. There are four frequent negative aspects mentioned by participants: frustration resulting from the inability of the system to detect gestures properly, a lack of confidence based on previous bad experiences, social embarrassment, and lack of privacy when performing gestures in front of the public.

Regarding the design of interfaces based on phone gestures, four frequent negative aspects were also given: the need to have a smartphone and an app to perform the interaction, the high effort resulting from switching between two screens, the lack of motivation to connect their personal device with the public display due to privacy risks and security issues, and the limited screen size of the smartphone. The latter may be related to the 3D objects not being well suited for exploration on a small screen, e.g. larger maps showing a planned project.

3.5.4 Limitations of the Study

Most participants were under 40 years old, highly educated, and experienced smartphone users. It is quite possible that the gestures obtained were influenced by the participants' technology experiences and backgrounds. Repeating the study with participants from other groups (e.g. children, older people, or people with little technology experience) would lead to a more complete picture of users' perceptions and needs regarding interacting with 3D objects shown on public displays.

3.6 Conclusion

In this paper, we presented an elicitation study exploring two interaction modalities for facilitating interaction with 3D objects shown on public displays. We recruited 28 participants for our study, during which we asked them to watch panoramic videos overlaid with 3D objects in an immersive video environment. They then performed seven tasks of examining 3D objects using their hands only (first condition) and then using a mockup of a futuristic smartphone (second condition). In total, we elicited 196 hand gestures and 196 phone gestures, which we analyzed to derive two gesture sets that can inform research and practice on interaction with 3D objects on public displays. In addition, we also collected qualitative feedback about the easiness and appropriateness of the elicited gestures. Participants mostly agreed on gestures for resizing 3D objects, while gestures involving the manipulation of buildings (e.g. *select, show back, show right, show left*) led to much lower agreement scores.

An immediate step for future work is to implement the identified gesture sets in a system and to evaluate their usability. Further studies regarding the functions that resulted in low agreement scores are also highly desirable, as are studies that replicate our setup with different user groups (e.g. different age range, technological background or culture).

4 User-generated Gestures for Voting and Commenting on Immersive Displays in Urban Planning

This part of research continually investigates the suitable interaction methods for citizen consultation, i.e. voting and commenting, in urban planning. This chapter has been submitted to the 2019 ACM CHI Conference on Human Factors in Computing System by Du, Guiying, Auriol Degbelo, and Christian Kray. (2018). "User-generated Gestures for Voting and Commenting on Immersive Displays in Urban Planning".

Abstract. Public consultation is an important task for the promotion of urban planning projects. However, traditional methods of public consultation (e.g. hearing meetings) only offer limited interactivity with urban planning materials, leading to a restricted engagement of citizens. Public displays and immersive virtual environments have the potential to address this issue, enhance citizen engagement and improve the public consultation process overall. In this paper, we therefore investigate how people would interact with a large display showing urban planning content. We conducted an elicitation study with a large immersive display, where we asked participants (N=28) to produce gestures (using their hands or a smartphone) to vote and comment on an urban planning material. Our results suggest that all things considered (i.e. easiness to come up with the gestures, their rated appropriateness, and their agreement scores for the tasks of voting and commenting), the phone interaction modality may be more suitable than the hand interaction modality for voting and commenting on large interactive displays. Our findings can inform the design of interactions for large immersive displays, in particular those showing urban planning content.

4.1 Introduction

Due to the reduction of the price and rapid technological advances (Kaviani et al., 2009), public displays have become increasingly prevalent in urban public life. There is an ongoing evolution from ambient non-interactive displays to large interactive displays deployed in a variety of real-world scenarios (e.g. shop windows or plazas

(Kuikkaniemi et al., 2011; J. Müller, Walter, et al., 2012; Peltonen et al., 2008; Valkanova, Jorda, et al., 2013)), and community displays. At the same time, research in exploring large interactive displays has been expanding from addressing technical concerns to studying topics such as public participation (Hinrichs et al., 2013). With this shift, one new research direction is emerging which is concerned with the use of large interactive (public) displays to facilitate the consultation of citizens and their provision of feedback on urban planning designs during the urban planning process.

There are three main limitations of traditional public consultation methods (i.e. brochures, leaflets and hearing meetings) when it comes to supporting public participation in urban planning processes (see (Howard and Gaborit, 2007)): lack of interactivity; lack of feeling of immersion; and the lack of a possibility to select specific objects and comment on them (which is a consequence of the lack of interactivity). Previous research (Allmendinger et al., 2000; Laurini, 2014; El Araby, 2002) pointed out that these limitations led to the loss of the public's interest in urban planning. There is also evidence in the literature (Hosio, Goncalves, Kostakos, and Riekki, 2014) that both citizens and local authorities value the possibility of giving/getting feedback through public displays. These findings from previous works have motivated us to examine the wishes of users when it comes to using gestures (both hand and phone) to provide their feedback on urban planning content in an Immersive Video Environment (IVE) (Ostkamp and Kray, 2014). In the IVE, we visualized spatial urban planning information using panoramic video footage of the environment overlaid with 3D building models. This type of audiovisual simulation can provide people a feeling of immersion (Prouzeau et al., 2016), and can enhance engagement and learning (Dede, 2009; Barab et al., 2007; Neulight et al., 2007).

Designing suitable interfaces for large public displays that support diverse citizens giving their feedback on urban planning designs is still a challenge (Du, Degbelo, et al., 2017). In this paper, we put our focus on exploring two means of interaction, namely hand gestures and mobile devices (i.e. smartphone). Hand gestures may bring a more intuitive way of engaging with immersive digital environments and urban planning material; mobile devices, as one of four main interaction modalities with large public displays (Ardito et al., 2015) have become increasingly present in people's everyday lives, with about 59% of the world's population currently owning a smartphone (Poushter et al., 2018). One motivation behind our work is to get a better understanding of the kind of gestures or actions people naturally produce with their smartphones and hands in order to trigger specific actions. Another goal is to explore user preferences regarding interaction with public displays using hand gestures or smartphone. To achieve these goals, we carried out an elicitation study to collect input from users on these interaction modalities in the context of an urban planning scenario. Our study is driven by previous research work (Jacob O Wobbrock, Morris, et al., 2009; Obaid, Kistler, Kasparavičiūtė, et al., 2016; Kray et al., 2010), which resulted in user-defined gestures for different interaction scenarios, i.e. a user-defined gesture set for tabletop systems, a set for navigating a drone, and user-defined gestures to connect mobile phones with tabletops and public displays. Based on our literature review of the research field (i.e. designing interfaces on large public displays that support diverse citizens giving their feedback), this eliciting input from users has not been done yet, which suggests that there is still a gap that needs to be filled.

The main contributions of this work are twofold: (1) a set of hand gestures and smartphone gestures for voting and commenting on large interactive displays. These gestures pave the way for the design of interactive displays with support the move from a lower level (i.e. informing) to a higher (i.e. consultation) on Arnstein (1969)'s ladder of citizen participation; (2) qualitative user perceptions on the advantages and drawbacks of using hand gestures and smartphones for giving feedback on urban planning material on large interactive displays. These contributions can help in the design of gestural interfaces for (immersive) large displays that are used to facilitate higher levels of participation in urban planning.

The remainder of the paper is structured as follows: we first review previous work on using public displays for public participation, and on mobile interaction as well as on gestural interaction with large public displays. Next, we report on the elicitation study we conducted to achieve the goals outlined above. After that, we discuss the implications of our results. The paper ends by summarizing our main findings.

4.2 Related Work

The topic of the paper is situated at the intersection of public display, public participation, gestural interaction, and mobile interaction. This section thus briefly reviews previous work in these areas. As observed in (Du, Degbelo, et al., 2017), the words 'engagement' and 'participation' are sometimes used interchangeably in the literature. In keeping with this practice, work on citizen engagement is also included in the review of work on public participation.

4.2.1 Public displays for public participation

The interplay of public displays and public participation has been investigated from various perspectives in the literature. For instance, Veenstra et al. (2015)'s study brought forth that interactivity is beneficial in engaging citizens, as well as stimulating them to spend more time with, and around a public display. Steinberger et al. (2014) also found that the tangible interaction was effective on enabling users to vote Yes/No questions through attracting people's attention and lowering participation barriers. Hespanhol et al. (2016) indicated, along the same lines, that public displays increase participation by encouraging group interaction. As to higher engagement of people, Wouters, Huyghe, and Vande Moere (2013) investigated the potential of citizen-controlled public displays (i.e. displays whose content is controlled by one citizen or household, rather than by a central authority such as a local government or a commercial agency). The authors reported that a more sustained engagement with citizen-controlled public displays can be enforced through a publication process that is explicitly distributed among multiple citizens, or delegated through some open and democratic process. In another study, Wouters, Huyghe, Sulmon, et al. (2013) suggested that analyzing published content and reactions of content creators on public displays, may be a way of better understanding preferences and expectations of citizens towards public displays.

Du, Degbelo, et al. (2017) recently reviewed work on public displays for public participation. They pointed out that current research has mainly targeted low levels of public participation, and that work is still needed to explore the use of public displays for higher levels of public participation (e.g. consult citizens or collaborate with them). As regards citizens' feedback, Hosio, Goncalves, Kostakos, and Riekki (2014) reported that offering the possibility for direct feedback was highly appreciated by citizens in their study. In Valkanova et al's research (Valkanova, Jorda, et al., 2013), the deployment of Reveal-it! confirmed the ability of urban visualization displays to inspire individual reflection and social discussion on an underlying topic. A comparison of paper, web forms, and public displays in (Goncalves et al., 2014) led to the conclusion that public displays are instrumental in generating interest: they manage to attract more comments from people (though feedback on public displays comes at the price of being noisy).

In sum, public displays have a great potential in the context of public participation; feedback from citizens on public displays are desirable, and increasing the interactivity of the displays would be beneficial. The study presented later builds upon these insights from previous work, and looks closely into gestural and mobile interaction for feedback elicitation on public displays.

4.2.2 Gestural interaction with public displays

The use of gestures to interact with public displays has been an active research topic for many years. Inspired by Jacob O Wobbrock, Morris, et al. (2009)'s seminal work, several researchers further explored user gestures for a variety of tasks and application scenarios. The review of about 65 papers in (Groenewald et al., 2016) crystallized the insight that most gestures so far have been designed for selection, navigation, and manipulation tasks.

Panning and zooming with gestures was the topic of (Fikkert, Vet, et al., 2010; Nancel et al., 2011). Fikkert, Vet, et al. (2010) identified about 27 gestures to manipulate (i.e. pan and zoom) a topographic map on a public display. Nancel et al. (2011) observed that linear gestures are generally faster than circular ones for panning and zooming, and that participants generally preferred two-handed techniques over one-handed ones for this task. Large datasets exploration was the subject of (Valdes et al., 2014), and the authors came up with a set of gestures to enable interaction with active tokens. Walter, Bailly, Valkanova, et al. (2014) investigated the selection of items on public displays, and pointed out that by default (i.e. without hint or instruction), people use a combination of pointing and dwelling gesture to select items they want. Rovelo Ruiz et al. (2014) identified a user-defined gesture set for interacting with omni-directional videos through an elicitation study. Walter, Bailly, and J. Müller (2013) found that spatial division (i.e. permanently showing a gesture on a dedicated screen area) was an effective strategy to highlight the possibility for gestural interaction to users, and help them execute an initial gesture called *Teapot*. Ackad et al. (2015)'s in-the-wild study showed that the icon-tutorial was effective on supporting learning gestural interactions with a hierarchical information on public displays. All in all, this subsection illustrates that much work has been done on user gestures for public displays. These have, however, barely touched on the topic of providing feedback in participation processes which is the core of the current article.

4.2.3 Mobile interaction with public displays

Using mobile phones to interact with large public displays has become a research focus in the past years (Ballagas et al., 2006). Boring et al. (2009) compared three different interaction techniques (Scroll, Tilt and Move) for continuously controlling a pointer on a large public display using a mobile phone. Their experiment revealed that *Move* and *Tilt* can be faster for selection tasks but introducing higher error rates. Lucero et al. (2012) designed the MobiComics prototype, which allowed a medium-sized group of people to create, edit and share comic strip panels using mobile phones. Using mobile phones, people could also share panels onto two large displays. Ruiz et al. (2011) proposed a useful distinction between surface gestures (i.e. two dimensional), and motion gestures (i.e. three dimensional), and introduced gestures to perform tasks such as placing/answering call, or switching apps on mobile phones. Liang et al. (2012) proposed both surface and motion gestures to remotely manipulate 3D objects on public displays via a mobile device. Medrano et al. (2017) explored the use of mobile devices for remote deictic communication, and reported that most participants used either the (assumed) camera of the device, or their fingers for pointing. Kray et al. (2010) investigated the use of gestures to combine mobile phones with other devices (i.e. other mobile phones, interactive tabletops, and public displays). They indicated that users generally liked gestures as a way to use their mobile phones to interact with other devices. Here also, one can see that mobile interaction with public displays is promising, and has already attracted interest from previous research. Nonetheless, previous work has not sufficiently addressed the design of intuitive gestural interaction or mobile interaction for gathering citizens' feedback on large displays. Our work aims to fill this gap.

4.3 User Study

The main goal of our elicitation study is to investigate user-defined interactions to enable citizens to provide feedback about urban planning proposals on large public displays. We focuse on four main tasks for collecting citizens feedback: *vote for yes*, *vote for no*, *leave a comment*, and *delete a comment*. More specifically, we are interested in finding answers to the following research questions:

1. Which gestures do users produce naturally to execute the four tasks using hand- or smartphone-gestures?

2. Which of these four tasks lend themselves well to being executed by either interaction modality, and which ones do not?

3. Are hand-gestures or smartphone-gestures more suitable for the four tasks?

In the following paragraphs, we describe the study and its design in more detail.

4.3.1 Study Design

In order to provide a realistic setting for the elicitation study, we created two urban planning scenarios as shown in Figure 4.1 and 4.2. These scenarios each consisted of a single proposed building to avoid any confusion that could result from complex proposals.

We presented the two scenarios using an Immersive Video Environment (IVE), where we overlaid urban planning materials over panoramic video footage. The IVE can immerse users in panoramic video footage and give them a feeling of "being there" rather than being here" (Bjork and Holopainen, 2004). This immersion can improve participants' engagement, which we thought would further reduce barriers and facilitate gesture generation.

We selected the two interaction modalities (hand gestures, smartphone gestures) based on the following considerations. First, we wanted to make sure that multiple users could easily interact with the system at the same time. Second, we were looking for interaction methods that are intuitive and do not require technical expertise so that many citizens could potentially use them. Third, we wanted to avoid reducing the immersive user experience (Ren et al., 2013), which could negatively affect participation. Finally, we took into account that smartphones have become ubiquitous and thus might be a realistic and readily available means of interaction.

In addition to the interaction modalities, we also had to select the tasks that participants had to perform. According to the Spectrum of Public Participation developed by the International Association of Public Participation (IPA2), the consultation of citizens aims "to obtain public feedback on analysis, alternatives and/or decisions"[1]. Voting and commenting are not only two main forms of giving public feedback in the urban planning process; they are also linked to higher levels of participation where citizens become actively involved rather than just passively absorb information.

Instead of providing participants with a specific phone model, we handed them a transparent (non-functional) mock-up prototype (as shown in Figure 4.1). We told the participants that the mock-up prototype was a "futuristic smartphone", which could have any features they could imagine. Our rationale for doing this mirrors the reasons mentioned in previous work (Medrano et al., 2017; Ruiz et al., 2011; Jacob O Wobbrock, Morris, et al., 2009). First, we did not want the participants' behavior to be influenced by technical limitations such as gesture recognition issues or smart phone sensor technologies. Second, we want to minimize the effect of the gulf of execution (Hutchins et al., 1985) from the user-device dialogue. The study was approved by the institutional ethical review board.

4.3.2 Participants

28 people participated our study, of which seven were female. Participants were between 22 and 39 years old (mean=28, SD=4.9). We advertised our study through emails, Facebook, and word of mouth. Though the study took place in Germany, all participants were able to speak and understand English. It was necessary since the

[1] https://sustainingcommunity.wordpress.com/2017/02/14/spectrum-of-public-participation/ (last accessed: July 6th, 2018).

whole study was conducted in English. At the end of the study, every participant received 10 Euros as a compensation for their time.

4.3.3 Tasks

In order to keep our study focused and manageable, we defined four tasks that are essential for actively participating in an urban planning process. These tasks were: (1) leave a comment about the design of the building; (2) delete a comment from the large public display; (3) vote yes whether the building should be built as proposed; and (4) vote no whether the building should be built as proposed. All four tasks were executed for both modalities and where presented to the participants as a question, resulting in a total of eight questions per participant. Four questions stated: “Which hand gesture would you use to do ACTION?" and four questions asked: “How would you use your smart phone to do ACTION?". ACTION stands for one of the four tasks listed above.

4.3.4 Apparatus and Materials

The study took place in a lab environment, where an Immersive Video Environment (IVE) was installed. It consisted of three big screens, which were arranged in a semicircular way and which were connected to a single PC running on Windows 7. The PC played back the two stimuli (as shown in Figure 4.1 and Figure 4.2) so that they spanned all three big screens. Each stimulus consisted of a panoramic video that showed a real-world location near our lab. This video was overlaid with a 3D building model, which was the proposed urban planning content. One building was a model of a supermarket and the other one the the model of a skateboard shop. We exported the two 3D models from Sketchup Pro 2017 into PNG format with transparent backgrounds, which were then overlaid on the panoramic videos using Final Cut Pro X. We also installed two video cameras to record all the details of the study. One camera was installed above the middle screen, recording the participant from the front, and one was mounted on a tripod to their left and slightly behind them (see Figure 4.1). During the study, every participant stood at the same location in the room, which was marked by one paper with two footprints. The mock-up smartphone consisted of two sheets of plexiglass that were attached to each other by green adhesive tape. The tape ran around all the edges of the mock-up, leaving the central part free. Users could thus look through the mock-up. The size was similar to a regular smartphone. Figure 4.1 shows the whole setting of the study and the transparent mock-up prototype of a future smartphone.

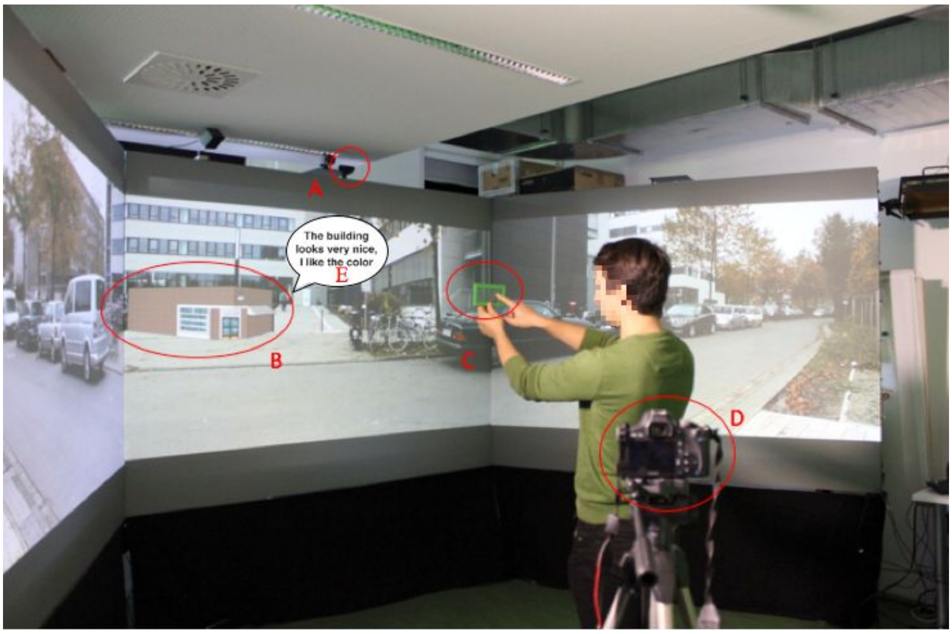

Fig. 4.1: Study setup: the participant with the transparent mock-up prototype (C) standing on the footprint mark (not shown) in front of the IVE with the urban planning material (B), and an example of a piece of comment (E), while the GoPro Hero4 camera (A) and the Canon camera (D) were recording their behaviors.

Fig. 4.2: The other stimulus played on the display in our study

4.3.5 Procedure

After welcoming a participant, the experimenter described the aims and the procedure of the study. Participants were then provided with a consent form they had to sign, while we also made sure that they understood the purpose of the study. Then participants were led to the immersive video environment and asked to stand on the marked location (footsteps) so that they faced the three screens, with the middle one right in front of them. Once they were so positioned, the following steps were carried out.

1. The experimenter briefly described the urban planning story corresponding to the first stimulus.

2. Participants were given time to familiarize themselves with the stimulus.

3. Participants were allowed to ask any questions they might have, and once they were answered (or if they had none), the recorded audio instructions for the first task were played back.

4. Participants then performed the requested gesture, thinking aloud if they chose to do so.

5. After a gesture was performed, participants were asked to rate the easiness and appropriateness of their gesture for this task.

6. The steps above were repeated for all eight tasks.

7. Once the eight tasks were completed for the first condition, the experimenter moved to the second stimulus and the second condition and repeated the procedure described above.

8. After completing the second condition, participants had to fill out questionnaires about their demographics, their general feedback and their attitudes regarding the interaction modalities.

9. At the end of the study, they could again ask questions, were paid for their participation and then discharged.

We used a within-subject study design and counterbalanced the order of exposure to the two conditions (hand gestures and phone gestures). For each condition, the order in which the tasks were given was randomized across participants. The order of the two videos/stimuli was also randomized across conditions and participants to avoid any order effects.

4.4 Results

The data collected includes videos and post-study questionnaires during which background information and further qualitative feedback on participants' experience were collected. We digitized all post-study paper questionnaires using SurveyMonkey, an online survey tool. In this way, we converted all paper information into electronic information for further analysis. Regarding the video data recorded during the main study session, we first screened them according to the taxonomies from Tables 4.2 and 4.3, which were defined mainly based on previous literature review. After that, a detailed annotation and analysis of the data were conducted.

Tasks Performed	Gesture	Voice	Both
All	178	9	32
Hand	83	0	24
Smartphone	95	9	8

Tab. 4.1: Distribution of use of interaction modalities.

Out of 224 interactions events, we had to excluded three from further analysis due to participants not producing any hand-gesture. In addition, two interaction tasks were completed by touching the large display rather than by producing hand gestures. Given the low usage of touch-screen, we did not count these two interaction tasks in our analysis either. Finally all user-defined interactions collected from our study involved three main categories of interactions: gestures (including hand-gestures and phone-gestures), voice, and both, i.e. the combination of voice and gestures, as shown in Table 4.1. Although we emphasized during the study that participants should focus on the hand and smartphone interaction modalities, some participants only use voice interactions while executing nine tasks. Data from these participants was not included in the final analysis. There are two main phone gestures classified by input modalities: surface gesture and motion gesture. Only one participant performed two motion gestures for the tasks *Vote for Yes/No* while all the other user-defined phone gestures were surface gestures. Given the low usage of motion gestures, we only constructed the surface gesture taxonomy for the phone interaction modality.

4.4.1 Gesture Analysis Method

The user-defined hand-gestures and phone-gestures were analyzed according to our taxonomies, which was based on previous work about eliciting user-defined gesture interactions (Obaid, Kistler, Kasparavičiūtė, et al., 2016; Ruiz et al., 2011; Jacob O Wobbrock, Morris, et al., 2009). Though different taxonomies have been proposed in the literature, we only focused on dimensions that are most relevant for gestural interactions by hands or smartphone. We manually classified each hand-gesture along three dimensions: form, body-parts, and complexity. Regarding phone-gestures, we extended existing taxonomies with one more dimension (i.e. spatial) to cope with the richness of our data. There were sub-categories for each dimension, and the sub-categories of the form and body-parts dimensions were different between the taxonomy for hand-gestures in Table 4.2, and the taxonomy for phone-gestures in Table 4.3.

The *form dimension* in the hand-gesture taxonomy was adopted from Obaid, Kistler, Kasparavičiūtė, et al. (2016) without modification. Gestures classified as static gestures imply that the gesture was kept in the same location without movement after

Dimension	*Sub-category*	*Description*
Form	static	A static body posture is held after a preparation phase
	dynamic	The gesture contains movement of one or more body parts during the stroke phase
Body-parts	right hand	The gesture is performed with the right hand only
	left hand	The gesture is performed with the left hand only
	two hands	The gesture is performed with the two hands
Complexity	simple	The gesture consists of a single gesture
	compound	The gesture can be decomposed into several simple gestures

Tab. 4.2: Taxonomy for user-defined hand-gestures.

Dimension	*Sub-category*	*Description*
Form	static pose	The hand pose is held in one position without any changes
	dynamic pose	The hand pose changes in one position
	static pose and path	The hand pose is held as hand moves
	dynamic pose and path	The hand pose changes as the hand moves
Body-parts	one finger	The gesture is performed with one finger only
	two fingers	The gesture is performed with two fingers
	multi-fingers	The gesture is performed with more than two fingers
Complexity	simple	The gesture consists of a single gesture
	compound	The gesture can be decomposed into simple gestures
Spatial	See-through	Perform gestures while looking through the transparent screen of the device
	Device-pointing	Device used an extension of the user's arm to point at targets on the display
	Standard-smartphone use	Device held in one hand, and one or two fingers used to simulate interaction

Tab. 4.3: Taxonomy for user-defined phone-gestures.

a preparation phase and before the retraction phase (McNeill, 1992). In contrast, gestures classified as dynamic gestures imply that the gesture has one or more movements during the stroke phase (which is the phase between the preparation and retraction phase). The classification was applied separately to each hand in a two-hand gesture. In the phone gesture taxonomy, we included the sub-categories under the form dimension from surface gestures (Jacob O Wobbrock, Morris, et al., 2009). Compared with the form dimension in the taxonomy for user-defined hand gestures, the form dimension in the taxonomy for user-defined phone gestures was extended into four sub-categories including *static pose, dynamic pose, static pose and path* and *dynamic pose and path*. We included these four sub-categories in order to capture more detailed information about surface gesture motions.

We modified the categories of the *body-parts dimension* also from Obaid, Kistler, Kasparavičiūtė, et al. (2016), since our study involved only the hands and no other body parts. We distinguished between right hand, left hand, and two hands. In the taxonomy of the phone gestures, we changed sub-categories of the body-parts dimension according the characteristics of phone-gestures, which described the number of fingers involved while performing gestures.

The *complexity dimension* was aiming at classifying how complicated one gesture is. The compound gesture could be decomposed into simple gestures by segmenting around spatial discontinuities (Ruiz et al., 2011), (i.e. the corners, pauses in motion, or inflection points) or path discontinuities, (i.e. pauses or discontinuities in fingers' movement) in the gestures.

Form, body parts and complexity were suggested as dimensions in previous work. To be able to cope with the richness of our data, we brought forth one more dimension, namely the *spatial dimension*. This dimension encodes how people hold or use the phone while interacting. We distinguish between three different ways: *see-through*, *device-pointing* and *standard smartphone use*. Some participants preferred performing gestures by holding the phone with two hands, and looking through the transparent screen of the mock-up device: these were classified as see-through (ST) gestures after (Medrano et al., 2017). Some participants also used the mock-up device as an extension of their arms to point at targets on the display, and this category was defined as device-pointing (DP). We also found that some participants designed gestures that mimicked actions occurring during standard smartphone use (i.e. the device was held in one of the hands, and one or two fingers were used to simulate interaction). These gestures were categorized as standard-smartphone use (SSU). The main difference between ST and SSU is that in the case of ST, participants systematically put the mobile phone in front of their eyes for ST, while they kept it in their hands regarding SSU.

4.4.2 Gesture Types and Frequency

Figure 4.3 shows the distribution of the 107 hand gestures according to their types. There were more static (60%) than dynamic (40%) left-hand gestures, while there were less static (47%) than dynamic (53%) right-hand gestures. However, the number of right-hand gestures (82) is larger than the two-hand gestures (10) or left-hand gestures (15). Most of the hand gestures tended to be simple gestures (66%). Figure 4.4 illustrates the distribution of all elicited phone gestures, i.e. surface gestures. Similar to the distribution of hand-gestures, there were more simple (54%) than compound gestures (46%) though the difference was not so big. More than 90% percent of gestures were performed by one finger; however, the number of SSU (49%) gestures was almost equal to the number of ST gestures (50%).

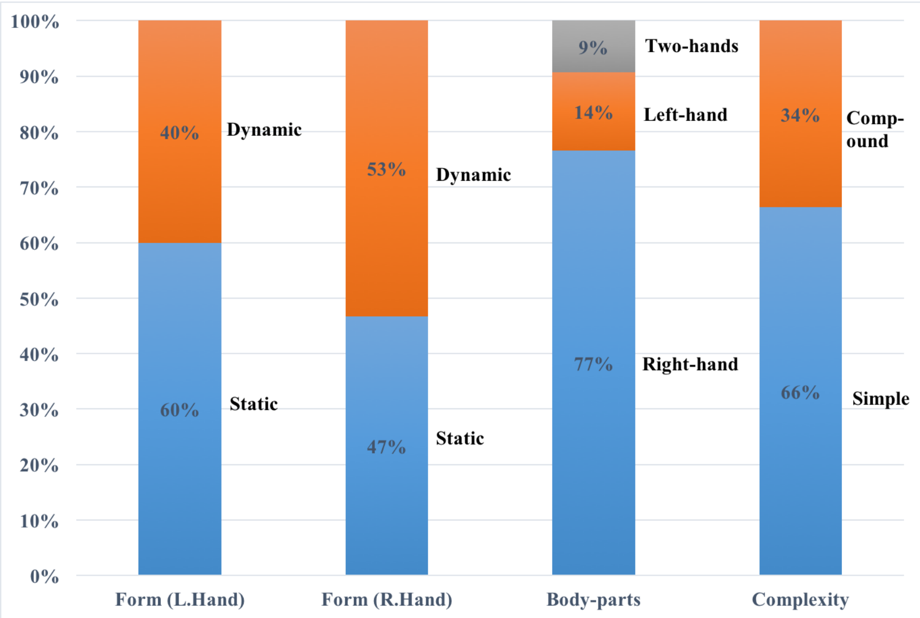

Fig. 4.3: Distribution of the elicitated hand gestures.

4.4.3 Gesture sets

Based on the elicited gestures, another main result of our study consists of two user-defined gesture sets for the specified tasks by conditions: hand gestures and smartphone gestures. Firstly, we had the set of proposed gestures for each task t, which was known as $P(t)$. Secondly for each task t, we grouped all identical gestures together. We used $P_i(t)$ to represent a subset of identical gestures from $P(t)$. Thirdly, the subset $P_i(t)$ with the largest size was chosen as the representative gesture, i.e. gesture candidate, for the task t. To avoid the conflict of two tasks getting the same gesture candidate, we added the second gesture candidate, which was chosen only when it accounted for least half of the first gesture candidate. Finally, the user-defined gesture set, which was also called the consensus set (Ruiz et al., 2011),

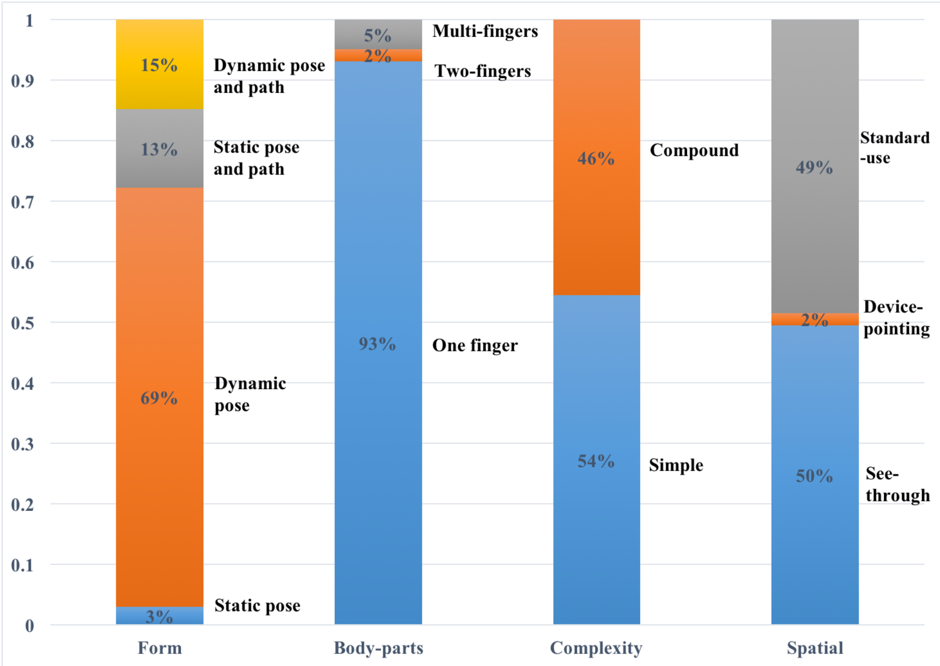

Fig. 4.4: Distribution of the elicitated phone gestures.

was generated with the representative gestures of all the tasks. The resulting user-defined sets are shown in Tables 4.4, 4.5. We also calculated an agreement score (AS) for each task to evaluate the degree of consensus among all the participants (Jacob O Wobbrock, Morris, et al., 2009; Obaid, Kistler, Kasparavičiūtė, et al., 2016; Ruiz et al., 2011; Obaid, Kistler, Häring, et al., 2014) following Jacob O Wobbrock, Aung, et al. (2005)'s formula:

$$AS(t) = \sum_{i=1}^{n} \left(\frac{P_i(t)}{P(t)} \right)^2$$

The agreement scores for the two conditions are shown in Figure 4.5. The overall agreement scores for phone-gestures are higher than the agreement scores for hand-gestures, indicating higher consensus for tasks carried out by phone-gestures in our study.

4.4.4 User Ratings

We also asked participants to rate the appropriateness and easiness of their proposed gesture or action, after each task. Our goal was to assess the quality of the match of their gestures and the tasks. Two questions were asked: (1) How easy was it for you to produce this gesture? (The scale given to participants ranged from 1 = quite hard to 5 = quite easy); and (2) How would you rate the appropriateness of your gesture/action to the task? (The scale given to participants ranged from 1 = quite inappropriate to 5 = quite appropriate)

Task	*Gesture candidates*	*Occurrence*	*Form*	*Body parts*	*Complexity*
Vote for Yes	thumb-up	64%	static	one hand	simple
Vote for No	thumb-down	61%	static	one hand	simple
Delete a comment	point to the comment, then swipe across the comment off-screen draw a X sign	36% 21%	dynamic dynamic	one hand one hand	compound compound
Leave a comment	air-point to the display to trigger voice input	43%	static	one hand	simple

Tab. 4.4: Gesture candidates for four tasks by hands

Task	*Gesture candidates*	*Occurrence*	*Form*	*Body parts*	*Complexity*	*Spatial*
Vote for Yes	tap the imaginary voting button	68%	dynamic pose	one finger	simple	SSU 58% ST 37% DP 5%
Vote for No	tap the imaginary voting button	68%	dynamic pose	one finger	simple	SSU 58% ST 37% DP 5%
Delete a comment	swipe across the comment off-screen	39%	static pose and path	one finger	simple	ST 55% SSU 45%
Leave a comment	tap the imaginary comment button, then keyboard-type	46%	dynamic pose	multi-fingers	compound	ST 54% SSU 46%

Tab. 4.5: Gesture candidates for four tasks by smartphone

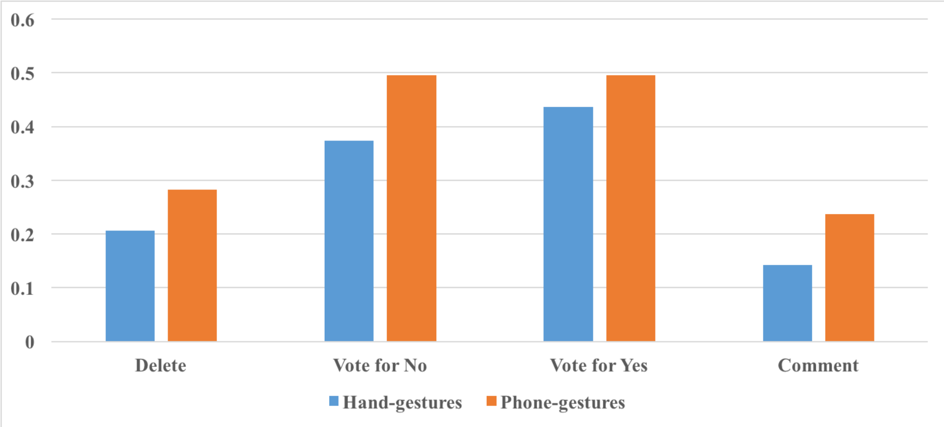

Fig. 4.5: Agreement scores for user-defined gestures in two conditions.

We used R to calculate the means of participants' ratings for these two questions. Figure 4.6 and Figure 4.7 show the mean ratings of appropriateness and easiness in the two conditions, respectively. It is interesting to observe that the means for appropriateness and easiness of phone gestures for the tasks *leave a comment* and *delete a comment* are higher than those of hand gestures, while the means of appropriateness and easiness of phone gestures for the tasks *vote for yes* and *vote for no* are lower than those of hand gestures. All mean ratings of easiness for phones gestures for the four tasks are bigger than 4 (4 = easy and 5 = quite easy), while the mean ratings of easiness for hand gestures for the four tasks fall in the range of 3-5 (3 = moderate). Similarly, all mean ratings of appropriateness for phone gestures are around 4 (4 = appropriate and 5 = quite appropriate), but the mean ratings of easiness for hand gestures fall within the range of 3.5-4 (3 = moderate).

In addition, a two-way repeated measures ANOVA revealed that the *ratings of easiness* did differ as a function of both tasks and interaction modalities, F(3) = 4.5428, $P < 0.01$. We also applied a two-way repeated measures ANOVA to the ratings of appropriateness but no significance was found. By applying one-way repeated measures ANOVA, we found that the ratings of easiness differed significantly between the tasks with F(3) = 6.978, $P < 0.001$ for hand interactions, but not for phone interactions. In particular, the task *leave a comment* received significantly lower ratings than the task *vote for yes* with $P < 0.001$ and *vote for no* with $P < 0.01$ for the hand interaction modality. No significant differences were found for the task *delete a comment*. Similarly, no significant difference was found among the tasks regarding the *ratings of appropriateness*, either for hand interactions or phone interactions.

4.4.5 User Feedback

At the end of study, we asked our participants about positive and negative aspects of using hands and phones as interaction modalities for giving feedback on the large

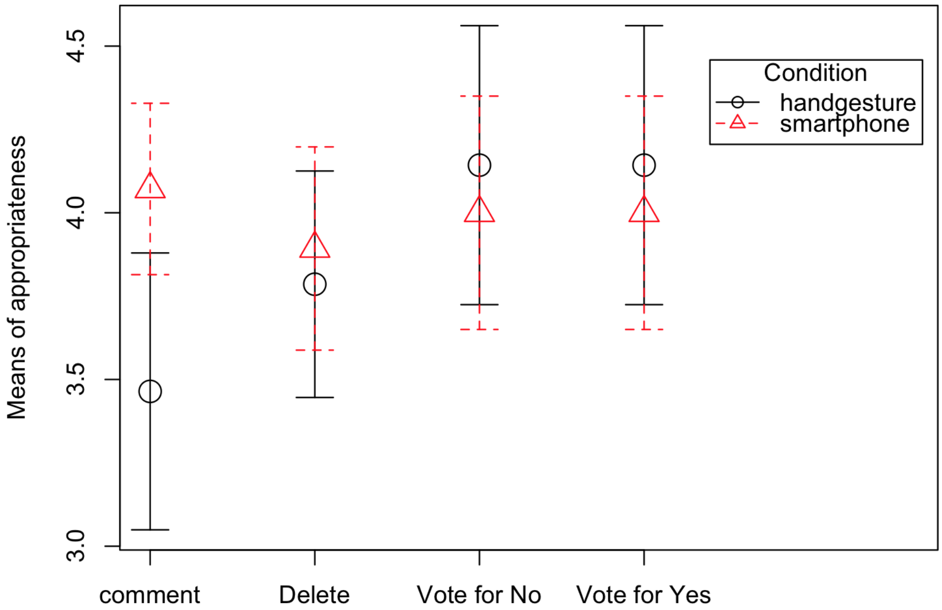

Fig. 4.6: Appropriateness ratings for the gestures proposed for the four tasks.

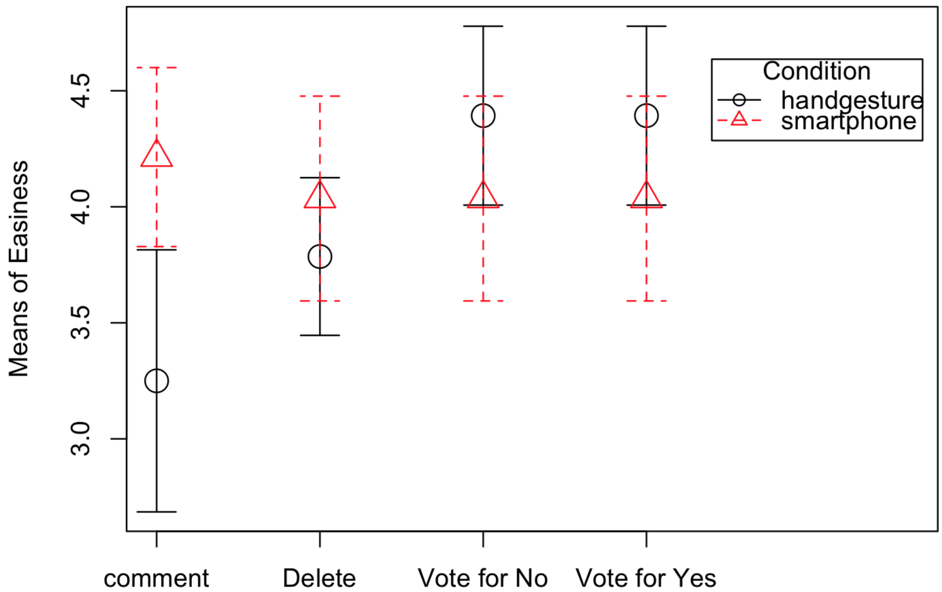

Fig. 4.7: Easiness ratings for the gestures proposed for the four tasks.

interactive display. We read and re-read all text answers from the participants and looked for common themes among all of them. Using Excel, we then counted the number of responses that applied to each theme. In the following, we list the most frequent positive and negative feedback themes (a 'most frequent feedback' was mentioned by at least two participants).

The four most frequent positive comments from participants about *hand gestures* were: no need for a personal device; more intuitive and natural; more fun and attractive to use; more accessible for boarder groups. Participants pointed out for example that hand gestures are “not needing an additional device", that there is “no need to bring phone out from pocket"; that they are “more natural", and “more fun, due to their game-play-effect"; also that they “can be more intuitive" and that “anyone will be able to join in". Regarding the *phone interaction modality*, the three most frequent positive comments were: more familiar with phone interactions; faster and easier; more private and less social embarrassment. Here, participants indicated, for instance, that interaction using phone gestures is “easy, fast, and familiar"; that “the generating of interactions are easier, because people are taught by certain apps and smartphone interaction how to use interactions like making things bigger or smaller". They also pointed out that “it is more private" and that “people have to perform less ‘embarrassing’ gestures in front of people. Also interaction can be made more accurate and potentially faster. Multiple users could add comments".

On the negative side, the four most frequent comments from participants regarding *hand gestures* include being unfamiliar with hand gestures; insensitive and inaccurate gesture recognition; social embarrassment of performing gestures in public; no privacy. Here, participants stated: “not easy to know how to use. Gesture detection can be complicated to detect. It can also be harder to define different gestures for similar actions. Frustration from the user if the system doesn’t detect gestures properly"; that it “does not feel familiar, might feel strange to move like this in the public"; that it comes with a “lack of privacy, everyone can see me perform, possible to clash with other people performing gestures". The four most frequent negative comments for the *phone interaction modality* cover the need for an additional personal device; more efforts involved in switching between two screens; more efforts for connecting their personal device with the public display; and the limited screen size of the smartphone. Participants perceived the “use of extra personal device. Might require to download a special app to be able to interact"; “more effort to check two screens (large and small)"; “the device needs some kind of connection to the public display" and “small screen size is not very comfortable"; as negative.

4.5 Discussion

Overall, feedback from participants with respect to using a smartphone and hand gestures to trigger activities for giving feedback on urban planning materials was positive. However, according to Figure 4.5, the agreement scores for user-defined phone gestures are higher than the agreement scores for user-defined hand gestures. Contrary to the opinion that the agreement score was an additional measure for the quality of the gesture candidates (Obaid, Kistler, Kasparavičiūtė, et al., 2016), we think this may only indicate that participants were more creative to come up with gestures for tasks by hands. We also observed that participants’ preference for two interaction modalities were substantially affected by the type of tasks.

Participants could represent actions with hand interactions more easily and quickly. They also thought the hand interaction proposed was more appropriate regarding the tasks *vote for yes* and *vote for no*. However, they performed better with the smartphone interaction and they thought the smartphone interaction proposed was more appropriate with respect to the tasks *leave a comment* and *delete a comment*.

Revisiting the three research questions listed in Section 4.3, the user-defined sets which are reported in Tables 4.4 and 4.5 provide an answer to the first research question. Providing an answer to the second research question (*"which of these four tasks lend themselves well to being executed by hand or phone interaction modalities, and which ones do not?*") depends on the definition of what "lending itself well" means. We adopted the notion that tasks which 'lend themselves well' for an interaction modality need at least a score of 4.0 for that interaction modality. This appeared to be the best match to the question asked to the participants and the likert scale given to them (as a reminder 3.0 meant 'moderate', 4.0 meant 'appropriate', and 5.0 meant 'quite appropriate' on that scale). Looking at Figure 4.6 and Figure 4.7, one can see that the tasks *leave a comment* and *delete a comment* lend themselves well to being executed by the phone interaction modality in our study (the hand interaction modality did not reach the threshold set at the beginning of the paragraph).

In contrast to the above, we obtained quite different results for the tasks *vote for yes* and *vote for no*. From the two figures, the mean ratings of rated appropriateness and easiness for the tasks *vote for yes* and *vote for no* are higher than 4, while the means for phone gestures are around 4, i.e. a little higher or lower than 4. This indicates that the tasks *vote for yes* and *vote for no* lend themselves well to being executed by both of the two interaction modalities (though the hand interaction is likely to be users' first choice in practice since it received overall higher ratings during the study).

Both interaction modalities have their own advantages and disadvantages on specific tasks as discussed in the previous paragraph. However, regarding the answer to the third research question, we can state that the phone interaction modality may be more suitable than the hand interaction modality for the four tasks, based the results in this study. The main rationale is that the mean ratings of appropriateness and easiness for phone gestures always kept around 4, which suggests that although the phone interaction modality did not perform as good as the hand interaction modality on the tasks *vote for yes* and *vote for no*, its overall performance was better. In addition, for the four tasks, the phone interaction was not only considered to be easy to come up with, but also appropriate for the tasks. Regarding the hand interaction modality, it executed the tasks *vote for yes* and *vote for no* better than the phone interaction modality based on the results of easiness and appropriateness ratings, but the difference was minimal. For the task *leave a comment*, the mean ratings of appropriateness was around 3.5 and the mean ratings of easiness was between 3.5 and 3, which shows a big difference for the phone interaction modality. The means ratings of appropriateness and easiness of hand gestures for task *delete a comment* were lower than 4.

4.5.1 Implications for system design

The user-defined gesture sets listed in Tables 4.4, 4.5 and some trends that emerged during the study provide several challenges for designers of gestural interaction with the public display. One trend that emerged is that not only gesture recognition sensors, but also sound sensors may be needed to collect feedback from participants on public displays in an urban planning context. 20/28 participants used voice or voice+gestures as input to leave their comments when using hand gestures, which means sound sensors should be sensitive enough to capture people's words. Another major trend which emerged was that participants performed gestures by looking through the transparent screen of the mock-up device. This may indicate that people do not want to make complicated connections between the smartphone and the display, instead, they mimic the connecting process as a way similar like the process of scanning QR code. In our study, we found that people expected real-time, synchronous responses to their interactions on the smartphone and the large display.

Furthermore, participants' comments on the drawbacks of the interaction modalities should be taken into account by interface designers to minimize risks of interaction blindness (Du, Lohoff, et al., 2016; Sorce et al., 2015) in the urban planning context. That "lack of privacy" was mentioned by several participants as a possible negative aspect, points at the need of further researching methods (such as (Röcker et al., 2008)) to guarantee a 'personal space' to users while interacting with public displays for voting/commenting in the urban planning context. Additionally, citizens' potential privacy concerns could be mitigated by deploying displays to gather their feedback in semi-public spaces (e.g. a controlled environment such as an office building of the local city council). In this case, local authorities could provide a smartphone in these spaces as a way to reduce potential hesitations of some citizens to use their personal devices. Overall, examining the effect of different interaction modalities (hand vs smartphone) and the type of settings (semi-public vs public) in which they are implemented, on trust and engagement of citizens with the displays during consultation processes is a gap that deserves a closer look in future work.

4.5.2 Implications for interface design

Gesture consistency and reuse: We observed that participants occasionally reused simple gestures for different tasks. For example, the gesture candidates for the task *vote for yes* and *vote for no* by hand were thumb-up and thumb-down, respectively, while the gesture candidates for these two tasks by smartphone were similar (i.e. tap the imaginary voting buttons). Participants reused some of their gestures not only among analogous tasks in the same condition, but among different conditions for the same task. For example, more than half participants used one hand to swipe across the comment off-screen from the display, and more than half participants chose to swipe across the comment off-screen from the smartphone by one finger. This emphasizes people's natural propensity to reduce learning and memorizing workload. Gesture reuse and consistency are thus important to increase learnability and memorability (Wu et al., 2006; Valdes et al., 2014; Jacob O Wobbrock, Morris, et al., 2009), and this should be taken into account when designing user interfaces helpful for citizens to provide their feedback in an urban planning context.

Interaction beyond single interaction modality: Figure 4.5 shows the agreement for the task *leave a comment* by hand is low, which suggests that participants found it challenging to complete the task with a gesture or an interaction. As said above 20/28 participants chose voice or voice+handgestures to leave their comments instead of hand gestures only. When they performed the tasks with the smartphone, some of them (8/28) also used voice or voice+phonegestures to finish the task of leaving their comments. Few people even insisted on only using voice interaction with smartphone. This indicates that voting/commenting in the urban planning context may benefit from a combination of the two interaction modalities.

4.5.3 Limitations

Overall, we found participants to be very creative to generate a lot of hand gestures in a very limited time. According to the background information on participants collected, almost 90% of them had rarely interacted with a public display by using hand gestures. However, we also found that the user-defined smartphone interactions were quite influenced by their experience of using smartphones during daily life. Around 96% of participants declared that they used smartphones very frequently in their daily life. This is also reflected on their generation of the user-defined set for smartphone interaction. So even though users participated in the co-design of interactions (and voiced their preferences), it may be the case that the interactions suggested have been slightly biased by (or towards) their smartphone use experience. Including more participants with less familiarity with smartphones in subsequent studies could help to get a more complete picture of gestural interactions required for the voting/commenting tasks examined in this work.

4.6 Conclusion

Public displays have the potential to reach a broad group of citizens in urban life, and increasing their interactivity would be beneficial in the context of citizen participation. This article has examined interaction modalities preferred by users when it comes to giving feedback on urban planning material on public displays using their hands, or a smartphone. Four main tasks were considered, namely *vote for yes*, *vote for no*, *leave a comment*, and *delete a comment*. A total of 219 interaction data were collected from 28 participants and analyzed.

Overall, our data suggests that smartphones would be more suitable for adding/deleting comments, while hand-gestures would be more convenient for the voting task. In addition, post-study questionnaires allowed us to collect participants' perceptions about the pros and cons of each interaction modality. Hand-gestures were viewed as more intuitive, natural, and accessible to broader groups by the participants. However users mentioned that may provoke social embarrassment on the part of citizens. Regarding the smartphone, using it to provide feedback on public displays was perceived as faster, easier, and more private by subjects from our sample. On the contrary, the limited size of the phone, and the need to switch between two screens were mentioned as drawbacks by the participants. The insights obtained in this work contribute to making large interactive displays more suitable for higher levels of public participation (i.e. citizen consultation or collaboration between citizens and local authorities).

Implementing the smartphone gestures identified in this article and evaluating their usability in the context of urban planning is part of an ongoing work. In addition, the experience with smartphones could have influenced the gestures proposed by participants, and a complementary elicitation study involving people with less familiarity with smartphones would be valuable in confirming/expanding the gesture set identified during this work. Finally, it has become clear during the course of the work that techniques to guarantee a 'personal space' to users while interacting with public displays would be key for the adoption of gesture-based interaction during citizen consultation in urban planning processes.

5

Interactive Immersive Public Displays as Facilitators for Deeper Participation in Urban Planning

This chapter proposes a new approach for using public displays for voting and commenting in urban planning, and a multi-level evaluation of a prototypical system implementing the proposed approach. It has been submitted to the International Journal of Human-Computer Interaction as Du, Guiying, Christian Kray, and Auriol Degbelo. "Interactive Immersive Public Displays as Facilitators for Deeper Participation in Urban Planning".

Abstract. Citizen participation is an important part of urban planning but few people participate, and most frequently they can do so only passively. This can result in excluding many people and to urban designs not reflecting peoples wishes. In this paper, we explore the use of interactive immersive public displays as facilitators for deeper participation in urban planning. We propose a novel approach that combines panoramic videos of locations with overlays depicting planned buildings. We evaluated the approach in a lab-based user study (N=21), where participants used a simple mobile client for interacting with a prototypical implementation to vote and comment on urban planning proposals. Usefulness, ease of use, ease of learning and user satisfaction were all rated highly by the participants. Furthermore, many comments users gave on the urban planning projects were of high quality. Overall, the results provide initial evidence that the approach succeeded in facilitating deeper participation.

5.1 Introduction

Citizen consultation is an important phase in the urban planning process to ensure, amongst other things, the resulting buildings and changes to the city to meet the needs and wishes of the inhabitants. There are long-established methods (Sanoff, 2000; Creighton, 2005; Howard and Gaborit, 2007), such as public presentations or publicly displayed plans for this purpose but they suffer from a number of issues. These problems include a lack of participation from citizens in general and from specific groups (e.g. vulnerable or disadvantaged people) in particular (Münster et al., 2017). In addition, Münster et al. (2017) also point out that standard ways to present urban plans (such as detailed architectural drawings or maps) are not necessarily easy to understand for everyone. The time and location where events take place or plans are exhibited, are also frequently only known to a small part of the population (Münster et al., 2017). Finally, participation often is realised at the lower end of Arnstein's participation ladder (Arnstein, 1969), where citizens are merely informed about planned projects with little if any means to voice their opinions or make suggestions.

Public displays as a technology have the potential to overcome many of these issues in participatory urban planning. First, they are increasingly ubiquitous (Davies, Clinch, et al., 2014), in particular in places that are visited by many people, e.g. shopping centres or transportation hubs. This would allow for pushing urban planning information to where people are rather than citizens having to find out where/when such information is on display and then having to go there at the right time. Secondly, public displays are accessible to anyone who is present at their deployment location. This, in turn, can raise awareness of urban planning projects and empower people who do rarely participate in traditional urban planning events (Oksman et al., 2014). Finally, public displays can support different ways to present urban planning information (Ishii et al., 2002; Hosio, Goncalves, Kostakos, and Riekki, 2015; Steinicke et al., 2006) and can facilitate different forms of interaction (Ardito et al., 2015). These properties can help to make information more accessible to a broader audience and to provide them with means to participate beyond simply absorbing information. Taken together, these observations indicate that it makes sense to explore the potential of public displays for deeper participation in urban planning.

In this article, we introduce a novel approach that relies on public displays to facilitate deeper participation in urban planning. We propose to combine an immersive public display with a simple mobile client to enable citizens to vote and comment on urban planning projects. The proposed projects are visualised using panoramic videos of the project site (in its current form), which are overlaid with 3D models of the planned buildings. We created a prototypical implementation that realises our approach and used to evaluate it in a lab-based user study with 21 participants. In our study, we investigated standard usability aspects as well as what comments participants would provide on the urban planning projects.

Our main contribution are a new approach for using public displays for voting and commenting in urban planning, and a multi-level evaluation of a prototypical system implementing the proposed approach. Our results can benefit designers of participatory public displays systems as well as urban planners wishing to deepen the level of citizen participation in their projects. The rest of this article first briefly reviews relevant related work and then introduces our approach in detail. The second half of the paper reports on the user study we conducted, presents key results, discusses implications and insights, and then summarises the main findings of our work.

5.2 Related work

Since the current work aims to evaluate the usability of public displays for deeper public participation in urban planning, this section reviews previous work that has been done on two relevant topics: public participation in urban planning, and public displays for public participation. Besides, the work later proposes a mobile-client, which enables voting and interaction on public displays. Accordingly, relevant work on mobile interaction with public displays is briefly presented.

5.2.1 Public participation in urban planning

According to the European Institute for Public Participation (European Institute for Public Participation (EIPP), 2009), public participation can be defined as: "the deliberative process by which interested or affected citizens, civil society organisations, and government actors are involved in policy-making before a political decision is taken. By deliberation, we mean a process of thoughtful discussion based on the giving and taking of reasons for choices". This definition emphasises involving different stakeholders in the public decision-making process.

A critical part of public participation theory is the redistribution of power among different stakeholders, e.g., government, institutions, communities, and citizens. Arnstein (1969)'s ladder of citizen participation suggests how much power citizens get at different participation levels. From the lowest 'no participation level' to the middle 'tokenism participation level' and finally reaching 'citizen power level', more power should be assigned to citizens until they become powerful decision-makers themselves. On the one hand, researches have been carried out to empower citizens for higher participation levels. On the other hand, the ladder indicates a scale upon which citizens' participation level can be measured while citizens are involved in participatory decision-making processes. Another well-known public participation theory is the public participation spectrum[1] from the International Association for Public Participation (IPA2), which defines five levels of realising citizen participation: informing, consulting, involving, collaborating with, and empowering citizens. Each

[1] https://sustainingcommunity.wordpress.com/2017/02/14/spectrum-of-public-participation/ (last accessed: August 28th, 2018).

of public engagement levels in the spectrum has a very clear goal and promise for the public. The spectrum has been actively referenced in the literature (Sheedy et al., 2008; Head, 2007; Creighton, 2005) and commonly used in the open government context.

Implementing public participation in urban planning processes is quite beneficial for several reasons. Firstly, it can reflect public interests, manage conflicts, and achieve better decision-making results (Pateman, 1970; Fagence, 2014; Berry et al., 2002). Secondly, decisions can be more realistically rooted in citizen interests, and the public can reveal hidden facts for tough decisions. Finally, though incorporating citizens into decision making-process needs effort, the potential benefits from the political, social, and economical perspectives give essential reasons to initiate citizen participation in decision-making processes (Pateman, 1970; Fagence, 2014; Berry et al., 2002).

Public hearing and hiring advisory committees are two frequently used techniques to enable public participation. Citizens conventionally contribute their participation in verbal or written form during specific events such as public hearing, workshops, and face-to-face dialogues (Sanoff, 2000; Creighton, 2005). However, the traditional methods mentioned above are usually criticised for low accessibility by the general public (Conroy and Evans-Cowley, 2006). For instance, citizens may not be able to attend a public hearing meeting that would occur at a specific location and time for some good reasons such as work pressure or family responsibilities. Furthermore, it is still a major challenge for traditional public participation technologies to involve a broad range of citizens in the decision process (Münster et al., 2017). Usually, only a subset of the potentially affected citizens can be involved in using traditional public participation methods. Howard and Gaborit (2007) pointed out three critical issues of conventional participation methods stopping the public from going into deeper levels of participation: lack of interactivity, lack of a feeling of immersion, and lack of specificity of the comments (in part due to the absence of concrete stimuli which people can use to articulate their opinions).

The development of information and communication technologies bring new methods for facilitating public participation in urban planning. Public displays as a promising information and communication technology, are getting more and more attention for facilitating public participation in modern cities (Hosio, Goncalves, Kostakos, and Riekki, 2015).

5.2.2 Public displays for public participation

As indicated by Schaeffler (2012), a public display means a sub-segment of electronic signage in public space that is “centrally managed and individually addressable for display of text, animated or video messages for advertising, information, entertainment, and merchandising to targeted audiences". Kostakos and Ojala (2013) and Urban et al. (2011)’s work showed that this technology has the potential to change our urban environments and urban life. However, in their review of previous work on using public displays for public participation in urban settings, Du, Degbelo, et al. (2017) found that current research on public displays was mainly targeting informing the public. The authors pointed out that, so far, public displays have often served as ambient information providers in shopping malls, shop windows, urban public space, airports, train stations and stadiums.

Public displays are also expected to collect feedback from citizens who use them for both civic engagement and public participation regarding different scenarios. There are two common methods on public displays to collect citizens’ input, i.e. voting and commenting.

There have been various researches on polling/voting systems on public displays, ranging from indoor deployments (Paek et al., 2004) to public spaces (O’Hara et al., 2004). ‘PosterVote’ (Steinberger et al., 2014) and ‘Swipe I Like’ (MM Behrens, 2011) were two light weighted polling/voting application with no screens, people can choose options by pushing buttons or swiping above sensors. Their advantages were as many as their drawbacks: easy to make and deploy, low cost but lack of vivid representation ability. Agora2.0 (Schiavo et al., 2013) was designed as a voting public display to collect citizens’ opinions for local civic issues. ‘MyPosition’ (Valkanova, Walter, et al., 2014) used a large projection to visualise locally relevant topics in opportunistically and engagingly. People could show opinions on four scales as ‘strongly disagree’, ‘disagree’, ‘agree’ and ‘strongly agree’ by raising their hands. Vote with your feet (Steinberger et al., 2014) provided tangible foot-buttons for uses to choose ‘yes’ or ‘no’, and displayed the results of the polling on a public screen. ‘Smart citizens dashboard’ (Moritz Behrens, Valkanova, Brumby, et al., 2014) was special among these voting applications. It employed media facades as screens, and a physical ‘console’ as a mediator to facilitate interaction. People can choose ‘sad’, ‘indifferent’ and ‘happy’ to express their emotions on different topics via the console and media facades adjust their content according to different choices.

Applications on public displays were also created for collecting citizens’ comments. Schroeter et al. (2012) proposed an application ‘DIS’ to collect citizens’ ideas from SMS, Twitter or mobile web interface about local topics in Melbourne. The study showed the importance of an easily understandable and simple interface for enhancing the engagement. TexTales (Ananny and Strohecker, 2009) was designed to encourage European young people to share photos and SMS annotation of daily city events or discussion on controversial public issues. Similarly, Hosio, Kostakos, et al. (2012) proposed Ubinion, a service that utilises large public interactive displays to enable young people to give personalised comments on municipal issues to local youth workers. Their work mainly used SNSs (Social Networking Services, i.e. Facebook and Twitter) to allow teenagers to share their photos and comments on a public display screen. Their field trials illustrated the effectiveness of public displays in collecting comments in youth, while their applications also collected many meaningless postings.

In summary, many researchers have tried to enable voting/commenting on public displays, but few specifically looked into enabling these two functions in spatial urban planning domain. Previous work collected feedback mainly based on text/questions provided to users, but a significant difference in the current practice is that a concrete urban planning design is offered to users as starting point to substantiate their opinions.

5.2.3 Mobile interaction with public displays

Ardito et al. (2015) conducted a comprehensive literature review on interactions with large public displays. During their survey, four main interaction categories were distinguished: *touch*, *external device*, *tangible object*, and *body*. Regarding the *touch* interaction modality, most of systems allowed multi-fingers simultaneously interacting (Vogel and Balakrishnan, 2004) while a few systems support one finger at a time (Kim et al., 2010). Steinberger et al. (2014) designed tangible buttons for voting on public displays. With respect to the *body* interaction modality, current research (Reitberger et al., 2009; Briones, Mottram, et al., 2007; Bellucci et al., 2014; Exeler et al., 2009; J. Müller, Exeler, et al., 2009) were mainly focused on *body presence*, *body position*, *body posture*, *hand gestures*, *facial expression*, and *gaze*.

According to Ardito et al. (2015), a considerable number of previous research described using external devices to interact with public displays. Mobile phones as ubiquitous input devices have become a research focus concerning interacting with public displays in recent years (Ballagas et al., 2006). Previous work (Liang et al., 2012; Boring et al., 2009; Lucero et al., 2012; Kray et al., 2010) regarding mobile interactions were mainly focused on two types of phone interactions: surfaces gestures (i.e. two dimensional) and motion gestures (i.e. three dimensional). Mobile interactions are quite useful when the display is very big. Also, they are very helpful in solving privacy issues, for instance, people can input their personal data through mobile phones without worrying others looking at the display (Magerkurth and

Tandler, 2002). Alt, Shirazi, et al. (2013) compared several techniques (i.e. direct touch at the display, paper-based, and mobile phone-based interaction) for creating content to be shown on public displays. In their study, users preferred mobile phones to create content in a privacy-preserving way/on-the-go.

5.2.4 Summary

To summarise, implementing public participation can bring significant benefits for urban planning processes. Public displays have an excellent potential for facilitating public participation in the context of urban planning, but so far have mainly targeted lower levels of public participation (i.e. informing). Previous work has highlighted the use of smartphones for interacting with public displays, showing that they are appreciated by users. Yet, supporting deeper participation by enabling both voting and commenting simultaneously on a concrete visual stimulus (i.e. urban planning design) shown on a public display has been barely touched upon. This paper aims to fill that gap.

5.3 A public display-based approach to facilitate deeper participation in urban planning

To address the urban planning issues outlined in the introduction and the previous section, and also to explore the potential of public displays in this context, we set out to design an approach that combines several elements. In the following, we first outline the underlying design rationale and then describe all components of the approach as well as their interplay. The final subsection briefly describes the prototypical implementation we realised to evaluate the approach.

5.3.1 Design goals and rationale

The overarching goal of our work was to facilitate deeper levels of participation in urban planning for everyone. More specifically, we intended to lower key barriers that hinder participation. Firstly, we wanted to present urban planning projects in such a way that they were easy to understand for anyone who is familiar with the site where the planned projects are located. Our second objective was to attract citizens and to immerse them in the planned project to increase participation rates. Thirdly, we wanted to make interaction easy and intuitive to ensure that as many people as possible can participate. Finally, we were keen to move participation beyond simply consuming prepared information by enabling citizens to vote and comment on urban planning projects.

5.3.2 Key components of the proposed approach

The approach we designed to achieve the goals outlined above consists of four main components: (1) a three-side immersive video environment; (2) panoramic videos overlays with planning content; (3) voting and comment panes also overlaid over the panoramic video; and (4) a simple mobile voting/commenting app. The *Immersive Video Environment (IVE)*[2] consists of three large displays arranged in a semicircular fashion (see also Fig. 5.1) that displays panoramic videos of the location where an urban planning project is intended to unfold. Previous work (Ostkamp and Kray, 2014) has shown that IVEs are easily understood and facilitate quick immersion into the depicted location. We also hypothesise that they might attract passers-by who might recognise the depicted location.

The actual planning content (e.g. planned buildings or landscaping measures) are depicted as *static overlays of 3D drawings* over the panoramic video footage. By this, we hope to enable users to appreciate the planned project in context, i.e. the familiar location shown as panoramic video. Also, the discernibly different style of the 3D object made sure it was clearly visible what is planned content and what is the current status-quo. Finally, we assumed that the sketchy nature of the planning content would invite comments, similarly to how paper prototyping (Snyder, 2003) lowers barriers for change requests compared to more sophisticated UI prototypes (Rudd et al., 1996).

Deeper participation was realised by enabling voting and commenting on proposed projects. A *simple mobile client*, running on a smartphone, provides the means for people to cast votes and enter comments. It connect to the IVE, which displays accumulated votes and all collected comments using two separate *content panes*, which are also overlaid over the panoramic video footage. Our previous work (currently under review) has indicated that using a mobile phone to vote and comment on urban planning projects seems intuitive to many participants. By realising voting and commenting in this way, we hoped to lower access barriers and to make it easy to learn how to vote and comment. At the same, time we wanted to protect the privacy of participating people by letting them vote and author comments on their personal devices.

5.3.3 Prototypical implementation

In order to evaluate our approach, we developed a prototypical implementation. It uses an existing open-source platform for realising immersive video environments, which is based on web-technologies and easily extensible. We extended the system to

[2] `https://github.com/sitcomlab/IVE`.

Fig. 5.1: Prototypical implementation of the proposed approach: immersive video environment consisting of three large screens; central screen shows panoramic video and planned building; side screens show voting results and comments; user votes/comments using simple web app on mobile phone.

support multiple overlays and also created a simple web-app for mobile phones that connects to the backend of the IVE system. Users can first vote and then comment on urban planning project using the mobile client, which then sends the results to the backend. The system was designed to run on a three-display environment. The left and right display show the voting/commenting results while the central display depicts the urban planning project as on overlay.

To run the study presented in the following section, we created panoramic video footage of several locations around Münster, Germany and collected freely available 3D objects to use as planned building projects. In the study, the experimenter used the default control application of the IVE to switch between different panoramic video scenes.

5.4 User Study

To evaluate the approach introduced in the previous section, we ran a lab-based study using the prototype described in Section 5.3.3. The study was approved by the local ethics review board. The main goals of the study were to determine if people would be able to use the large interactive public display for voting and commenting on the urban planning process. We were also keen to see how the approach with respect to standard usability measures (such as ease of use or learning), and to observe how people would use the system. In the following, we describe the study and its design in more details.

5.4.1 Study design

We simulated a case of public consultation in the real world, in which we asked people to examine an urban planning design and give their feedback in the forms of votes and comments. To make the simulation as realistic as possible, we created six urban planning scenarios involving existing locations in Münster. Two urban planning projects were involving the *city level*'s participation, i.e. one project was about adding two pillar gates at the entrance of the city centre to signal people their entering into the city centre, and another project was about building a new music centre, where citizens can enjoy concerts, operas and other music events. The other four urban planning projects were involving the *community/neighbourhood level*'s participation. These were: adding a garden house in the community; having a teaching building in the university; building a bookstore in the campus of the university; adding bike racks in the community.

The tested application on the smartphone had two functions: voting and commenting (which also were two tasks for our participants in the study). The main reason for having these two tasks for the our study is that according to the Spectrum of Public Participation developed by the International Association of Public Participation (IAP2), the goal of the *consult* level is "to obtain public feedback on analysis, alternatives, and or decisions". Since the purpose of our prototype was to support citizen consultation, voting and commenting were chosen as the ways of obtain citizen feedback. Compared to passively absorbing information, voting and commenting make citizen more actively involved in the urban planning process.

To increase the realism of the scenarios, each urban planning design had three initial comments prepared by the researchers following the rule: one negative, one positive and one neutral (i.e. expressing mixed feelings). The comments were shown on an immersive display, and their order of appearance was randomised. The six scenarios, the initial examples provided to the participants, as well as some sample comments they produced during the study are provided in Appendix 5.8. The full datasets about the votes/comments of all participants are available upon request to the authors.

5.4.2 Participants

In total, 21 participants (7 female, 14 male) were recruited for our study via paper advertisements that we posted in the different parts of the city. Participants were between 21 and 38 years old (mean=26, SD=4.5). All the participants could speak English, which was necessary since our study was conducted in English. At the end of the study, each participant was paid 10 Euros as compensation for their time.

5.4.3 Apparatus and material

The study has been run in the lab environment, where the large immersive display was deployed. The display has three screens arranged in a semi-circular way. The three screens were connected to a single PC running on Windows 7. Our study involved six urban planning scenarios (briefly presented above), and each scenario included three different urban planning designs. Hence, there were 18 stimuli in our study, and each stimulus consisted of an overlay and a panoramic video that showed a real-world location in the city. The stimuli for the same urban planning scenario shared the same panoramic video. Each overlay was a PNG format image of a 3D model with the transparent background[3]. One camera was installed to record participants' behaviours during the study, and was mounted on a tripod behind them. A Samsung Galaxy S7 smartphone was prepared for participants with the tested application for voting and commenting running on it.

5.4.4 Procedure

The experimenter described the purpose and the procedure of the study to each participant at the beginning of the study. The participant was then asked to sign a consent form. After signing the consent form, the participant filled a questionnaire, which was used for collecting background information. Then the participant was led to the large immersive display, and they were free to choose a preferable position to stand at or sit in front of the display. A few participants chose to sit during the study process, which may because they were tired after one day's working or studying. Once they were ready, the experimenter followed a script to walk the participant through the six different urban planning scenarios, and the voting/commenting tasks on the three different urban planning designs per scenario. The main steps can be described as follows.

- The experimenter briefly described the concept of the immersive video and its overlay on the large display in the urban planning context.

- Participants were given a smartphone with the application for voting and commenting on the display.

[3] All models and videos for the six urban planning scenarios can be obtained upon request to the authors

- Participants were then allowed to ask any questions for further clarification. Only questions related to how to use the application on the smartphone were excluded, as that was part of what we were evaluating.
- Once all the questions of the participants were answered, the experimenter started the main study session with the first urban planning scenario.
- The background information of the first urban planning scenario was presented to the participants by the experimenter.
- After the participants understood the background story of the urban planning project, they were asked to use the smartphone to give their votes and comments to the first urban planning design by self-exploration.
- The steps above for the first urban planning scenario were repeated for all five remaining scenarios.
- After completing all six urban planning scenarios, participants were asked to fill in the USE questionnaire.
- Finally, a short interview was conducted with each participant. The interview collected information regarding user perceptions on specific features of the interactive immersive public display.
- The participants were then paid and received thanks from the experimenter for their participation.

The study followed a within-group design. The order of exposure to the six urban planning scenarios was randomised. For each urban planning scenario, the order in which the three alternative urban planning designs were shown, was fixed. For each participant, we video-recorded the entire study process. These video records were used to count the number of times help was required by each participant during the study. Besides, each participant's interaction data, i.e. votes and comments, were also collected in log files.

5.5 Results

As mentioned earlier, the goal of the study was to determine if the general public would be able to use the interactive public display for public consultation in urban planning processes. This section reports on the usefulness, ease of use, ease of learning, user satisfaction with the prototype developed, and presents insights from the qualitative feedback from the participants. Among all the participants, only two participants asked us for the help regarding the phone interface, and each of them happened only one time. The results of the USE questionnaires will be presented first in the following subsections. Each participant went through six different urban planning scenarios, and voted/commented on three different urban planning designs per scenario, resulting in about 378 votes/comments. The final subsection analyses those comments in more detail.

5.5.1 Usefulness

The analysis of the USE questionnaires shows some interesting results. Regarding the scale of *usefulness*, our prototype averaged 5.98 out of 7. Table 5.1 shows each question with its weighted average. The mean score of 5.98 shows that participants considered the prototype to be useful. The lowest score in this set of questions is about whether the prototype meets the participants need. This occurred maybe because most of the participants have little experience of participating in the urban planning decision-making process during their daily life. According to the information collected in the background questionnaires, more than 80% participants never gave an online vote regarding an urban planning project through a smartphone in the last year, while more than 70% participants never gave online comments regarding an urban planning project through a smartphone in the last year. But when they were asked how important it is for them to give their votes and comments, more than 60% participants thought it was important. The highest score in this set of questions is about whether the participants think the prototype is useful for them. The weighted score of this question is 6.52 out of 7, which is a quite high score. It reveals that although people are not sure they will need to use it to participate in the urban planning process, they think it could be a useful tool for voting and commenting.

Usefulness questions	**Score**	**SD**
It helps me be effective to give my feedback	6.48	0.69
It helps me be productive to give my feedback	6.33	0.80
It is useful	6.52	0.68
It gives me more control over the activities	5.57	1.12
It makes the things I want to accomplish easy to get done	5.95	1.07
It saves me time when I use it	5.95	1.02
It meets my needs	5.48	1.17
It does everything I would expect it to do	5.58	1.29
Usefulness score:	5.97	0.44

Tab. 5.1: User scores for questions related to the prototype's usefulness, as well as their standard deviations.

5.5.2 Ease of use

The second set of questions were used to evaluate the *ease of use* of the prototype. The prototype scored well on this scale as well, with a mean of 5.92 of 7. Table 5.2 shows each question in this set and its score. Two questions got the highest score: *it is easy to use* (6.62) and *it is simple to use* (6.62). The lowest score is about whether or not the participants think this prototype is flexible to use. We believe this occurred because, for each round of voting and commenting, participants needed to refresh the interface by themselves. During the interview session, many participants mentioned this issue should be improved or fixed.

Ease of use questions	**Score**	**SD**
It is easy to use	6.62	0.59
It is simple to use	6.62	0.74
It is user friendly	6.33	0.73
It requires the fewest steps possible to accomplish what I want to do with it	5.67	1.35
It is flexible	5.14	1.71
Using it is effortless	5.90	1.30
I can use it without written instructions	5.52	1.57
I don't notice any inconsistencies as I use it	5.90	1.22
Both occasional and regular users would like it	5.81	1.12
I can recover from mistakes quickly and easily	5.33	1.31
I can use it successfully every time	6.33	0.73
Ease of use score:	5.92	0.50

Tab. 5.2: User scores for questions related to the prototype's ease of use, as well as their standard deviations.

5.5.3 Ease of learning

The scale of *ease of learning* is highly correlated with the scale of ease of use. In our study ease of learning of the prototype got a high score also, with an average of 6.62 out of 7. Table 5.3 shows each question and its weighted average. The highest score is about whether the participant can easily remember how to use the prototype, with a score of 6.76. It shows that the prototype is easy to learn without instructions, and it is easy to use without many efforts once it's learned. Because the prototype is designed for public use in urban planning, these aspects of high learnability and memorability are considered necessary and important. The scores obtained here indicate that cognitive efforts required to get started were minimal so that users can focus on the important tasks of voting and commenting.

Ease of learning questions	Score	SD
I learned to use it quickly	6.62	0.59
I easily remember how to use it	6.76	0.44
It is easy to learn to use it	6.67	0.58
I quickly became skillful with it	6.43	0.60
Ease of learning score:	6.62	0.14

Tab. 5.3: User scores for questions related to the prototype's ease of learning, as well as their standard deviations.

5.5.4 User satisfaction

The mean score of 5.82 suggests that participants were satisfied with the prototype. Table 5.4 shows all the questions for the scale of user satisfaction and the weighted average of each question. The highest score for these questions is about whether users would recommend it to a friend, with a score of 6.48. Since our prototype is designed for collecting public feedback on the urban planning designs, this is an evidence for the good prospects of public participation using public displays. The lowest score is about whether or not participants think the prototype is a wonderful application and whether they feel the need to have it. Given the *public* nature of the public display, it is understandable that people not necessarily feel the need to have it. As to why people could have rated wonderfulness lower than other items, it could be simply because people think there are still some other features which could be included in the final system for citizen consultation.

User satisfaction questions	Score	SD
I am satisfied with it	6.19	0.93
I would recommend it to a friend	6.48	0.93
It is fun to use	5.76	1.22
It works the way I want it to work	5.90	1.04
It is wonderful	5.29	1.49
I feel I need to have it	5.29	1.62
It is pleasant to use	5.81	1.40
User satisfaction score:	5.82	0.44

Tab. 5.4: User satisfactions scores and their standard deviations.

5.5.5 Participants' comments on urban planning projects

In addition to obtaining feedback about various aspects of the immersive public display itself, we also analysed the comments that participants created while interacting with the phone interface. In total, we recorded 378 pieces of comments for six different urban planning projects with three alternative proposed buildings each. In order to get a deeper understanding regarding the quality of these comments, we analysed the comments along four dimensions: *Type*, *Level of Detail*, *Tendency*, and

Features. Table 5.5 provides an overview of the different classes we defined for each dimension.

Dimension	Classes	Description
Type	rationale provided	comment or opinion that is supported by an argument or rationale
	opinion only	opinion without supporting rationale or argument
Level of Detail	non-specific	comment does not refer to specific aspects of the proposed building
	specific	comment refers to a specific aspect of the proposed building
Tendency	negative	comment refers to proposed building only in a negative way (e.g. dislike, rejection)
	neutral	comment does not have clear tendency or includes both negative and positive components
	positive	comment refers to proposed building only in a positive way (e.g. like, acceptance)
Features	colour	comment on the colour of the proposed building
	size	comment includes reference to width or height of the building
	placement	comment refers to where the proposed building is located
	material	comment talks about the material of the proposed building
	other	comments about other features than the one listed above (e.g. window design, furniture)

Tab. 5.5: Dimensions and classes for categorising participants' comments on proposed urban planning projects.

The *Type* dimension captures whether a comment or opinion is supported by an argument or rationale. If a rationale is included, citizens and urban designers can gain a deeper understanding about the reasoning behind a comment. The second dimension *Detail of Detail* encapsulates whether a comment refers to a specific aspect of the proposed design (e.g. the entrance being too small to be easily identified) or not. Specific comments arguably can enable urban designers to revisit the specific design element referred to in the comment – unlike general comments, where it may be unclear what part of the building they refer to. The third dimension *Tendency* encodes how the comment refers to (elements of) the proposed design: positively, negatively or in a neutral way. The final dimension *Features* dimension captures what feature of the urban planning design the comment refers to. The spread, volume and variety of classes in this dimension can be an indicator for how well urban designers can map the comments to specific aspects of the proposed design.

Figure 5.2 summarises the distribution of all 378 comments across the four dimensions of analysis. As shown in the figure, about half of the comments (185) contain a rationale and more than half (211) refer to specific aspects of the proposed design.

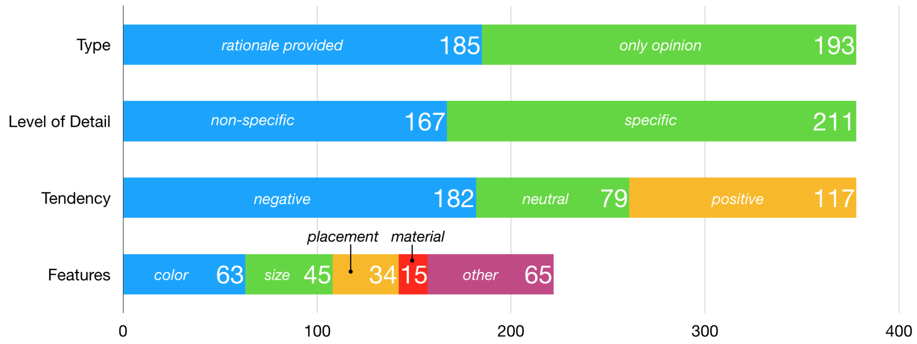

Fig. 5.2: Classification of the 378 comments participants provided on the presented urban planning projects; a single comment could refer to multiple features.

Comments falling into both classes can potentially be useful for urban designers as they help them understand *why* citizens hold a particular opinion and *which element* of the design they refer to. In addition, these comments hint at a high willingness of people to participate beyond simply voting – there was no external motivation to enter longer comments. The distribution along the *Tendency* dimension indicate that participants varied in their perception of the proposed designs and did not hesitate to express their (dis)like.

A large number of comments referred to specific *Features* of the overall design of the proposed building. More specifically, these comments included references to the colour (63), the size (45), the placement (34), the material (15) as well as some other features (65) of the proposed building. These numbers indicate that people made use of the commenting feature to provided feedback on a broad range of aspects of the design.

Overall, we could thus record a variety of comments, including a substantial number that went beyond simply stating opinions and that included specific details that could potentially be useful to urban designers.

5.5.6 Pros and cons of the system according to users

Further comments on the advantages and drawbacks of the systems were collected during the short interview after the study. Participants were asked seven questions touching upon: (i) how important it is for them to see other people's comments before giving their comment; (ii) whether or not they want to see other people's vote results before giving their votes; (iii) features of the system which attracted them to use it; (iv) features of the system which stopped them from using it; (v) additional features they wished should be added to the system; (vi) the likelihood of using the system should it be deployed in the real world; and (vii) some additional general feedback about the application, the designs or the experiment. These questions intended to inform further usability improvement rounds of the mobile-client, and collect some evidence on the needs of users as regards mobile interaction with public displays for public consultation purposes.

An interesting observation here is that more than 95% of the interviewee claimed that they had no interest to see other people's voting results before giving their own votes. And more than 70% of interviewee said that they did not want to see other people's comments before giving their own comments. The main reason behind this is that people do not want to be influenced by other people's opinions. The people who want to see other people's voting and commenting results are mainly because that they think collective thinking is important to help them find their real opinions, and they can get some inspiration to propose some useful comments. Most of people also explained that although they would like not to see the voting/commenting results before giving their own opinions, they are willing to see other people's comments and voting results after they voted and commented.

From the interview data, user perceptions of the features of the prototype were also collected. From our analysis, there were two features of the prototype that attract most appreciation from participants, i.e. the interface design on the smartphone, and the way of representing the urban planning design and its surrounding environments on the large immersive public display. To make it more specific, people like the interface design because: firstly, using a smartphone is a natural and familiar way to interact with the public display, e.g. one participant saying "that was my first time to use public displays with a smartphone. But it was so natural to use the smartphone"; secondly, the interface is simple and easy to use, example feedback are like "The application was very simple and easy to use", "As a citizen, worried about my city, I would go for it. Just because it is simple to understand and it is simple to use"; thirdly, little effort is needed to learn how to use it, as it is presented in the example feedback "It does not take time to use it", "It was very clear that how I can use it." Participants also appreciated the way of representing the urban planning design and its surrounding environments on large immersive public display quite a lot. Almost every participant mentioned their preference on this feature during the interview process. Based on participants' feedback, this feature is attractive for people on these aspects: the immersive video overlayed with the 3D object help them easily understand what is planned and how it looks like, e.g. "Regarding the visualisation, I don't have to put much efforts to imagine what the plan looks like and I can already easily imagine how it looks like in the future"; the setting of three big screens provides a feeling of immersion and a better extended view for understanding the design and its surrounding. As some users said: "With this screen, you feel like you were in the real world", "The three-screens setting is easy to understand the urban designs and environment".

There are also some features that participants thought should be improved or included according to our interview. Regarding the interface design, users suggested that the order of commenting and voting should not be preset, instead, it should be optional; the page should be refreshed automatically so that users do not need to refresh it every time after each round of voting and commenting; instead of only having two choices for voting (i.e. like and dislike), participants wish they had more choice, for example, a 1-5 or 1-7 voting scale. With respect to the immersive video and the overlay, few people pointed out that the urban planning design, i.e. 2D image, overlayed on the immersive video should be better qualified to make it more realistic; more interaction possibilities should be added to checking the urban planning design, such as zoom in/out, changing the color or the size of the urban planning design; more angles of an urban planning design and its surrounding building should be provided. There were some further useful suggestions from few participants: some other interaction techniques should be also provided for the public displays, such as a physical keyboard or directly touching interaction; the interface could provide the function to list all the urban planning design alternatives for people to choose and check; additional information related to urban planning designs could be also provided, such as the timetable when the vote would stop or when the final decision would take place, how much space the (planned) building would take, and the materials of the building; the display should be deployed in a public space, where people have time and feel convenient to use it.

5.6 Discussion

Reflecting on the results of the user study, we can observe that the system was received positively by the participants who used it to comment and vote on several urban planning proposals. They were able to effectively use the combination of an immersive public display with overlaid 3D models and the mobile client to express their opinions and thoughts on the presented projects. In the following, we discuss the implications of the results in more detail as well as the limitations that our work was subject to. We first reflect on the results related to usability (Sub. 5.6.1) and to the design of the user interface (Sub. 5.6.2). We then highlight implications for the design of public displays for citizen consultations (Sub. 5.6.3). Finally, we discuss key limitations of our work (Sub. 5.6.4).

5.6.1 Usability

Evidence from the user study indicates a high degree of usability of the prototypical system. The USE scores were high across all four categories (close to or above 6 out 7). Users perceived the system as useful (5.97), easy to use (5.92), and easy to learn (6.62), and they were also satisfied with it (5.82). All users were able to vote and produce comments on all proposed urban planning projects. The outcome of the interview part confirmed these results. For example, more than 95% of the respondents said they would like to use this system if it was deployed in the real world. Participants also made some suggestions for improving the system. They asked for more fine-grained voting options than just yes/no and for more flexibility regarding the order of voting and commenting.

5.6.2 User interface

The high ratings regarding usability as well as several direct comments during the interviews indicate that the overall interface of the system was received positively as well. Participants commented positively on the combination of panoramic videos shown in an immersive display environment with overlaid 3D models of planned buildings. They perceived it as a good and easy-to-understand way to communicate planning projects. We used a very straightforward way to visualise comments and votes (using the entire leftmost and rightmost screen of the environment), which occluded the corresponding parts of the panoramic videos. This is only one possible option: the question of how/when to visualise comments and/or votes (and how to interact with them) is an interesting venue for future research as it can have a big impact on whether people decide to engage with a system deployed in the real world. Another open question relates to the quality of the overlays. We used fairly simple 3D models in our study, but it would be interesting to investigate further how realistic the models would need to be to still elicit useful comments from participating citizens. For example, would the system still attract useful comments when using early sketches rather than realistic 3D models, and how would different visualisations of planned projects affect participation and user behaviour.

5.6.3 Immersive public displays and public participation

The positive results from our study highlight the potential of interactive immersive public displays for (deeper) public participation. The users' comments regarding usability, ease of learning and intention to use all point towards this combination potentially attracting citizens to participate in urban planning projects while lowering the barriers to do so. Another promising factor in this regard was the depth and quality of the feedback participants provided on the urban planning projects: they gave detailed comments on various features of the proposed buildings and provided rationales for their opinions without being prompted to do so. This detailed feedback can potentially be very useful for urban planners to understand what issues citizens have with a project and why they have them. In addition, these results provide some indication that citizens might want to participate on a deeper level. Whether or not this positive potential can be realised in practice needs to be investigated in a deployment study but is also subject to factors such as where the display is placed and/or whether there a bystanders observing users interacting with the system. Furthermore, the proposed system requires users to carry a smartphone to participate, which would still preclude a number of peoples from participating. Enabling touch-interaction with the large display or providing a small kiosk system in front of the large display are two ways to address this issue.

5.6.4 Limitations

Our study and the proposed system are subject to a number of limitations. All study participants were less than 40 years old; many were students and experienced smartphone users. Repeating the study with more diverse participants (e.g. older people, or people with little technology experience) would lead to a more complete picture of users' perceptions and needs. Furthermore, the study was carried out in the lab with artificial (and fairly simple) content. A deployment study with actual content from an ongoing urban planning project would be highly desirable for several reasons. It would most likely require modifications to the prototype (e.g. regarding dealing with large numbers of content and votes, or managing concurrent usage by multiple users) and would provide insights with respect to appropriation and long-term use. In addition, we provided participants with a smartphone with the voting/commenting app already running and connected to the system. In a real-world deployment, users would have to obtain and connect this app by themselves, which would introduce another barrier. A potential way to solve this would be to prominently display a short URL or QR code on the large screen that could direct citizens to a web app connected to the system. This approach would, however, require an internet connection. An alternative would be for the public display to include a wifi hotspot that people can connect to in order to start the web app. In our study, the order of showing the three alternatives in each urban planning scenario was fixed, this might have affected the results. But we think the effect was probably very small since the main aim of our study is to collect feedback on each design alternative but not to select one winner among them.

5.7 Conclusion

In this article, we introduced an approach for deeper participation in urban planning, based on an interactive immersive display. It combines panoramic videos of the locations, where projects are planned, with 3D overlays of the planned buildings. We implemented a prototype, where users can vote and leave comments on urban planning projects using a simple mobile web site that is connected to the larger display. The lab-based user study we conducted with 21 participants provides initial evidence that people perceive the system as useful, usable, and easy to learn. It also scored highly regarding user satisfaction. In addition, a large share of the comments participants provided on urban planning projects included information that could potentially be useful for urban designers. In addition, they hint at a willingness for deeper engagement and participation. Although they were in no way prompted to do so, participants commented on specific features of the design and provided rationales with their comments. Overall, the results thus indicate that the proposed approach has the potential to facilitate deeper participation in urban planning.

While these outcomes are encouraging, further research is needed to confirm and explore the potential of interactive immersive displays in urban planning. The logical next step would be to deploy the system in the real world for an actual urban planning project. This would allow for deeper insights into system appropriation and participation, including who participates how, when and where as well as how urban designers use the information provided by citizens. The latter aspect also deserves further research regarding how to present comments and votes to urban designers and how to enable them to respond to citizens. Finally, other interaction methods for voting and commenting could lower barriers further (e.g. by eliminating the need for a mobile device).

5.8 Appendix-Scenarios used during the user study

Scenario 1 - Garden house in your community The whole community agrees to build a new garden house, where you can have a rest and enjoy the outdoor leisure time with your friends or family. There are three design alternatives for the garden house. The designers wish to receive your feedback on the design of this garden house. Your feedback will influence the final decision on the design of the garden house. Your feedback can be given in two ways: voting and commenting.

Initial comments added by the researchers - Urban Design 1 (a) I would like it more, if the color of the roof was green. (b) I like the design but I think there should be chairs inside. (c) The design of the garden house is too simple.

Sample comments from (different) participants - Urban Design 1 (a) The style is kitsch and doesn't fit the rest of the garden. Something more country side style would be better rather than neoclassical. (b) I like the structure but the colour is not really fitting. Wood brown would be very nice. (c) Design is ok but overall very pale and unattractive...should [be] more of garden theme to the design.

Initial comments added by the researchers - Urban Design 2 (a) I like the sofa and it is a highlight of the design. (b) The green color is too dark for me. (c) It looks ok for me.

Sample comments from (different) participants - Urban Design 2 (a) We are not in Japan. Again I would prefer something more casual. The sofa won't last a day and the cushions are horrible. (b)[The] style is nice, but the material can get spoiled easily. (c) Though it is in outer environment, it more looks like a room couch with too many pillows. I would prefer simple wooden chairs. Some flowers or small green trees and the green colour I think is not necessary as every thing outside is green. I rather prefer wooden colour on the roof.

Initial comments added by the researchers - Urban Design 3 (a) The design of the house matches the surrounding environment. (b) In my opinion, the house is a bit small. (c) I am not quite sure what to think about this.

Sample comments from (different) participants - Urban Design 3 (a) Chairs don't look comfortable table is too small and there's not enough shade. (b) The roof is too simple but the rest is nice. (c) I like the simplicity again but prefer the first shown environment colored with this wooden color. Chairs here are more like a hotel. So prefer wooden chairs are small.

Scenario 2 - Future gate in your city center The city council intends to build a gate at the entrance of the city center area to signal people the entering into the central area of Muenster. There are three design alternatives for the future gate. The city council wishes every citizen can share their opinions on the design of this future gate. Your feedback will influence the final decision on the design of the gate. Your feedback can be given in two ways: voting and commenting.

Initial comments added by the researchers - Urban Design 1 (a) Choosing marble as material could be better. It will look more chic. (b) The material is brick, I like that. (c) Cool gate shape, but I wish the height of the gate was smaller.

Sample comments from (different) participants - Urban Design 1 (a) It looks like a stone pillar. The entrance isn't that significant. (b) Personally I don't think there is a need to build a gate but in case they are this design is fine old themed. (c) I really like the concept of gate at the entrances, but I would prefer some artistic designs that represent Münster at a glance.

Initial comments added by the researchers - Urban Design 2 (a) I like the design of the lights on the two pillars. (b) The color is a bit too bright but still ok. (c) The pillar is too thick.

Sample comments from (different) participants - Urban Design 2 (a) Even in the night people can be aware of the pillars. If the pillars are increased in height, it will be nice. (b) The light on the top is a good idea so as to light the entrance to the city center at night. It also makes it look attractive. (c) The light effect is ok but the colour is not suited.

Initial comments added by the researcher - Urban Design 3 (a) I have really no idea what to say about this design. (b) I like the golden ball on the pillar. (c) You should use bricks as material instead. This will be cheaper and still look good.

Sample comments from (different) participants - Urban Design 3 (a) It's too short for an entrance. I don't like the colour of the balls. And also it can be a little higher in terms of height. (b) This "rock" style doesn't fit with the brick walls of the surroundings buildings. (c) It can have better artistic meaning and shape. Too simple.

Scenario 3 - Working/teaching building in your working/studying places Your institute/company decides to build a new building next to the building where you are working/studying now. There are three design alternatives for the new building. You will move to the new building to study/work in the future. So your participation to the design of the building is very important and necessary. Your feedback will influence the final decision on the design of the building. The feedback can be given in two ways: voting and commenting.

Initial comments added by the researchers - Urban Design 1 (a) The design of the building matches the surrounding environment very well. (b) The building should have more floors. (c) I am ok with the color but the height could be changed.

Sample comments from (different) participants - Urban Design 1 (a) More floors would be good to really use the available space. (b) There should be open space near and surrounding the current Geo1 building. (c) It's a good complement to the main building. It keeps the same colour scheme.

Initial comments added by the researchers - Urban Design 2 (a) This building is too dark. Could the architect change the color somehow? (b) The design of the building is ok for me. (c) Humm... I have mixed feelings about this. I like the color, but am not really sure the place for the building is ideal.

Sample comments from (different) participants - Urban Design 2 (a) Feels grotesque, too brutal and not friendly for being education related. (b) The form of the building seems quite odd. I don't like the curved shape in the bottom and the lack of colour.

(c) I don't like the design of the building and it does not match with the building behind.

Initial comments added by the researchers - Urban Design 3 (a) The height of the building looks reasonable. (b) The color of the building should be gray and green. (c) So-so.... Great location, but the space is not really used efficiently.

Sample comments from (different) participants - Urban Design 3 (a) Looks good for a fire station or a hospital in 1960 maybe. It ruins the view out of context. (b) Colour and facade material do not fit to the rest and it's way too simple designed compared to the older building. (c) Nice. Simple and elegant. Just the colour should be changed to match the surroundings.

Scenario 4 - Book store in your university Students wish to have a book store in the campus, where they can buy newspapers, magazines, CDs, and other literature books. There are three design alternatives for the book store. As a student, your participation of the design of the book store is very important and necessary. Your feedback will influence the final decision on the design of the book store. Your feedback can be given in two ways: voting and commenting.

Initial comments added by the researchers - Urban Design 1 (a) I have seen better designs in my life. (b) This looks ok. (c) The windows are very nice.

Sample comments from (different) participants - Urban Design 1 (a) I like the size of the building but it should be coloured according to the FH's colour/design. (b) The material of the wall does not fit the buildings around it. (c) The position of this store looks weird to me.

Initial comments added by the researchers - Urban Design 2 (a) Very nice color. (b) I am not sure whether the design of this building fits the surroundings. (c) Make the building larger! Please...

Sample comments from (different) participants - Urban Design 2 (a) Like the front visible glass design. As everything inside is visible outside. But the area is small hope the store is not very small. (b) The colour is good but odd to the other buildings. Structure is satisfactory. (c) It's a modern building in a bright colour. I like it.

Initial comments added by the researchers - Urban Design 3 (a) I like the design of the building very much. I can't wait to sit inside. (a) The building should be wider. (a) I personally prefer white as color, but the design is also not bad as is.

Sample comments from (different) participants - Urban Design 3 (a) I like the material but the shape and the general design look terrible. (b) Haven't see such a fancy design for a book store. It's really nice. (c) It is a nice design, but it does not fit with the surroundings.

Scenario 5 - Bike rack in your community There are a lot of bikes in your community but no bike racks for those bikes. So the city intends to build a bike shelter for the whole community. There are three design alternatives for the bike shelter with bike racks. The designers wish to receive your feedback on the design of this bike shelter. Your feedback will influence the final decision on the design of the shelter. The feedback can be given in two ways: voting and commenting.

Initial comments added by the researchers - Urban Design 1 (a) The bike shelter looks big enough for the community. Very nice project! (b) I like the design of the bike rack but the shelter should be made a bit smaller. (c) The color of the whole design is too dark.

Sample comments from (different) participants - Urban Design 1 (a) Nice idea. Functional and minimal. The racks are perfect for locking the bike safely. (b) Really useful, although i would use a lighter color. (c) It has a good design and it actually good as it has a roof to avoid bicycle to be affected by rains or hot sun.

Initial comments added by the researchers - Urban Design 2 (a) The bike shelter is a little smaller than I wished. (b) The color of the bike shelter is a reasonable choice. (c) I think the design is not bad, but it would be good if the planners think also about some space for other shops/businesses nearby, for example a bike repairing shop. I can't see this space in the project now, and this a problem.

Sample comments from (different) participants - Urban Design 2 (a) I think it is too light colour for the background, but still it is nice. (b) Convex roof makes more sense to me. (c) I don't like the style of the roof, should direct to the ground, not to the sky

Initial comments added by the researchers - Urban Design 3 (a) I'm proud to be Munsteranian when I see this. I'm already looking forward to the final rack! (b) There are some much more important things the Mayor should think about. Spending all that money on a new bike rack... pfff. (c) The design is not bad, but it's not outstanding also.

Sample comments from (different) participants - Urban Design 3 (a) Small and I don't like the fact the placement and that sort of wall towards the street. (b) The shading wall doesn't look too practical, besides it could be used for more bike parking. (c) Looks good and sophisticated but again I feel there isn't optimal use of space.

Scenario 6 - A music center in your city Our city lacks an art center, where you can enjoy concerts, operas and other music performance. So the whole city decides to build a new music center. There are three design alternatives for the music center. As a citizen, your participation of the design of music center is very important and necessary. Your feedback will influence the final decision on the design of the music center. Your feedback can be given in two ways: voting and commenting.

Initial comments added by the researchers - Urban Design 1 (a) Door, height, style, all features of the building are just great. (b) I don't like the green color of the building. (c) No comment.

Sample comments from (different) participants - Urban Design 1 (a) It's too brown without any design or name boards. Entrance also looks small and not very pleasing. (b) The circle style is nice and it will nice to sit and watch opera's. But I don't know how good the acostics will be. But like the design. (c) Looks futuristic and interesting but I am missing some windows.

Initial comments added by the researchers - Urban Design 2 (a) I don't like the colour of It. And the window looks tiny for the building. (b) Concept is nice but structure should be modified with the ticket counter on the sides. (c) It's too brown without any design or name boards. Entrance also looks small and not very pleasing

Sample comments from (different) participants - Urban Design 2 (a) It's just an architectural masterpiece! Fantastic! (b) The building should be made smaller, this is too much space of land for a music center in my opinion. (c) Undecided. Can't say if I like/dislike this.

Initial comments added by the researchers - Urban Design 3 (a) The design seems ok. (b) What a disaster. I don't want to see this in Münster. The whole project team should be sacked tomorrow. (c) The building looks like a piano. This is gorgeous! I like it very much!

Sample comments from (different) participants - Urban Design 3 (a) I like the large windows. The part on top of it not as much. I'd remove the white part. (b) Like/74520/Good design for an art building. Reminds to other museums like in Berlin. (c) Looks really modern. Nice use of glass.

6 Reflections

This chapter firstly recaps the most important results with regard to the three research questions of the thesis (Section 6.1). Secondly, it discusses more general issues that have not been mentioned in the previous chapters (Section 6.2). These issues concern some fundamental consideration regarding the use of public displays for higher public participation in urban planning processes. Finally, it ends with a conclusion (Section 6.3).

6.1 Summarized Results

This thesis studied the use of public displays for citizen consultation in the urban planning domain. Each research question and its main results are summarized, as well as the details described in the remainder of this Section.

What are the main challenges and opportunities of using public displays to support citizen participation in urban settings?

Chapter 2 aimed to get an understanding of the current achievements and gaps of research on public displays for public participation in the urban context. A review of recent research progress of using public displays for public participation in urban settings was given by analyzing the previous work along eight dimensions. They are: type of political context, type of scientific contribution, standalone displays vs displays with a device, single vs multi-purpose displays, the shape of the displays, lab vs field study, deployment in public vs semi-public space, and the level of public participation addressed. A number of trends and insights were revealed by the review analysis. Also, two key challenges/opportunities were identified for future research in using public displays for public participation in the urban context.

To summarize, the challenges or the opportunities are:

1. As mentioned above, current research has, by and large, addressed the inform level of the IPA2's public participation spectrum. Moving up on the spec-

trum of public participation is challenging, but is generally desirable and also constitutes a research opportunity.

2. Evaluating public displays for public participation is a challenge. This applies both to the evaluation methods to use as well as to evaluating various aspects of relevance in urban settings.

We tackled the first challenge above by proposing the other two research questions in Chapter 3, Chapter 4, and Chapter 5.

How to design interactions with public displays for citizens' consulting activities in urban planning processes?

An elicitation study to determine the interaction methods for people's consulting activities to answer this question was presented in Chapter 3, and Chapter 4. According to IPA2, two key goals for citizen consultation are to keep the public informed and to obtain public feedback. Two interaction modalities were investigated in the study: hand and smartphone. To choose the suitable interactions for realizing these goals, we determined the tasks to include in our study by first classifying tasks into two categories: examining urban planning designs, i.e. 3D models, and giving feedback. In doing so, we also followed the typology of general interactivity (Crampton, 2002) for geographic visualization. According to this typology, there are four interactivity types: (1) the data; (2) the data representation; (3) the temporal dimension; and (4) contextualizing interaction. In this thesis, the interactivity type is the data representation, which means "the user obtains different views (perspectives) of the data by manipulating their 'look'". Crampton (2002) pointed out that *viewpoint*, rescaling were two of representative interaction types for the data representation. Based on this, seven tasks were selected, i.e. *show left*, *show right*, *show back*, *re-size bigger*, *re-size bigger*, *re-position*, and *select*, which were representative of typical activities of examining urban planning designs. The other four consulting activities, i.e. *vote for yes*, *vote for no*, *leave a comment*, and *delete a comment* were also selected as representative of typical activities of giving feedback. The main results are presented into two parts, which are introduced in the following part under each of two sub-research questions of the research question presented above. The first sub research question is concerned with designing interactions for scrutinizing urban planning designs, which is consistent with the goal of keeping the public informed. The second sub research question is focused on designing interactions for supporting citizens voting and commenting, which aims for contributing to the goal of obtaining public feedback. Thus, the second research question is answered and informed by these two sub-research questions.

How do citizens envision interacting with public displays to scrutinize urban planning designs?

Chapter 3 is focused on answering this question. A total of 196 hand gestures and 196 phone gestures from 28 participants were collected for the seven consulting activities of examining urban planning designs as mentioned above, and this group of activities are corresponding to the first goal of citizen consultation: informing the public what happened. All elicited hand gestures were analyzed along five dimensions: form, nature, body parts, temporal, and complexity. In addition, all elicited phone gestures were also analyzed by a taxonomy including eight dimensions: types of gestures, form, temporal, spatial, touch-fingers, complexity, and nature. As shown in Fig 3.2, (Chapter 3), these gestures tended to be simple dynamic gestures, which were mostly involving the right hand, and which required continuous recognition and real-time reactions. From the overall taxonomy distribution for all the phone gestures in Fig 3.3 (Chapter 3), more surface gestures were found than motion gestures, and more than 90% of gestures were performed by one or two fingers. Similar to the hand gestures, most phone gestures were simple gestures and required continuous recognition and real-time feedback.

Two sets of user-defined gesture candidates for the seven tasks were shown in Table 3.3 (Chapter 3), Table 3.4 and Table 3.5 (Chapter 3), as well as the information how often the participants performed each task with the gesture candidate, and all the gesture candidates' taxonomies. Participants mostly agreed on gestures for *resizing* 3D urban planning designs, while gestures involving the manipulation of buildings (e.g. *select, show back, show right, show left*) led to much lower agreement scores. Overall, the degree of consensus for phones gestures was higher than for hand gestures. Besides, the easiness and appropriateness of the elicited phone and hand gestures were also evaluated. By applying a one-way repeated measures ANOVA, only a significant difference of the means of rated appropriateness was found between the actions for all the phone gestures.

Two sets of user-defined gesture candidates show how citizens in our study envision interacting with public displays to scrutinize urban planning designs with two different interaction modalities. People rated phone gestures as more appropriate than hand gestures, although they commented in general that phone gestures were less intuitive to recall than hand gestures.

How do citizens envision interacting with public displays to give their voting and commenting?

This question is addressed in Chapter 4. This part of work is concerned with the other category of tasks for consulting activities: giving feedback, i.e. *vote for yes*, *vote for no*, *leave a comment*, and *delete a comment*. In total, there were 112 hand gestures and 112 phone gestures from 28 participants were collected for the four tasks mentioned above. A taxonomy including three dimensions: form, body-parts, and complexity, was applied to analyze the elicited hand gestures. The phone gestures were analyzed along four dimensions: form, body-parts, and complexity, spatial. Fig 4.3 (Chapter 4)shows the overall distribution of the elicited hand gestures. The distribution showed that there were more static than dynamic left-hand gestures, while there were less static than dynamic right-hand gestures. However, the number of right-hand gestures is larger than the two-hand gestures or left-hand gestures. Most of the hand gestures were simple gestures. Fig 4.4 (Chapter 4) illustrates the distribution of all elicited phone gestures, i.e. surface gestures. Similar to the distribution of hand gestures, there were more simple than compound gestures though the difference was not so big. More than 90 percent of gestures were performed by one finger; however, the number of SSU gestures, i.e. the device was used as a current smartphone and held on one of the hands, was almost equal to the number of ST gestures, i.e. perform the gesture while looking through the transparent screen of the device.

Similar to the first sub-question, two sets of user-defined gesture candidates for the four tasks were also summarized in Table 4.4 (Chapter 4) and Table 4.5 (Chapter 4). All agreement scores for phone gestures were higher than the agreement scores for hand gestures, indicating higher consensus for tasks carried out by phone-gestures. With respect to the qualitative feedback about the easiness and appropriateness of all elicited gestures, there were also some main findings: the two-way repeated measures ANOVA showed that ratings of easiness did differ as a function of both tasks and interaction modalities. By applying one-way repeated measures ANOVA, we found that the ratings of easiness differed significantly between the tasks hand interactions, but not for phone interactions. In particular, the task *leave a comment* received significantly lower ratings than the task *vote for yes* and *vote for no* for the hand interaction modality.

Two sets of user-defined gesture candidates show how citizens in our study envision interacting with public displays to vote and comment with two different interaction modalities. The overall results suggested that all things considered (i.e. the rated easiness, the rated appropriateness, and the agreement scores for the tasks), the phone interaction modality may be more suitable than the hand interaction modality for voting and commenting on large interactive displays.

In summary, each sub research question answered one part of the second research question. Both hands and smartphone interaction modalities are shown to be potential interaction methods for citizen consultation in urban planning processes. It is not so easy to say which one is a better choice, since each of them has its own advantages and disadvantages, as we observed in the study.

How to enable citizen consultation using interactive public displays in urban planning?

Chapter 5 provides the answer to this research question. In this chapter, we explored the use of interactive immersive public displays as facilitators for citizen consultation. A novel approach that combined panoramic videos of locations with overlays depicting planned buildings. This approach was evaluated in a lab-based user study (N=21), where participants used a simple mobile client for interacting with this prototypical implementation to vote and comment on different urban planning design alternatives.

A high degree of usability of the prototypical system was indicated by the user study. The results of USE questionnaires showed that users perceived the system as useful (5.97), easy to use (5.92), and easy to learn (6.62), and they were also satisfied with it (5.82). The interface of the system was received positively based on the analysis of the interview data from all participants. People liked the interface because: using a smartphone was a natural and familiar way to interact with public displays; it was simple and easy to use; and it was effortless to learn how to use it. The potential of interactive immersive public displays for citizen consultation was also highlighted by the positive results of the questionnaires and interviews. This feature was attractive on two aspects: the immersive video overlayed with the 3D object help them easily understand what is planned and how it looks like; the setting of three big screens provides a feeling of immersion and a better-extended view for understanding the design and its surrounding.

Overall, the novel approach has the potential to facilitate citizen consultation in urban planning. It provides the initial evidence that the approach of using interactive public displays succeeded in enabling citizen consultation.

6.2 Discussion

6.2.1 Potentials and challenges of using public displays in urban planning domain

In terms of potentials and challenges of using public displays for citizen participation in urban planning, except the potentials summarized in the literature review in Chapter 2, more possibilities were identified in the thesis, especially in Chapter 5. It can be stated that public displays being used for citizen participation in urban planning domain hold potentials in: (1) Large public displays visualizing spatial urban planning information. The big screens provide enough spaces for showing a whole urban planning design and its surround environments. According to the analysis of the interview in the usability study in Chapter 5, this kind of setting reduced citizen participation efforts with respect to connecting the future urban planning design and current real world environments. (2) Immersive public displays can create spatial immersion (Bjork and Holopainen, 2004) that citizens are spatially integrated into the planning area. Spatial immersion occurs when a user feels the simulated world is perceptually convincing and empathizes a feeling of 'being there' rather than 'being here'. This kind of immersion can provide spatial context to help citizens understand the planning proposals. This potential can be supported also by the interview data. (3) It can enhance context-related communication by sharing qualitative and quantitative feedback among citizens on screens. During the usability in Chapter 5, people's voting and commenting results were visualized on the side parts of the large public display. In this way, other people's votes, comments, and urban planning designs could be easily read on the same screen. By analyzing people's feedback about different urban planning projects, we found almost all of their feedback is closely about the urban planning designs with little unrelated noise. (4) The suitable deployment of public displays in public spaces can move spatial and temporal barriers, which means people do not need to physically participate a public meeting in a fixed location on a certain time to get the urban planning information and give their votes or comments. During the interview in Chapter 5, some users emphasized that the deployment of public displays should be closed to their home, where they can easily and quickly arriving. (5) With the respect to supporting citizen participation, public displays can make the consultation more concrete to urban planning direction. As shown in Chapter 5, most people's feedback clearly showed their like or dislike about the physical properties. This kind of feedback can provide quite useful information for urban planners or authorities to see whether an urban planning design should be changed and where it could be improved according to citizens' opinions.

Besides, public displays can broaden the spectrum of participation with engaging the miss demographic group of citizens. Due to the evolution of public displays, most of the deployed public displays have the potential to support different interaction modalities including touch, external devices, tangible objects, and body (Ardito et al., 2015). So it is necessary to require people to have mobile devices to interact with it, which provides the participation possibility for people, who are not used to using smartphones or computers to follow the urban planning projects. Because of the public nature, people can easily get access to public displays, which enhance the participation change for people who usually do not have free time to physically participate in public meetings.

In terms of challenges of using public displays for citizen participation in urban planning, part of the reviewed challenges were addressed in our work: using public displays for higher levels of citizen participation, i.e. citizen consultation. However, some extra challenges and disadvantages were also observed during our study. These challenges can be summarized as follows: (1) How to help people overcome the social embarrassment when they are using public displays in public space. In the elicitation study in Chapter 3 and Chapter 4, one of frequent negative aspects mentioned by participants is that they feel embarrassed (Rogers and Brignull, 2002) when using public display in public spaces. Brignull and Rogers (2003) pointed out that one means of overcoming social embarrassment is to design ways of encouraging people to cross the thresholds from peripheral awareness to focal awareness without being self-conscious, such as offering free goods like food and beverages. (2) How to design public displays with effective affordance for different levels of citizen participation. Inspired by the main findings in the literature review in Chapter 2, we realize that further research issues are not only related to how to use public displays for higher levels of citizen participation, but also how to make public displays possible for different levels of participation. Multipurpose public displays (Ojala et al., 2012), which has more than one application, can be a solution, the concept of which has already been proposed by previous work. However, Ojala et al. (2012) also have admitted that the transition to multipurpose displays also raises new research questions, such as "What is the best way to present multiple applications to users?", "How many applications should a display have?", "Should displays present one identical application grouping to all users, or should they adapt and customize their menu structure?" (3) How to overcome the technical limitation of public displays. Based on participants' qualitative feedback regarding interactions with public displays presented in Chapter 3, no matter what kind of interaction methods will be taken, the interface should give an immediate and accurate response to users' inputs. For example, users would easily feel frustrated resulting from the inability of the system to detect their interactions properly. The bad experience could make them a lack of confidence to use public displays.

6.2.2 PD-participation and Urban planning

From the definitions points of view, PD-Participation, which refers to the use of public displays in participation processes, is defined as a subset of a broader concept e-Participation. The challenges and disadvantages were discussed in the Section 6.2.1, there are still some critical reflections on PD-participation from the researcher's point of view. The first issue is designing the suitable interactions for diverse citizen groups. In this thesis, only two interaction modalities, i.e. smartphone and hand, were investigated in the urban planning scenarios for citizen participation. More interaction possibilities could be explored in later research, such the gaze-based interaction method. Gaze-based interaction method is recently introduced as a promising technique for intuitive, fast, spontaneous and natural gaze interaction (Sibert and Jacob, 2000; Vertegaal et al., 2003; Vidal et al., 2013).

The second issue is there is a lack of promising and well-implemented examples in the field of PD-participation. Since the research on using public displays for public participation are still on the way, which is still a relatively new research field in participation discourse. This issue can influence the willingness of urban designers and authorities about implementing PD-participation for real urban planning projects. Therefore, more studies and lines of research should be conducted to explore the different possibilities and features of PD-participation. More approaches can be integrated into the research on public displays for public participation, such as Gamification and Virtual reality.

The next critical issue is the data privacy issue. Since the European Union's new General Data Protection Regulation ('GDPR') [1] went into effect, it caused critical changes to be aware of in terms of digital feedback collection. This regulation applies to all local privacy laws in the European Union (EU) and European Economic Area (EEA) region and applies to all business which are storing personal data about EU and EEA citizens. As defined in the GDPR directive, *Personal data* [2]is "any information related to a person such as a name, a photo, an email address, bank details, updates on social networking websites, location details, medical information, or a computer IP address". According to Article 4 in GDPR [3], there is no exemption for the public authorities. It clearly includes public authorities in the definition of data controllers and processors. So it is important for current researchers to pay attention to the issue of how this new regulation will affect the way of collecting digital feedback on public displays.

Since the focus of this thesis is on public participation in the urban planning process, it is important and necessary to discuss the implications of using public displays for public participation in the urban planning process. As mentioned in Chapter 1, our thesis intends to support both formal participation and informal participation for showing urban planning design alternatives to citizens and collecting feedback from them through public displays in the urban planning process. According to the German legal regulations, formal processes are mandatory. "Legal regulations lay down who takes part, how far rights of participation extend, how the process is structured and what is done with the findings. The most extensive rights in a formal process go with party status. From this perspective, the contribution of using public displays for public participation can be argued. From one side, the public displays provide the possibility to involve a board spectrum of citizens (e.g. voting and commenting) in the public decision making process over an urban planning project. This can increase the speed of the decision-making process but on the

[1] https://ec.europa.eu/info/law/law-topic/data-protection/data-protection-eu_en (last accessed: July 20th, 2018).
[2] https://www.eugdpr.org/gdpr-faqs.html (last accessed: July 20th, 2018).
[3] http://www.privacy-regulation.eu/en/article-4-definitions-GDPR.htm (last accessed: July 20th, 2018).

other hand, it is not clear that whether this kind of speeded-up is legitimate and whether it is a logical and reasonable way to speed up the decision-making processes, since urban planning processes are so complex, involving diverse stakeholders and having many benefit conflicts. Compared to the formal participation, the realm of information participation is more open and flexible, which can be viewed as a laboratory for participation E. Müller et al. (2011). New approaches and methods are often implemented in informal participation, which is not always attainable and successful in addressing or activating all of the stakeholders. In summary, it may be more suitable and easier applying the PD-participation for the informal participation, and careful attention should be paid when using it for the formal participation.

According to the observation of our research, clearly and accurately understanding the goal of each level of participation is a very important part for starting the research on using public displays for different levels of public participation. Based on the International Association for Public Participation (IAP2), each level of public participation has its own public participation goal and promise to the public. In this thesis, the main research focus stays on the second level of public participation, i.e. *Consult*. The goal of this level is to obtain public feedback on analysis, alternatives, and/or decisions [4]. In Chapter 3, based on the goal mentioned above, we determined which tasks should be included in our study by first classifying tasks into two categories: examining urban planning materials, i.e. 3D objects, and giving feedback, i.e. commenting and voting. Hence, the goal determined that, in the context of urban planning, the information types including what type of information would be shown on public displays, and what type of information would be collected from public displays, and also the interaction practices including what kind of interactions are needed for achieving certain levels of participation.

6.2.3 Limitations

In terms of the methodology in this thesis, there are a few limitations. Firstly, all participants in our studies were less than 40 years old, and many of them are students and experienced smartphone users. A more complete picture of users' needs and perceptions would be achieved by repeating studies with more diverse participants, e.g. older people, or people with little technology experience. Secondly, both of our user studies were carried out in the lab environment with artificial contents. Thirdly, a deployment study with an ongoing urban planning project would be highly desirable for several reasons. The high ecologic validity of the data can be assumed (Alt, Schneegaß, et al., 2012). The deployment study can also "enable researchers to

[4] `https://sustainingcommunity.wordpress.com/2017/02/14/spectrum-of-public-participation/` (last accessed: July 20th, 2018).

investigate longitudinal effects of use that cannot be investigated with other means" (Alt, Schneegaß, et al., 2012).

Regarding the approach of combining panoramic videos of locations with overlays depicting planned buildings, the modification would be required in the real-world deployment. It should be modified to deal with the possible large numbers of comments and votes, the concurrent usage by multiple users; the suitable connection between the public display and personal smartphones.

The general topics of this thesis are public displays, urban planning, and public participation. However, the main focus is studying public displays for citizen participation specifically in showing urban planning design alternatives to citizens and collecting feedback from them through public displays. Therefore, this thesis may exclude public displays related to other topics such as environmental planning, landscape planning, urban management, sports planning, etc. Hence a limited urban planning context is explored in this research.

In terms of citizen participation, the limitation was that the researcher only studied the *Consult* level, which is the second level of participation according to IAP2. Deeper participation levels have not been touched, due to the time and resources that were available. Moreover, as an exploratory research based on HCI research methods, the focus of this work in on exploring challenges, possibilities, and implications of using public displays in citizen participation. Therefore the conclusions should be tested furthermore in other cases, such as a field study with deploying the public display in the real world.

6.3 Conclusion

This final section summarizes the main contributions of this thesis. The subsection 6.3.1 presents them according to the research questions and sub-research questions that were established in the subsection 1.2.1, chapter 1. Furthermore, the next subsection 6.3.2 discusses potential future work based on the presented research.

6.3.1 Contribution

As the title shows, this thesis is focused on how to design interactive public displays to support public participation. To provide a comprehensive answer, the main research topic and domain were studied through different Human-Computer Interaction (HCI) research methods. Three research questions are proposed to inform the main research focus. Overall speaking, the thesis makes three main contributions that inform researchers, citizens, urban authorities, and urban designers.

Based on a systematic literature review, this thesis identifies two main research challenges, which also indicate research opportunities, for the research in using public displays for public participation in urban contexts: designing public displays which support higher levels of public participation and evaluating them in the context of public participation. The identification of key challenges and opportunities constitutes the first scientific contribution to the first research question. Besides, there are also some trends observed in the literature review: current research on public displays lacks diversity of political contexts; beyond empirical contributions, more types of scientific contributions would be desirable to add diversity to the existing body of knowledge; there was a gap of research regarding the respective effectiveness of single-purpose displays and multipurpose displays in achieving public participation; rectangular shapes of displays were most common, and most research emphasized community awareness, interaction and discussion for the purpose of public participation.

Two sub-research questions are proposed to inform the second main research question. An elicitation study has been conducted to find the answers for these two sub-research questions. In this elicitation study, two interaction modalities are explored, i.e. smartphone and hands, to design end user-centered interactions with public displays for citizens' consulting activities. By applying the elicitation study approach, the thesis has revealed that how users envision interacting with public displays using mobile phones and gestures to scrutinize urban planning materials. The main results of this elicitation study constitute the second research contribution, which includes two sets of user-defined gestures for two sets of user-defined phone gestures and hand gestures for performing eleven consulting activities, which are about examining the urban planning designs and giving feedback related to design alternatives, are also identified.

Finally, this thesis presented a novel public display participation prototype for voting and commenting on urban planning design alternatives. The prototype has addressed an issue that how to effectively engage citizens into the higher participation level, i.e. citizen consultation. A usability study has been conducted to validate this public display prototype. The core contribution of this study are: (1) design a public display participation prototype for voting and commenting; (2) the evaluation of the usability of the prototype and the user experience. The answer to the third research question is identified by this contribution.

Designers and researchers can use the contributions of this thesis, to create interactive public displays combined with user-defined interactions that facilitate public consultation in an urban planning process, to do further research on using public displays for supporting higher public participation, i.e. citizen collaboration and empowerment, to get inspiration from our research and extend public displays research in other possible public decision-making scenarios.

6.3.2 Future work

Based on the scientific contributions provided in this thesis, new research potentials are emerging. Future work on these potentials may push the research progress on using public displays for public participation further. For instance, subsequent work could address the research opportunities as identified in the subsection 6.1 in this chapter. It would be also highly desirable to update the literature survey with recent publications, in order to keep track of the most advanced research in this field. Also, a further interesting line of research relates to the three research challenges observed in the subsection 6.1 under the first research question.

Based on the encouraging results on the usability of the interactive immersive public display prototype, new potential research areas for future research are emerging. First of all, a logical next step is to evaluate it in the real world instead of in the lab. The scenarios should be the real ongoing urban planning projects, which need citizens' feedback for the final decisions. It would most likely require modifications to the prototype, e.g. regarding dealing with a large number of comments and votes from multiple users, who would concurrently use the prototype in the real world. Next, with respect to the phone-based interface, more interactions for manipulating the urban planning contents on the immersive public display can be implemented. It would be highly desirable that if users can have more interactions, such as changing the color of the designs, re-scaling the height of the building, or re-positioning the location of the designs. By having more functions, users can have a more intuitive understanding of how the urban planning designs should look like, therefore, they can give more accurate feedback. Finally, more work may be needed to explore the most suitable way of visualizing users' feedback including votes and comments. It can be interesting to see that the comments can be located to the specific parts, where they are related. Another possibility can be running a comparative study to see whether should visualize the votes and comments separately on two side screens or should visualize them just on one side screen.

With respect to using public displays for different levels of public participation in urban planning, the results of this thesis can lead future research on using public displays for higher levels of participation, i.e. public involvement, and public collaboration. According to the spectrum of public participation developed by the International Association of Public Participation (IAP2), it could be investigated how to design public displays to ensure that public concerns and aspirations are consistently understood and considered; and how to design public displays to partner with the public in each aspect of the decision including the development of alternatives and the identification of the preferred solution.

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