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Article

Methodological Reflections on Capturing Augmented Space: Insights From an Augmented Reality Field Study

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Abstract
The growing popularity of augmented reality has led to an increased overlaying of physical, offline space with digital, augmented space. This is particularly evident in the public space of big cities, which already feature a multitude of holographic content that can be experienced via augmented reality devices. But how can we methodically capture the interrelation between physical and augmented space? In this augmented reality field study, a historical building was holographically reconstructed in its original size on a public city square. The test people were then able to move around and view the hologram from different angles via high-tech augmented reality glasses. Due to its explorative character and constantly changing field conditions, including, among other things, the Covid-19 pandemic, we had to critically reflect and adapt our methods to take into account technical, environmental, social, operationalisation, and recruitment issues. After evaluating our solutions to these issues, this article aims to illustrate the methodological challenges and opportunities of augmented reality field studies and to provide an overview of best practices for capturing the interrelationship of physical and augmented space.

Keywords
augmented reality; augmented space; locative tracking; methodology; polarity profiles; spatial meaning; spatial movement; spatial perception; thinking aloud

Issue
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1. Introduction

Augmented reality (AR), defined as the holographic overlay of physical space with virtual objects in real-time (Azuma, 1997), is bound to the conditions of physical space like no other medium. As such, it also has the potential to fundamentally change our personal relationship with physical space by adding new layers of meaning to it (Liao & Humphreys, 2015). This is particularly evident in urban space, which, as a burning lens of media developments, is already affected by a multitude of holographic content like AR navigation apps, Pokémon Go, or augmentations of tourist attractions (Aurigi & Cindio, 2008). Even today, users can experience historical structures like the Berlin Wall (Zaubar, 2021) or buildings at their original location as holograms on their smartphone (e.g., the Urban Augmented Reality application launched by the Netherlands Architecture Institute; Verhoeff, 2012, p. 160). Of all the fields of application within the realm of the smart city, urban planning and tourism are set to be influenced the most by AR in the near future (Allen & Robinson, 2018), as has been shown in a number of interdisciplinary studies. For instance, Reinwald et al. (2014) demonstrate that the holographic representation of an urban construction contributes to a better architectural understanding for stakeholders compared to traditional visualization methods (e.g., building plans). Oleksy and Wnuk (2016) conclude that the holographic reconstruction of the Warsaw Ghetto conveys its cultural meaning to tourists more powerfully than a two-dimensional representation on a personal computer. While these results indicate a short-term effect of AR on the knowledge of specific stakeholders like urban planners and tourists, they also give rise to a set of general questions regarding its long-term influence on the city dwellers' relation to space: How does AR, in general, and holographically reconstructed buildings, in particular, change our perception of space and the personal meaning it develops in our daily lives? And how can we methodically capture the appropriation of both physical (offline) space and augmented (online) space, experienced through head-worn AR?

To answer these questions, we began by researching historical buildings with potential significance for city dwellers that were to be reconstructed in AR and chose the stock exchange of Augsburg, Germany. This building, which had been destroyed during air raids in the Second World War but was never rebuilt, was holographically reconstructed in its original size at its original location on the city's central square. Test people were then able to view the building as a hologram by wearing high-tech AR glasses (Microsoft HoloLens 2) that project virtual objects onto a display in front of their eyes. Since this display is transparent, there is a "perceptual illusion of non-mediation" that makes the hologram appear to be real which is also known as "presence" (Lombard & Ditton, 1997). In order to resurrect this building in AR, old photographs, paintings, and postcards were assessed. Using mobile AR glasses, test people were able to move freely around the square, observe the hologram from different angles, and walk into it. Using this approach, we sought to illuminate how AR might influence the relationships of city dwellers to the urban space based on three dimensions: the spatial perception of the square (dimension 1), its spatial meaning in the lives of city dwellers (dimension 2), and their spatial movement patterns on the square (dimension 3). The project was initiated and realized by an interdisciplinary research group comprising architectural historians and computer and communication scientists analysing the digitalisation of the city (www.digista.de). Since our scientific research was the primary focus, urban stakeholders like city planners or local politicians were not involved in the project.

In order to capture the appropriation of augmented space within these three dimensions, we relied on a mixed-method approach using both qualitative and quantitative tools. Due to its explorative character and constantly changing field conditions, including the Covid-19 pandemic among other things, we had to critically reflect and adapt our study to take account of several unpredictable obstacles. These included the technical and environmental issues of working with highly sensitive AR equipment on a public square in winter, the development and combination of theoretical frameworks and empirical tools, extensive interviewer training, and the administrative issues involved in implementing a field study during a pandemic. After evaluating our theoretical, empirical, and practical solutions for these emerging obstacles, the following article sets out to present insights into the methodology of an AR field study and to provide an overview of best practices regarding data collection and data analysis when capturing the interrelationship of physical and augmented space.

First, we will provide an overview of the theoretical background, taking into consideration various dimensions of augmented space and empirical tools used to capture it (Section 2). Next, we dive into the methodological issues when capturing augmented space (Section 3.1), divided into technical and environmental issues (Section 3.2); interviewer issues (Section 3.3); operationalization issues with standardized questionnaires, thinking-aloud protocols, and locative tracking (Section 3.4); and, lastly, recruitment and issues that arose due to the Covid-19 pandemic (Section 3.5). These empirical opportunities and pitfalls of AR field studies are evaluated and discussed in the final section (Section 4) of this article.

2. Theoretical Background

As a site-specific medium, AR might be described as "a form of creative contribution, which not only adds to space but inherently also modifies it" (Verhoeff, 2012, p. 162). While this modification is often related to spatial concepts like "hybrid space" (de Souza e Silva, 2006), "third space" (Thielmann, 2007), or "augmented space" (Allen & Robinson, 2018), it is less the space itself and more our relation to space that is modified through AR. Consequently, scholars should focus less on constructing theoretical (and often hypothetical) concepts about the emergence of augmented space and more on investigating our personal relationship to it. This relation to space is often a very subtle one, which forms gradually over years through daily habits, personal memories, and unconscious perceptions often unknown to the subject. Thus, for a systematic survey of AR, it is important to consider the various dimensions that constitute an individual's relationship to space. To achieve this goal, some AR scholars refer to abstract theoretical models indicating a complex nexus of spatial dimensions to describe an augmented engagement with space—e.g., Liao et al. (2020), building upon Lefebvre's triad of perceived, conceived, and lived space. Others simply focus on one spatial dimension (mostly spatial perception, e.g., Woods, 2020), neglecting other aspects of our multi-dimensional relationship to space. However, if we step back and take a look at the ongoing discussion regarding the "spatial turn" (the increasing attention to spatial circumstances in social sciences), at least three spatial dimensions can be identified: the perception of space (Löw, 2008), the meaning of space (Gustafson, 2001), and its influence on human behaviour (de Certeau, 1985). Since each of these dimensions describes a key aspect of our personal relationship to space, they might be termed as spatial perception, meaning, and movement. While bearing some resemblance to Lefebvre's (1991) triad of perceived, conceived, and lived space, these dimensions offer a more appropriate, hands-on approach to explaining our multifaceted engagement with space. If we transfer these considerations to augmented space, which is defined as the holographic overlay of urban space with virtual objects (Allen & Robinson, 2018, pp. 262–263), there are several ways in which AR applications or content can influence our relationship with the city: It might change how we perceive the cityscape (i.e., augmented spatial perception, following Löw, 2008); the personal meaning of urban places with regard to the self, to others, and to the environment (i.e., augmented spatial meaning, following Gustafson, 2001); and the way we behave or move through the city (i.e., augmented spatial movement, following de Certeau, 1985). These assumptions form the main research question:

> RQ: To what extent does the holographic reconstruction of a historical building through AR influence (a) spatial perception, (b) spatial meaning, and (c) spatial movement in the city?

The interview study took place between February and March 2021 and was carried out by three interviewers (one research assistant and two student assistants) from the Department for Media, Knowledge, and Communication (University of Augsburg). The participants were recruited via third parties and selected based on their place of residence and length of residence in Augsburg (or the district of Augsburg). In addition, we ensured an even gender distribution. A total of 78 Augsburg residents (40 women and 38 men) took part in the study. Before meeting at the Rathausplatz, the participants had to fill out an online questionnaire capturing their spatial perception and spatial meaning prior to the AR experience. On the day of the survey, the interviewer explained the background of the study and the AR glasses to the participant, who was then able to view the hologram and speak everything that came to their mind. After the AR experience, they both walked to a seminar room close to the Rathausplatz where the participant had to fill out a second questionnaire capturing their spatial perception and meaning after the AR experience. The survey was completed with a short interview.

When searching for theoretical frameworks and empirical tools to conceptualize and capture these three dimensions of augmented space, it is striking that most AR studies focus only on one spatial dimension and often derive their categories from highly specific considerations. For instance, Tsai (2020) analyses the place satisfaction (i.e., a narrow form of spatial meaning) of heritage tourists provoked by different AR applications. She concludes that AR can generate a positive impact on the visitor's satisfaction with heritage tourism sites that is mediated by user engagement and perceived authenticity. While studies like these allow for new insights into the influence of AR on a single spatial dimension, our goal was to analyse the appropriation of augmented space with regard to several dimensions. This means that our approach should allow for a more general, multi-dimensional analysis of augmented space that is not limited to specific considerations and intervening factors. Instead of creating empirical tools to generate tailor-made results that are restricted to certain applications and/or places (e.g., place satisfaction in heritage tourism sites), we were looking for theoretical concepts and methods which allow a sufficiently high level of abstraction. This holistic perspective should improve the generalisation and comparability of our results. To capture (augmented) spatial perception, semantic differentials are a practical and valid tool for individuals to assess a perceived surrounding. Originally implemented by Osgood et al. (1957), semantic differentials are a rating scale in which the respondent is asked to describe his or her perception on a scale between two polar adjectives. This method, which is used regularly in architectural studies to measure the experience of built environments—e.g., the 36-item semantic environmental scale by Küller (1991, p. 122) to assess the Sturup Airport—was also utilised in the early 2000s to compare the sensory perception of building interiors and their identical, virtual reconstructions (Westerdahl et al., 2006). Kuliga et al. (2015, p. 368) adopted the empirical concept into a semantic differential to capture the perception of a non-existent, virtual building based on 20 polarities. While these semantic differentials have proven useful for analysing the perception of entirely virtual environments, they have never been implemented to assess the spatial perception of holographically augmented, physical environments.

Finding a method to capture (augmented) spatial meaning posed more difficulties since most empirical tools are customised to measure the significance of preselected places of interest instead of providing a holistic perspective. For instance, Manzo (2005) analyses the multidimensional meaning of home and residence via semi-structured interviews, while Lalli (1992) uses a 20-item urban-identity-scale to capture the personal relevance of the city of Heidelberg. While these studies successfully measure the significance of specific places, there is a lack of theoretical framework and empirical methods suited to holistically capture the spatial meaning of different types of places. One exception is the three-pole model by Gustafson (2001), who conceptualizes spatial meaning in relation to the self, others, and the environment. Based on an extensive interview study, he assigns different attributes to each of these poles (self, others, environment) and its axes (self–others, others–environment, self–environment). This allocation of meaning within a field of poles and axes helps to "avoid simplified categorization" and allows for "analyses that recognize the plurality and complexity of meanings" (Gustafson, 2001, p. 12). For instance, the significance of a place can be measured by personal experiences (self), a certain clientele (others), or institutions (environment) that people associate with that particular place. Furthermore, the model can be applied to places of various different types and scales, e.g., a residence, neighbourhood, village, city, region, nation, or continent. Due to its high degree of abstraction and its holistic perspective, Gustafson's (2001) three-pole model of spatial meaning also lends itself to the analysis of augmented space. However, it has never before been applied in the context of virtual, or, respectively, augmented environments.

Finally, virtual objects or holograms can influence our behaviour in space, specifically our movement patterns. For instance, the more they perceive them to be real, people tend to adapt their movement in augmented or virtual environments to avoid colliding with virtual objects. This "perceptual illusion of non-mediation" (Lombard & Ditton, 1997), referred to in media effects research as "presence" (Wirth et al., 2004), can alter the way we move through space. To capture this spatial behaviour, most studies rely on built-in tracking systems in the devices to locate respondents' motion. The spatial movement can then be visualized and compared in movement paths. For instance, the comparison of walking lines in virtual reality (VR) by Steptoe et al. (2014) shows that virtual objects with a higher rendering quality tend to generate a higher sense of presence and a stronger adaptation of movement patterns compared to virtual objects with a lower rendering quality. While tracking lines have been established to analyse entirely virtual environments, the question that arises is how to adjust this empirical tracking tool to capture spatial movement (c) in augmented environments.

3. Methodological Issues When Capturing Augmented Space

3.1. Study Design and Overview of Issues

To capture augmented spatial perception (a), spatial meaning (b), and spatial movement (c), we conducted a field study on the central square in Augsburg that had been augmented by a holographic reconstruction of the former stock exchange building. The first part of the data collection took place a few days before the AR session. Each participant had to fill out a preliminary online questionnaire that had been sent to them via e-mail to indicate their perception of the non-augmented square and the personal meaning it unfolds in their daily life. After that, the participant met the interviewer at the central square in Augsburg. The interviewer explained the AR glasses to the participant and provided a short overview of the study. After sanitising and putting on the AR glasses, the study participants were able to view the hologram of the Augsburg stock exchange in its original size and at its original location (Figures 1 and 2). First, they listened to a short audio file explaining the historical background of the building and the square. Afterwards, they were able to move freely around the square, view the hologram from different angles, and say aloud everything that came to their minds (thinking aloud, the second part of the data collection). The third part of the data collection took place after the AR session when the participants followed the interviewers to a nearby interview room and filled out a follow-up questionnaire on a tablet. After that, they were shown a point-of-view (POV) video recording of their previous AR session on a laptop and were asked to think aloud again.

During our research process, we encountered several methodological issues that can be traced back to the novelty of the technology, the current lack of AR field studies, and a de-contextualized research focus. Thus far, most empirical studies working with sensitive AR equipment have limited their research to controllable laboratory settings and/or a mono-dimensional perspective on space (e.g., place satisfaction, following Tsai, 2020). Multi-dimensional field studies combining their interest in different relationships to space are scarce and rely mainly on guided interviews and the influence of small-scale, generic AR content on handheld devices (e.g., the influence of Pokémon Go on spatial perception, following Woods, 2020). For this reason, the multitude of sociological methods—both quantitative or qualitative, traditional, or explorative—has yet to be fully introduced and adapted to AR field studies, especially those concerning head-worn devices. However, in addition to the many opportunities they provide, AR field studies using AR glasses still pose several issues for the scholars that should now be discussed in further detail (see Table 1).

3.2. Technical and Environmental Issues

Implementing an AR field study with a large-scale, building-sized hologram on a public city square poses several technical and environmental issues, which often build on each other and should thus be described in one section. To guarantee a consistent starting position and reliable field conditions, interviewers had to start every session from the exact same location and place the hologram of the historical building precisely in its original location when adjusting the AR glasses (errors in hologram positioning). After sanitizing the AR glasses and handing them over to the study participant, the interviewers had to monitor and adapt to constantly changing field conditions in order to guarantee stable AR exposure and reliable data collection (Figure 1). Technical issues posed the biggest challenge since the hologram tended to disappear (hologram break-off during usage) or move away from the spectator as a result of jerky body or head movement or harsh weather conditions like low temperature, rain, or snow (highly sensitive AR equipment, unpredictable weather conditions). In this case, the interviewer had to leave the participant at the break-off point, walk back to the starting point, readjust the AR glasses, re-sanitize them, walk back to the participant, and restart the session again.

Table 1. Overview of methodological issues when capturing augmented space.

	Issues
Technical/Environmental	• Errors in hologram positioning • Hologram break-off during usage • Highly sensitive AR equipment • Unpredictable weather conditions
Social	• Curious and/or intrusive passers-by • Participant's feelings of insecurity
Interviewer	• Extensive interviewer training • Step-by-step interviewer guideline (script) • Flexibility and strength of nerve
Measurement	• Limitations of established methods in AR studies • Multi- instead of mono-dimensional perspective • Finding concepts of spatial meaning • Combining mixed methods
Recruitment and Covid-19	• Developing a hygiene concept • Agreement with police and health authorities • Difficulties in recruiting older participants

3.3. Social Issues

Another important methodological issue was the social context of the experiment and regular encounters with passers-by. While police officers and city authorities had been previously informed about the study and were rather reserved, we were regularly watched and sometimes even approached by curious pedestrians who asked about the study or if they could try out the AR glasses themselves (curious and/or intrusive passers-by). Due to our interviewer training, the interviewers were able to anticipate and respond to these encounters by providing additional information on the project or by referring or the university's VR and AR lab for try-outs. However, these encounters reportedly led to a feeling of social pressure or exposure for some of our participants: "But I paid more attention to the other people, how they perceived us, whether they were watching us, whether I seemed strange. I felt a bit like an outsider" (No. 75, female, length of residence: four years). This feeling of social attention is not uncommon in AR field studies (Hofmann & Mosemghvdlishvili, 2014, p. 277), especially when working with high-tech equipment like the Microsoft HoloLens 2. However, other participants were not bothered by these intrusions at all:

> There was also a moment when the other person came to us and wanted to join in. Then again, the wall [of the holographic building] was slightly broken, but I didn't find that so disturbing. I didn't feel like an outsider. (No. 70, male, length of residence: five years)

Regardless of the participants' attitudes towards these intrusions, AR scholars should be aware that the technology they are using is an unusual sight for most bystanders and is likely to provoke a reaction, either in a positive or a negative way (participant's feeling of insecurity).

3.4. Interviewer Issues

To be able to adapt to these technical and environmental issues and unstable field conditions, the interviewers had to be briefed accordingly (extensive interviewer training). An interviewer guideline was created at an early stage of the study design and expanded regularly until it comprised detailed, step-by-step instructions. Just like learning a script, interviewers had to be prepared against all eventualities and practice their responses in several pre-tests, in which they played either the participant or the interviewer. The interviewer guideline was complemented by a best practice video tutorial in which all relevant actions and responses were portrayed by the lead investigator. To keep track of all possible technical and environmental issues during the data collection process, the interviewers briefly reported on their experiences after each session in a shared interviewer diary (Google Docs). These potential threats or changes to the existing methodology were regularly discussed and the guideline was adapted accordingly (step-by-step interviewer guideline/script). Despite these preparations, interviewers working with high-tech AR equipment always had to remain flexible and calm in order to adapt to continually changing field conditions (flexibility and strength of nerve).

Figure 1. Test subjects wearing AR glasses on an augmented city square.

3.5. Measurement Issues

3.5.1. Limitations of Established Methods for Capturing Augmented Space

As the global number of AR users grows and is expected to reach 1,73 billion active users in 2024 (Statista, 2021), so does the number of AR studies and scholars attempting to analyse its influence on users (Pognon et al., 2020). While this has led to the development of valid and reliable research tools—especially for assessing the usability of AR applications—there are a number of empirical limitations when it comes to capturing our relationship to augmented space.

First, quantitative studies on augmented space mostly rely on post-stimulus questionnaire data collected directly after the AR experience. For instance, the augmented reality immersion questionnaire by Georgiou and Kyza (2017) helps in measuring an augmented spatial perception during and after AR usage, without comparing it to the non-augmented perception of a particular place (preliminary and follow-up questionnaires and polarity profiles).

Second, qualitative studies on augmented space often make use of explorative methods mainly designed for analysing the long-term influence of AR. For instance, Richardson et al. (2022, p. 673) combine participant observations with in-depth interviews and re-enactments to discover spatial "scenarios of use" for Pokémon Go in the city of Badalona, Spain. While these methods may be useful for investigating established AR applications like Pokémon Go, they are less suited for exploring the influence of high-tech AR glasses on our relationship to space, since users have not yet developed any spatial "scenarios of use" (Richardson et al., 2022, p. 673) that they could re-enact. Instead, qualitative methods that are less structured and more open are required to elicit unfiltered statements on immediate and/or reflected emotions and thoughts (concurrent and retrospective thinking-aloud protocols).

Third, mixed-method studies on augmented spatial movement often use locative data tracked by the AR device to generate walking lines and compare patterns of movement (Steptoe et al., 2014). However, this "circus of numbers, lines and points, contradictory in information and strangely empty in narrative is a peculiar rendition of meaning" (Wilmott, 2016, pp. 1–2) that should always be contextualized with interview statements. On the other hand:

> Interviews provide participants' narratives about what they think they do with their devices, yet do not necessarily bring insights into how these play out experientially….[Thus,] collaborative mapping exercises [are useful] to understand their perceptions of the spatiality of their use outside the home. (Pink et al., 2016, p. 242)

Therefore, a logical combination of tracking- and interview-data is needed in order to investigate augmented spatial movement (locative tracking and verbal evaluation). To avoid these limitations, we used and improved the following research tools that will be described in detail in the following sections.

3.5.2. Preliminary and Follow-Up Questionnaires and Polarity Profiles

When measuring the appropriation of augmented space, it is important to consider its multi-dimensional nature rather than focusing on one-sided or overly specific concepts (multi- instead of mono-dimensional perspective). To determine (in)significances of the influence of AR on spatial perception and spatial meaning, we used preliminary and follow-up questionnaires and mean value comparisons. The influence on spatial perception was captured via polarity profiles including 20 opposite pairs derived from the study by Kuliga et al. (2015, p. 368). The test subjects (n = 78) were shown a questionnaire before and after viewing the hologram to record how they perceived the city square in its augmented and non-augmented form on a six-point Likert scale. Comparing these questionnaires resulted in a polarity profile for each participant's perception of space, showing both an augmented and non-augmented spatial perception. These individual profiles were summarised and tested for statistical significance by comparing the means of connected samples (see Figure 2).

Polarity profiles like this combined with single mean comparisons are a clear and hands-on means of capturing the influence of AR on spatial perception on a visual scale. For instance, a score of two out of six on the "cold–warm" polarity means that the city square in its augmented form is perceived as rather cold compared to its non-augmented form. This example of an augmented spatial perception proves to be significant, whereas the differences in the "bare–decorated" polarity could not be generalized for all study participants. While polarity profiles allow for a diverse and detailed overview of the augmentation of spatial perception, they also tend to swamp the viewer with a multitude of incoherent insights, especially when illustrated in an unstructured manner.

To structure our results and increase comparability, a factor analysis (principal axis analyses with oblique rotation, oblimin, delta = 0) was then calculated to reduce the 20 polarities to a few factors. Two items were excluded from the analysis due to double factor loadings or factor loadings that were too small. This resulted in the five factors of a differential spatial perception comprising a total of 18 polarities (see Figure 2). It shows the differences in spatial perception induced by viewing the hologram on a differential scale from −6 to +6. For instance, our participants perceived the augmented square as less accessible (−2.01 scale points) and less simplistic (−1.08 scale points) compared to the non-augmented square.

Deducing standardised tools to measure an influence on spatial meaning posed more difficulties, as described in further detail in Section 3 (finding concepts of spatial meaning). After identifying the three-pole model by Gustafson (2001) as a suitable concept, it had to be operationalized and adapted for questionnaires. First, the different elements and attributes of spatial meaning were articulated into 56 questionnaire items by university students in a creative pro-seminar and integrated into an online survey. After evaluating this survey (n = 181) by means of a factor analysis, a total of 30 attributes were assigned to capture spatial meaning in relation to its six constituting elements: self, others, environment, self–others, self–environment, and others–environment (Figure 3). This catalogue of items was rated by the test subjects (n = 78) before and after viewing the hologram on a five-point Likert scale. The comparison of before and after questionnaires resulted in a profile of augmented spatial meaning similar to those created to capture spatial perception. However, this time, the graphs did not range between polarities but between the scale points of the Likert scale (1 = *strongly disagree* to

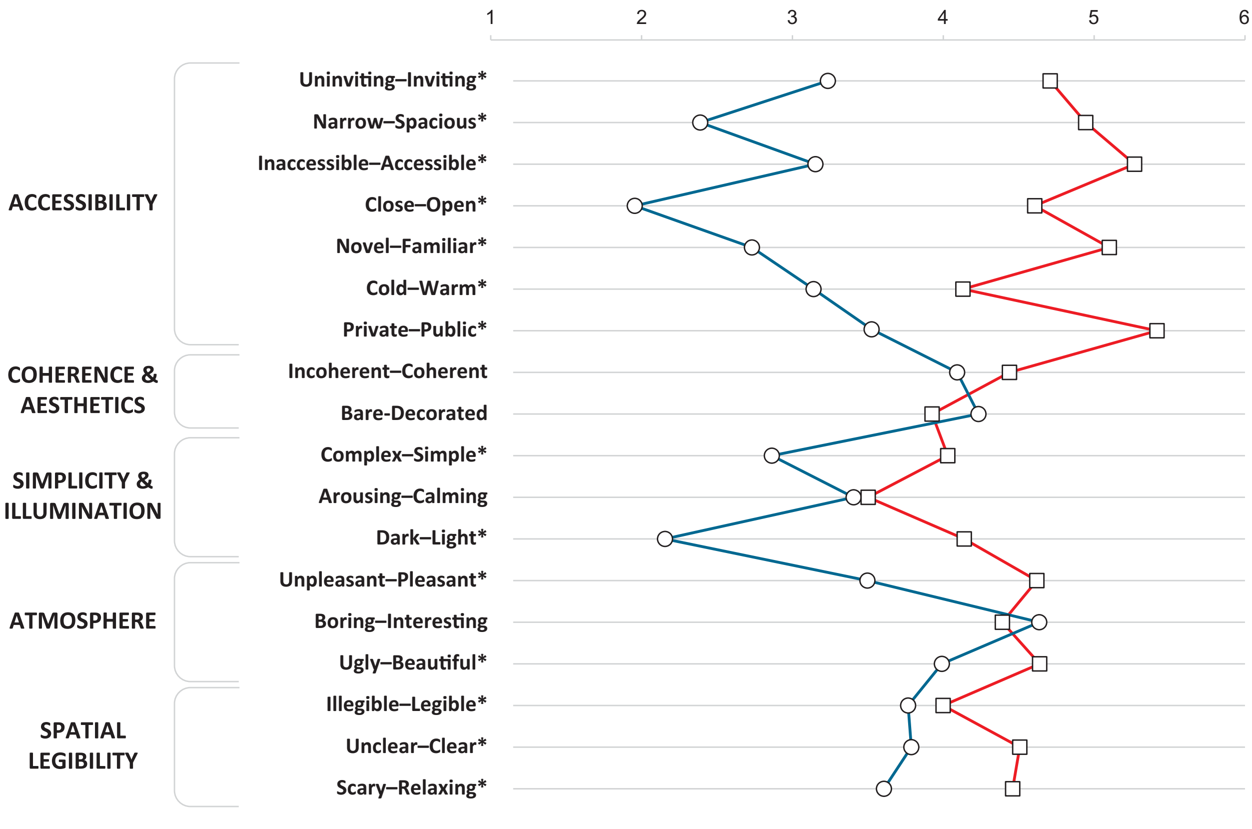

Figure 2. Augmented (blue) and non-augmented (red) spatial perception. Note: * = mean comparison significant.

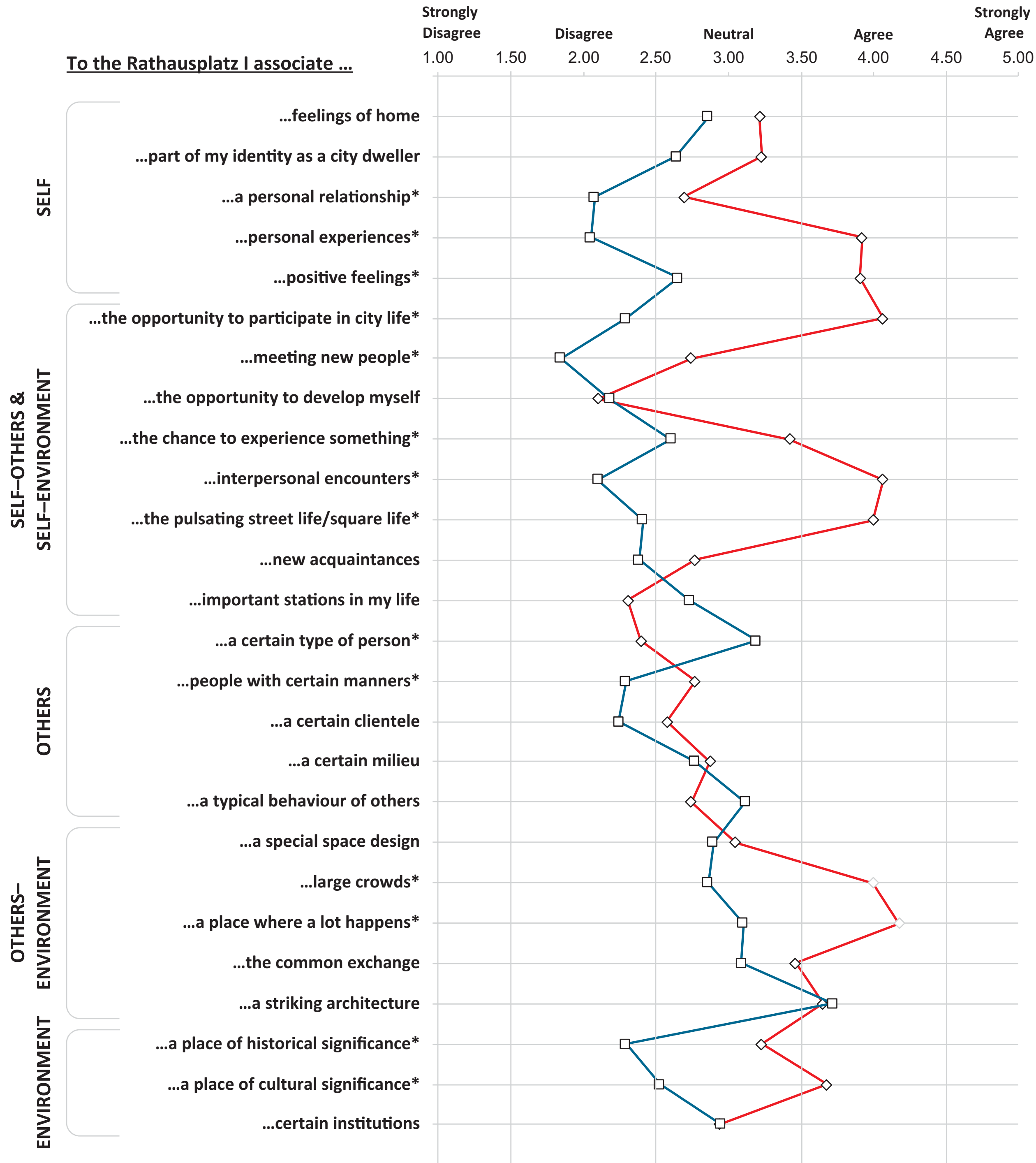

Figure 3. Augmented (blue) and non-augmented (red) spatial meaning. Note: * = mean comparison significant.

5 = *strongly agree*). Using comparisons of means in connected samples, we tested this empirical tool to measure augmented spatial meaning for statistical significance.

Again, a factor analysis was calculated to reduce the complexity of this visual tool and to increase its comparability, whereby four items were excluded from the analysis due to double factor loadings or factor loadings that were too small. This led to the creation of five factors of augmented spatial meaning, consisting of 26 items in total: self (five items), others (five items), environment (three items), others–environment (five items), and self–others and self–environment (eight items; Figure 3). Unlike in Gustafson's (2001) theoretical model, the items measuring spatial meaning with regard to self–others and self–environment could not be sufficiently differentiated by participants, which led to the merging of these two elements into one single factor. It shows that test subjects consider attributes like "meeting new people" or "the chance to experience something" as part of the same construct, which scholars analysing spatial meaning should take into consideration when implementing Gustafson's three-pole model in their studies.

3.5.3. Concurrent and Retrospective Thinking-Aloud Protocols

In addition to standardized questionnaires, the influence of AR on spatial perception and meaning was also explored using qualitative thinking-aloud-protocols (TAP; combing mixed-methods). This method is commonly used in human-computer-interaction research to assess the usability of technological or software applications. However, there is an ongoing methodological discussion on the suitability of four different forms of TAP: concurrent vs. retrospective TAP and undirected vs. directed TAP (van den Haak et al., 2003). In simpler terms, they also might be named instant vs. subsequent TAP and guided vs. unguided TAP. While some scholars point out the reactivity of concurrent TAP, which tends to overstrain the participant, others refer to its potential to elicit spontaneous responses compared to a TAP in retrospective (Alshammari et al., 2015). The same applies to instructions. While most scholars rely on undirected TAP to allow for an unfiltered expression of thoughts, there might be studies where "the verbal probe may be constructed to induce the subjects to generate information specifically relevant to the hypotheses under consideration [i.e., directed TAP]" (Ericsson & Simon, 1980, p. 222). With regard to AR studies, TAPs are mostly implemented in the concurrent, undirected form to instantly evaluate the user interface of holographic applications in specific situations (Santos et al., 2016).

Due to these mixed views on TAP as an empirical method, we decided to evaluate its most prevalent forms to verify their validity before conducting our field study. As part of a pre-test, participants were asked to say aloud everything that came to their minds while experiencing the hologram on the city square, using both open-ended (i.e., undirected) and space-specific questions (i.e., directed). During this concurrent TAP, their statements, gaze direction, and gestures were videotaped via the built-in recording system of the Microsoft HoloLens 2, which records the POV of the user. Immediately after the AR experience, the POV videotape was shown to them on a laptop in a private room close to the city square and they were asked to think aloud again, this time in retrospect.

The pre-test showed that undirected TAP in AR, while undoubtedly eliciting unfiltered reactions on obvious aspects like usability, is less suitable for capturing specific aspects like augmented space. It mainly led to overblown statements regarding the graphic quality in general, the light weight of the AR glasses, or the intuitive handling of the application:

> So, it's definitely very detailed for that. Yes. Okay, wow!...Well, I think it's amazing, I can see the buildings really well, even from the 3D view. I can really see around the corner, which impresses me....And the picture is now much more stable than before, probably because the menu window is gone. No, that's great. (Pre-Test No. 2, male, length of residence: five years)

This focus on graphics and usability might be traced back to the fact that head-worn AR is not yet established, and many subjects were wearing AR glasses for the first time.

In directed TAP, queries can guide the narrative of the subject towards specific aspects of the AR experience. For instance, interviewers could ask the participants to share their thoughts on how the hologram might change the square in their eyes, which often provoked statements on an augmented spatial perception. They also asked them what personal associations they have with the square, which triggered thoughts about an augmented spatial meaning. Despite the advantages of directed TAP in guiding the statements into a direction relevant to our research question, its disruptive character can be seen as a trade-off. Some participants initially had problems focusing on the hologram while simultaneously having to direct their statements to specific aspects of the AR experience. Some initially wanted to speak freely about other aspects of the AR experience, like its graphic quality or usability. However, even those participants quickly adapted to this form of directed TAP and after a short time casually shared their thoughts and feelings about spatial perception or meaning. For instance, one participant described how the holographically reconstructed building fundamentally changed her relationship with the city square:

> I think that it [the real building] would definitely change my relationship to this square or would have changed if it had been there....I went to school here, there in [anonymised], that's not far away, we often sat here ourselves in the summer and I think it would definitely have changed my relationship to the city centre. (No. 72, female, length of residence: 20 years)

With regard to the timing, we found that concurrent TAP is better suited to capturing spontaneous reactions or references to special AR content, while also evoking cognitive overload and a sense of social undesirability regarding pedestrians. Some participants had problems with immediately articulating their thoughts during usage or reported a feeling of being watched. In retrospective TAP, an ego-centred video recording of their AR experience was shown to the subjects on a laptop, while their verbal comments were captured via microphone and screen recording. This led to more reflected statements and in-depth thoughts since subjects could relive their previous AR experience and focus on specific aspects they had previously overlooked. However, these reflected, retrospective thoughts might also be a disadvantage for certain research questions.

Based on this pre-test, we decided to use directed-concurrent TAP during the AR experience to provoke spontaneous reactions regarding the influence of the hologram on spatial perception (a). The effects on spatial meaning (b) and spatial movement (c) were captured immediately after the AR experience in an interview room close to the city square via directed-retrospective TAP.

3.5.4. Locative Tracking and Verbal Evaluations

The spatial movement was collected mainly by means of locative tracking within the AR glasses. This method was initially implemented by scholars on VR like Steptoe et al. (2014), who investigated the "presence" of virtual objects by analysing the movement patterns of their participants. By implementing this empirical tool in our AR field study, we were able to generate walking lines and compare how subjects placed themselves vis-à-vis the hologram. The walking lines of our participants were layered over a satellite map of the city square. The area in light blue indicates the location of the hologram.

Figure 4 shows that most participants initially approached the hologram straight from the starting point (located at 0, x-axis) and then turned right to walk alongside its front façade or to circle it entirely. Only a small number of participants walked right through the hologram or traversed it entirely, while others decided to distance themselves to capture its full size. Comparing these walking lines indicates a strong sense of presence, whereby the hologram was partially perceived as a non-mediated, real object. However, locative tracking provides only a one-sided, initial insight into the presence and augmented spatial movement and has to be contextualized with the verbal evaluations of TAP. Only then can the participants' motivation for moving through augmented space and for adapting their movement patterns be analysed fully. For instance, one participant who entered the hologram later described the inner conflict felt before breaking into its space: "My mind just said: 'Don't stress out, there is nothing in front of you.' But somehow my body first said: 'Damn, there's a wall, normally we don't go through walls.' Exactly, that was probably a bit of a conflict." This shows that the reasons for feeling (or breaking into) a hologram's presence can be manifold and might influence our movement patterns in different ways. However, this augmented spatial movement can only be captured by combining locative (but incoherent) tracking data with qualitative, contextualizing statements (combining mixed methods).

3.6. Recruitment and Covid-19 Issues

The AR field study took place between February and March 2021. Due to lockdowns and contact restrictions during the Covid-19 pandemic, we encountered considerable recruitment difficulties. For instance, a strict hygiene concept had to be developed in consultation with the Augsburg health department and local police authorities (development of a hygiene concept, agreement with police and health authorities). However, these measures were not enough to entirely alleviate the reservations of older city dwellers, who reportedly did not want to participate in the study for fear of infection (difficulties in recruiting older participants). As a result, the average age of our sample is just 24 years old (minimum: 18 years of age, maximum: 54 years of age).

Luckily for scholars dealing with the appropriation of space, it is not so much age but the length of residence along with personal memories and experiences

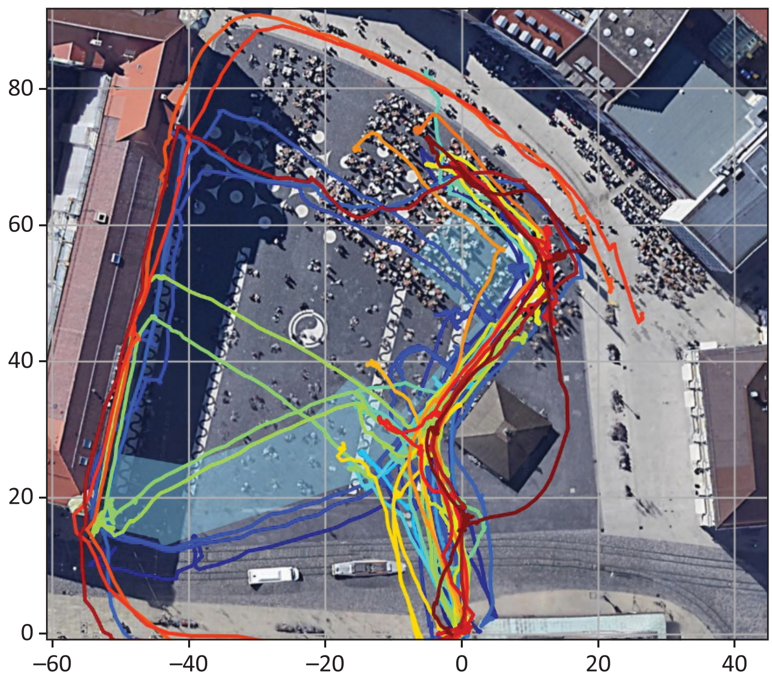

Figure 4. Walking lines in augmented space.

that are decisive for the development of spatial meaning (Gustafson, 2001). In our case, even younger city dwellers can develop a personal connection to urban space if they have lived in the city long enough to build a bond to certain places like central squares. For this reason, participants who have lived in Augsburg or the surrounding area for less than three years were excluded from the study; the average length of residence in the study is 11 years (minimum: three years, maximum: 39 years). The study participants were thus recruited based on their place of residence and length of residence in Augsburg (or the district of Augsburg). In addition, we ensured an even gender distribution (40 women, 38 men). No further sampling criteria were applied due to the recruitment difficulties caused by the pandemic.

4. Methodological Conclusions for Capturing Augmented Space

AR has the potential to fundamentally change our relationship to space by augmenting our perception, the personal meaning we associate with certain places, and our movement patterns. In our field study, we combined established empirical methods of social scientific research—both quantitative and qualitative tools—to capture the formation of augmented space.

Preliminary questionnaires (or interviews) are an appropriate tool to sensitise the participants and to focus their attention on their relationship with physical space before overlaying it with virtual content. Only then can a participant evaluate their augmented spatial perception, meaning, and movement by comparing it to their previous experiences in daily life. Polarity profiles and mean value comparisons are useful tools to visualise these temporal aspects of spatial relations. They illustrate the mixing of physical, offline space and virtual, online space which ultimately results in the appropriation of an augmented space.

However, even with this sensibilization for spatial relationships, test subjects tend to focus on technical or graphical aspects when using AR (or VR) glasses for the first time, which may be attributable to the novelty of these high-tech applications. For this reason, unlike usability studies, AR scholars investigating augmented space (or spatial references in general) should stick to directed TAP to avoid deviations and to elicit spontaneous, verbal reactions relevant to the research question. In concurrent TAP, interviewers may direct (but not compel) the participants to express their thoughts and feelings about apparent, graspable concepts like spatial perception (e.g., "How would this change [the place] in your eyes?"). Unapparently, more abstract concepts like spatial meaning, sense of presence, or spatial movement should be explored using retrospective TAP. By combining these two forms of verbalization, which Ericsson and Simon (1980) regard as a hybrid mode of TAP, the participants are given the opportunity to complement their instant reactions to holographic content with a deeper, more reflected perspective on AR. This retrospective TAP should be carried out immediately after the AR experience in a private environment and can be supported by re-watching a video-recorded POV from the AR glasses.

In order to direct TAPs and analyse the statements that they generate, "basic theoretical assumptions are necessary" that might later be used as a coding scheme for qualitative data analysis (Wirth et al., 2004, p. 353). To code augmented spatial meaning, the elements of the three-pole model by Gustafson (2001) might serve as fitting categories for deductive analysis. However, with regard to spatial perception, we took an inductive approach by assigning the qualitative statements to the five factors of augmented spatial perception based on our factor analysis: accessibility, coherence and aesthetics, simplicity and illumination, atmosphere, and spatial legibility.

This shows how our mixed-method approach not only enhanced the data collection by combining the visualising potential of factor analyses and polarity profiles with the contextualising potential of qualitative statements but also added to our data analysis. Without the participant's concurrent and retrospective TAP, the questionnaire results would have only scratched the epistemological surface of augmented space. Without the prior questionnaires on spatial perception and meaning, participants might have been confused when it came to speaking about their personal relationship with physical space and its augmentation during the AR sessions. Moreover, without the locative tracking and walking lines, the insights about spatial movement would have been based on the video material and TAP, making it much harder to compare.

With all of these aspects in mind, high-tech AR applications like the Microsoft HoloLens 2 remain a delicate technology that is still susceptible to many technical and environmental issues like holographic tracking problems, unstable weather conditions, and social reactions of curious pedestrians or authorities. As such, implementing an AR field study requires detailed interviewer guidelines (script) and the interviewer's ability to adapt to constantly changing field conditions.

The results of this work point to new fields of study in the sociology of space that are also touched on in this specific aspect of the intersections between different spaces. How can the meaning of space on a physical, offline level be measured and differentiated from its significance on a virtual, online level? How can we guide the participants' attention to the ever-converging hybrid of offline and online space? And what are appropriate research areas for hybrid space in a literal sense?

The challenge of answering these questions lies in the technological, environmental, interviewer, measurement, and recruitment issues that often accompany AR field studies. As well as tackling these issues, scholars must consider that in hybrid space, the meaning of virtual environments is most likely linked to the significance of the physical environment rather than the other way around. Without their previous experiences and memories relating to the central square in Augsburg, the participants would hardly have been able to reflect on their augmented spatial meaning. However, since our personal relationship with space is often a very subtle one, participants should be sensitised to that relationship before taking part in the study. In addition to preliminary questionnaires, a detailed study description might be an appropriate solution. Only when participants are aware of the research focus (e.g., spatial meaning) can they better reflect their subliminal and maybe even subconscious relationship with certain places (e.g., public city squares). Finally, though humans can develop a personal relationship with any kind of hybrid space, scholars should focus on places that are potentially charged with layers of meaning rather than places that are likely to be insignificant. For our study, we chose the central square of Augsburg that had been layered with personal and historical meaning and augmented it with a building-sized hologram and AR glasses. We hope this might motivate AR scholars working with sensitive equipment to take themselves outside the safe haven of laboratory settings and bring the significant potential of head-worn AR into the field.

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Conflict of Interests

The authors declare no conflict of interests.

References

Allen, P. T., & Robinson, D. (2018). Urban encounters reloaded: Towards a descriptive account of augmented space. In T. Jung & M. C. tom Dieck (Eds.), *Augmented reality and virtual reality* (pp. 259–273). Springer.

Alshammari, T., Alhadreti, O., & Mayhew, P. (2015). When to ask participants to think aloud: A comparative study of concurrent and retrospective think-aloud methods. *International Journal of Human Computer Interaction*, *6*(3), 48–64.

Aurigi, A., & Cindio, F. D. (2008). *Augmented urban spaces: Articulating the physical and electronic city*. Routledge.

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators & Virtual Environments*, *6*(4), 355–385.

de Certeau, M. (1985). Practices of space. In M. Blonsky (Ed.), *On signs* (pp. 122–45). Johns Hopkins University Press.

de Souza e Silva, A. (2006). From cyber to hybrid: Mobile technologies as interfaces of hybrid spaces. *Space and Culture*, *9*(3), 261–278.

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review*, *87*(3), 215–251.

Georgiou, Y., & Kyza, E. A. (2017). The development and validation of the ARI questionnaire: An instrument for measuring immersion in location-based augmented reality settings. *International Journal of Human-Computer Studies*, *98*, 24–37.

Gustafson, P. (2001). Meanings of place: Everyday experience and theoretical conceptualizations. *Journal of Environmental Psychology*, *21*(1), 5–16.

Hofmann, S., & Mosemghvdlishvili, L. (2014). Perceiving spaces through digital augmentation: An exploratory study of navigational augmented reality apps. *Mobile Media & Communication*, *2*(3), 265–280.

Kuliga, S. F., Thrash, T., Dalton, R. C., & Hölscher, C. (2015). Virtual reality as an empirical research tool—Exploring user experience in a real building and a corresponding virtual model. *Computers, Environment and Urban Systems*, *54*, 363–375.

Küller, R. (1991). Environmental assessment from a neuropsychological perspective. In T. Gärling & G. Evans (Eds.), *Environment, cognition and action: An integrated approach* (pp. 111–147). Oxford University Press.

Lalli, M. (1992). Urban-related identity: Theory, measurement, and empirical findings. *Journal of Environmental Psychology*, *12*(4), 285–303.

Lefebvre, H. (1991). *The production of space*. Blackwell.

Liao, T., & Humphreys, L. (2015). Layar-ed places: Using mobile augmented reality to tactically reengage, reproduce, and reappropriate public space. *New Media & Society*, *17*(9), 1418–1435.

Liao, T., Yang, H., Lee, S., Xu, K., & Bennett, S. M. (2020). Augmented criminality: How people process in situ augmented reality crime information in relation to space/place. *Mobile Media & Communication*, *8*(3), 360–378.

Lombard, M., & Ditton, T. (1997). At the heart of it all: The concept of presence. *Journal of Computer-Mediated Communication*, *3*(2), Article JCMC321. https://doi.org/10.1111/j.1083-6101.1997.tb00072.x

Löw, M. (2008). The constitution of space: The structuration of spaces through the simultaneity of effect and perception. *European Journal of Social Theory*, *11*(1), 25–49.

Manzo, L. C. (2005). For better or worse: Exploring multiple dimensions of place meaning. *Journal of Environmental Psychology*, *25*(1), 67–86.

Oleksy, T., & Wnuk, A. (2016). Augmented places: An impact of embodied historical experience on attitudes towards places. *Computers in Human Behavior*, *57*, 11–16.

Osgood, C. E., Suci, G., & Tannenbaum, P. (1957). *The measurement of meaning.* University of Illinois Press.

Pink, S., Sinanan, J., Hjorth, L., & Horst, H. (2016). Tactile digital ethnography: Researching mobile media through the hand. *Mobile Media & Communication*, *4*(2), 237–251.

Pognon, J., Chi, J., Salabert, A., Kim, K., & Kim, S. J. (2020). Meta-analysis of global activities in augmented reality (AR) and virtual reality (VR). In T. Jung, C. tom Dieck, & P. A. Rauschnabel (Eds.), *Augmented reality and virtual reality* (pp. 335–347). Springer.

Reinwald, F., Berger, M., Stoik, C., Platzer, M., & Damyanovic, D. (2014). Augmented reality at the service of participatory urban planning and community informatics—A case study from Vienna. *The Journal of Community Informatics*, *10*(3). https://doi.org/10.15353/joci.v10i3.3441

Richardson, I., Hjorth, L., & Piera-Jimenez, J. (2022). The emergent potential of mundane media: Playing Pokémon GO in Badalona, Spain. *New Media & Society*, *24*(3), 667–683.

Santos, C., Miranda, B., Araújo, T., Carneiro, N., Marques, A., Mota, M., Morais, J., & Meiguins, B. (2016). Guidelines for graphical user interface design in mobile augmented reality applications. In S. Lackey & R. Shumaker (Eds.), *Virtual, augmented and mixed reality: 8th International Conference, VAMR 2016, held as part of HCI International 2016, Toronto, Canada, July 17–22, 2016. Proceedings* (pp. 71–80). Springer.

Statista. (2021). *Number of mobile augmented reality (AR) active users worldwide from 2019 to 2024 (in billions)*. https://www.statista.com/statistics/1098630/global-mobile-augmented-reality-ar-users

Steptoe, W., Julier, S., & Steed, A. (2014). Presence and discernability in conventional and non-photorealistic immersive augmented reality. In S. Julier, R. W. Lindeman, & C. Sandor (Eds.), *2014 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)* (pp. 213–218). IEEE.

Thielmann, T. (2007). “You have reached your destination!” Position, positioning and superpositioning of space through car navigation systems. *Social Geography*, *2*(1), 63–75.

Tsai, S.-P. (2020). Augmented reality enhancing place satisfaction for heritage tourism marketing. *Current Issues in Tourism*, *23*(9), 1078–1083.

van den Haak, M., De Jong, M., & Jan Schellens, P. (2003). Retrospective vs. concurrent think-aloud protocols: Testing the usability of an online library catalogue. *Behaviour & Information Technology*, *22*(5), 339–351.

Verhoeff, N. (2012). *Mobile screens: The visual regime of navigation*. Amsterdam University Press.

Westerdahl, B., Suneson, K., Wernemyr, C., Roupé, M., Johansson, M., & Allwood, C. M. (2006). Users’ evaluation of a virtual reality architectural model compared with the experience of the completed building. *Automation in Construction*, *15*(2), 150–165.

Wilmott, C. (2016). Small moments in spatial big data: Calculability, authority and interoperability in everyday mobile mapping. *Big Data & Society*, *3*(2). https://doi.org/10.1177/2053951716661364

Wirth, W., Wolf, S., Mögerle, U., & Böcking, S. (2004). Measuring the subjective experience of presence with think-aloud method: Theory, instruments, implications. In M. Alcaniz, & B. Rey (Eds.), *Proceedings of the Seventh Annual International Workshop on Presence* (pp. 351–358). Universitat Politècnica de València.

Woods, O. (2020). Gamifying place, reimagining publicness: The heterotopic inscriptions of Pokémon Go. *Media, Culture & Society*, *42*(6), 1003–1018.

Zaubar. (2021). *Tagesspiegel 89/19*. https://zaubar.com/project/tagesspiegel-89-19

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