The AR-Marker in the Urban Space

Affordances and Roles of AR Markers from an HCI Perspective

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ABSTRACT

When considering the role of Augmented Reality (AR) in the urban space, most previous work is focusing on touristic and everyday life use cases. However, the project “Archäologie der Gegenwart” which we present in this paper illustrates the different aspects of change in Hamm during the last 50 years. Thus, our AR approach opens up a deeper understanding of the urban cultural change processes by the means of AR. Our considerations lead to adding an AR layer as a fifth social dimension in the urban space. Technically, we robustly link this fifth layer with the existing topography by marker-based tracking with six degrees of freedom (6 DOF).

When building AR applications for the urban space, the deeper understanding of the marker paradigm is crucial: During our workshops we identified and analyzed seven requirements for the utilization of markers in the public urban space. Additionally, we analyzed the general AR marker paradigm from the human-computer interaction (HCI) perspective by considering the affordances and signifiers of the marker objects themselves, analyzing the tracking technology and summarizing the marker’s role for past, present and future AR applications.

Thus, the role of the AR marker is twofold: On the one hand the marker is part of the 6 DOF tracking technology, on the other hand it makes AR layers perceivable in the urban space. We expect that the importance of these markings for guiding citizens through AR experiences will emerge in urban spaces, whereas the role of markers for technical tracking purposes will decrease.

CCS CONCEPTS

CCS → Human-centered computing → Human computer interaction (HCI) → Interaction paradigms → Mixed / augmented reality

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KEYWORDS

Augmented Reality (AR), Urban Space, AR Marker, Marker-based Tracking, Human-Computer Interaction (HCI), Affordances, Signifiers

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1 Introduction

According to spatial sociologist Dieter Läpple the social construction of the urban space emerges within four different dimensions: a material physical dimension, the dimension of social interactions, an institutionalized system of regulations and a semiotic dimension that includes signs, symbols and representations [1]. Considering the introduction of an AR (Augmented Reality) application will add a fifth layer, the augmented space [2].[1]

When considering the role of AR in the urban space, most of the previous work is focusing on touristic [4] and everyday life [5] use cases, e.g. dealing with the question “how tourists acquire knowledge about an unfamiliar urban environment through AR” [6]. Early concepts for ubiquitous AR such as the touring machine from Feiner et al. [7] aim at assisting the everyday interactions with the world.

From the HCI (human-computer interaction) perspective, AR can be interpreted as a new interface paradigm, generally speaking it belongs to the category of the so-called post WIMP (window, icon, menu, pointing device) interfaces [8]. However, from the sociological perspective, AR is a technology which will make the city itself become the object of the ongoing penetration by media [9]. Tutor described the role of location-based media in the urban public space the following way: “(...) brings the art installation and its public (...) from the contained space of the gallery into the body of the city.“ [10].

During our project “Archäologie der Gegenwart”[2] we established a new AR layer in the city Hamm in North-Rhine Westfalia,

[1] For further discussion see Löw et al. [3]

[2] https://hamm.archivdeswandels.de/#info

Germany which contains archival material, pictures, interviews and objects. The goal of the project is to illustrate the different aspects of change in Hamm during the last 50 years and to open up a deeper understanding of the history of the place – for the population as well as for tourists. However, before going live a vernissage was organized, this art exhibition took place at a central public location in Hamm as well as in the overall urban space. In this paper we at first briefly introduce the possible technological approaches, in the third section we will analyze the requirements originating from our context, the urban space, before we take a closer look at the affordances, signifiers and roles of the AR marker in the fourth chapter and finally discuss our results.

2 Technologies

From the technological perspective we need 6 DOF (six degrees of freedom) tracking for appropriate pose estimation and in order to be able to robustly link our fifth AR layer with the existing material / physical layer. Tracking is the basic fundamental to implement AR solutions which fulfill all three aspects of AR applications as defined by Azuma (Combination of real and virtual, real-time interactivity, 3D registration) [11]. Especially the last of these aspects is critical, as we will see in Section 3.

Although tracking for Augmented Reality is already solved in many different ways in appropriate quality there is still a lot of ongoing discussion and research on tracking in the context of AR. The analysis of Zhou on the main research areas discussed at ISMAR (International Symposium on Mixed and Augmented Reality) revealed, that 20.1% of all papers discussed tracking techniques and 14.1% of all papers dealt with calibration and registration, whereas interaction techniques (14.7%), applications (14.4%) and display technologies (11.8%) were less important [12].

Basically, AR tracking can be solved by three different concepts: Marker-based tracking, markerless tracking and location-based tracking. In the next step we will analyze these concepts briefly.

2.1 Marker-based

A well-established possibility to facilitate the link between the material / physical space and the virtual space (the augmentations) is the usage of AR markers. The underlying basic principle is described by Kato et al. in the following way: "The relationship between marker coordinates and the camera coordinates is estimated by image analysis." [13]. The hardware requirements for marker-based AR are quite low: A commercial smartphone which has a camera on its backside in combination with a popular AR framework (e.g. Vuforia[3], EasyAR[4], Kudan[5]) is already sufficient. As a consequence, Schmalstieg et al. state: "Handheld devices seem to be a superior alternative for AR - especially for untrained users in unconstrained and non-supervised environments." [14]. Historically, these markers contain characteristic black and white patterns, what made them easily perceivable for the user. Popular marker systems (among others) were ArToolKit markers, IGD (Institut Graphische Datenverarbeitung) markers, SCR (Siemens Corporate Research) markers and the HOM (Hoffmann marker system) [15]. In the context of our project the perceivability of the marker in the urban space is crucial; thus, we will discuss this aspect in further detail when analyzing affordances, signifiers and roles of AR markers in Section 4. However, due to technological advancements these restrictions do not exist anymore, most AR frameworks work trouble-free with image markers as well.

2.2 Markerless

Whereas the pose estimation is frequently done on the basis of indoor and outdoor fiducial markers, in literature we see various approaches which do not rely on markers, e.g. by detecting geometric features, such as segments, straight lines, contours, points on the contours, conics, cylindrical objects or a combination of these different features [16]. According to Andrew et al. the major weakness of these approaches is the dependency on the 3D models of the tracked objects: "These 2D-3D registration techniques rely on the use of a 3D model of the tracked objects. When such 3D models are not available, other approaches are required." [16].

While the markerless pose tracking works best when a model (or a map) of the environment is a priori available, other approaches to markerless AR are capable to generate the map on the fly, such as the so-called Simultaneous Localization and Mapping (SLAM) [17]. One of the most popular AR devices, the Mirosoft Hololens[6], uses this approach to provide a markerless tracking of the environment. However, regarding the SLAM approach various limitations have to be considered, the most critical one is the lack of robustness, especially for monocular SLAM implementations. Williams et al. state that "rapid camera motions, occlusion, and motion blur (...) can often cause tracking to fail.". This failure is mainly caused by the SLAM relying on visual feature correspondences during a rapid frame-to-frame localization [17].

2.3 Location-based

In literature location-based approaches to Augmented Reality are quite well understood. From a technologic perspective this approach is even more lightweight than the marker-based approach: Location-based AR just requires a combination of GPS receivers and a compass device; nowadays both technologies can be found in nearly every smartphone. However, many researches argue, that this tracking approach does not meet the definition from Azuma [11]; thus, strictly speaking location-based AR is no AR.

We share this perspective; nevertheless, the hype around Pokémon GO has somehow redefined the definition of the term

[3] https://developer.vuforia.com
[4] https://www.easyar.com
[5] https://www.kudan.io
[6] https://www.microsoft.com/en-us/hololens

Augmented Reality [18]. Whereas we stick to Azuma's definition, the public perception might be different [19]. Therefore, for the sake of completeness, we at least briefly mentioned this third approach as well.

3 Requirements

Due to our strict interpretation of the term Augmented Reality and the need for a lightweight, platform independent solution we used a marker-based approach (we chose Vuforia) for our project and identified seven concrete requirements for the markers in the public urban space in our workshops with the city marketing of Hamm, our project stakeholder.

3.1 Natural markers

Although the installation of markers in the urban space is feasible from the technological perspective, practical considerations speak against the installation of additional objects. Within the public authorities' new responsibilities and processes for regularly checking the proper installation and visibility of the installed markers have to be established – whereas by using already existing marker objects (such as graffiti, signs, logos and so on, see Figure 1 in the urban space, the responsibility and process for maintaining these objects is already well defined.

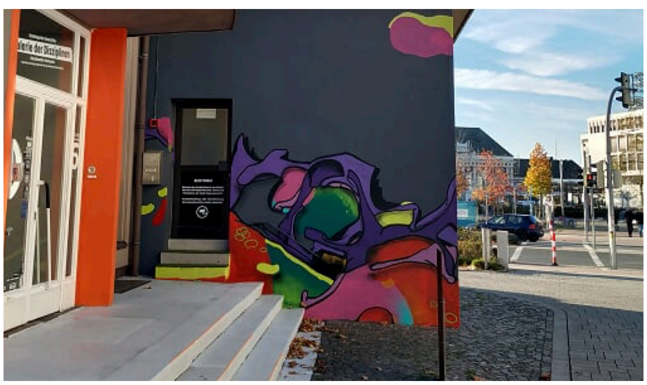

Figure 1: We used already existing marker objects in the urban space (such as this graffiti).

3.2 Focal distance

While these natural markers are widely spread in the urban space, the distance to the augmentation has to be taken into consideration: The focal distance between the marker and the augmentation should be as low as possible. Ostensibly, this requirement results from technical considerations. However, the perceivability of the marker and the link between marker and augmentation is additionally improved by reducing this distance; for instance, in Figure 2 the sign for wireless network would not be an appropriate marker for augmenting the Kaufhof building in the back.

Figure 2: The focal distance between sign (front) and building (back) is too large.

3.3 Spatial proximity

The aspect of proximity is not limited to the z-Axis. Additionally, the spatial proximity in the other two dimensions is crucial as well, as shown in Figure 3: The sign of the shop would be no appropriate marker for the tracking of the high-rise bunker above. The reasons are practical: Spatial proximity is essential to keep the marker in the viewport of the camera while looking at the object.

Figure 3: The spatial proximity between the sign of the shop (bottom) high-rise bunker (above) is too low.

3.4 Appropriate size

Considering the appropriate size of these natural markers, our markers have to meet two constraints: On the one hand the markers have to be big enough to be trackable from distance and on the other hand they have to be small enough to be viewable up close. Thus, the sign in Figure 4 would be not appropriate: The sign as a whole would be too big, whereas the logos on the sign would be too small.

Figure 4: The size of the sign is not appropriate: The sign (as a whole) is too big, the logos on the sign are too small.

3.5 Suitable texture

When we were exploring objects, which are appropriate for augmentations in the context of our project, we challenged another requirement: The texture of the marker object must be well suited for the tracking algorithm which is used by the AR framework. Basically, this means, that the texture has to provide enough features in order to make the object trackable and augmentable. However, many facades of these buildings of interest looked similar to the one shown in Figure 5 and consequently could not be used as a marker.

Figure 5: Many facades of urban buildings provide not enough features to be used as markers.

3.6 Uniqueness

However, the suitability of the texture is not limited to the features it contains but also to its uniqueness. The ideal marker is unique in the complete urban space, an adequate usable marker is at least unique within a certain area of interest. Especially logos regularly do not meet this requirement as shown in Figure 6.

Figure 6: Many potential marker objects are not unique within a certain area of interest (such as these signs).

3.7 Permanence

We decided to use natural markers for the sake of low maintenance efforts and a permanent operability of our AR solution. However, especially the graffiti apparently do not meet this requirement. For instance, in Figure 7 we could not identify an appropriate marker which would make our application permanently (or at least for an sufficient amount of time) available.

Figure 7: Many objects in the urban space are not permanent – and thus are not appropriate to be used as markers (such as this graffiti).

4 Affordances, signifiers and role

We now have gained a deeper understanding of the requirements for the usage of Augmented Reality markers in the urban space. Thus, in the next step the resulting marker concept has to be analyzed from an HCI (human-computer interaction) perspective. In this section we at first will consider the affordances and signifiers of these marker objects themselves, then we will try to analyze the marker technology by the means of the technology acceptance model, the technology life cycle and the s-curve concept before we will finally summarize the marker's role during the different phases of technology maturity.

4.1 Affordances

The term affordance goes back to James J. Gibson who defined the term in 1966 [20]. "The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. (…) I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment." [21]. In 1988 the term was adapted by Don Norman in the context of human-computer interaction [22] and describes what an object can do on a human's interaction.

However, the intended interaction with a marker is not physical: Although markers can be touched, these physical interactions will not make the AR layer accessible for humans. The interaction with AR markers is cyberphysical: Humans create a logical link between the physical space (e.g. the marker) and a technical solution for exploring the AR layer. As a consequence, they have to decide which device (e.g. their smartphone) and which application (e.g. our app "Archäologie der Gegenwart") they use for accessing the AR layer within the urban space.

However, the affordance concept is already used in the field of Augmented Reality: Kaptelinin et al. proposed a framework which is capable of looking on these affordances from an individual perspective [23]. Bodker et al. identify three different dimensions of these affordances: maintenance, aggregation and learning [24], Gjøsæter summarizes these concepts as instrumental affordances and extends them by a domain specific remediation affordance and uses this adapted affordance model for his mobile Augmented Reality application [25].

A deeper understanding of these affordances helps us to analyse the underlying interaction process: The Augmented Reality experience depends on successfully triggering the appropriate application on a supported device in an urban space with an AR layer. From the perspective of human-computer interaction the human-marker interaction can fail because of two different reasons: On the one hand, the marker itself might be not recognized as a marker (*gulf of evaluation*) and on the other hand humans might use a device which is not supported within the specific urban space or might use the wrong application (*gulf of execution*).

4.2 Signifiers

As described in Section 2, the historic black and white patterns are easily perceivable by humans. However, when using image targets or natural features the affordances are less clear, humans might face gulf of evaluation problems and additional signifiers are a necessity.

The purpose of a signifier is the clarification of the affordance, e.g. by enriching the AR marker with additional textual information such as "This is an AR marker of the project Archäologie der Gegenwart, Hamm. Check https://hamm.archivdeswandels.de for more information and in order to install the AR app on your smartphone.".

According to the differentiation from Bodker et al. [24], in our urban context the focus lies on the learning affordances: Identifying the marker in the urban space, pointing the camera to the marker and rotating and translating the content by moving the camera. Once the basic concept of (camera based) Augmented Reality is well understood by the citizens, the first of these steps on the one hand will highly depend on the specific marker itself and on the other hand will be the most challenging one.

As a consequence, in the urban space AR experts as well as AR novices will benefit from these signifiers: Humans who are not familiar with AR applications in general rely on signifiers in order to get access to the fifth AR layer. The second group, humans who are already familiar with the AR paradigm, rely on signifiers because our markers are not easily perceivable in the urban space.

However, when strictly transferring the differentiation between affordances and signifiers as proposed by Don Norman [22] to Augmented Reality, we need an additional paradigm: The marking. Whereas the marker's affordance is a measurement for the marker's quality from the citizen's perspective and the marker's perceived quality is – besides the seven requirements identified in the previous section – crucial for the successful implementation of Augmented Reality applications in the urban space, the marking is an object which facilitates the interaction with augmented urban spaces.

These markings help humans to virtually link the urban physical layer to an appropriate application on the smartphone and thus to explore the AR layer within the urban space.

4.2 Technology acceptance model

Before we analyze the current, past and future role of these markings we will first analyze the distribution and utilization of markers from the perspective of the technology acceptance model (TAM) [26]. Due to the fact that – as analyzed above – the marker technology is a crucial part of the Augmented Reality application; the considerations of AR from the TAM perspective will include the markers.

The TAM provides a deeper understanding of the motivations for the usage of new technologies, such as Augmented Reality. As shown in Figure 8 the actual system use is mainly influenced by perceived usefulness (U) and perceived ease of use (E). Whereas these two dimensions are for their part influenced by external variables, they will influence the attitude towards using (A) and the behavioral intention to use (BI) which will finally influence the actual system use.

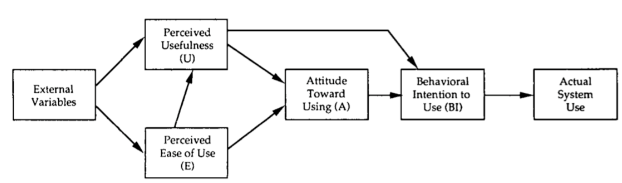

Figure 8: Technology acceptance model (TAM) [26]

Thus, the perceivable aspects of the technological solution play the most import role for the actual system use. Successful AR applications convince humans on the one hand by the two dimensions usefulness and ease of use of the system and on the other hand by the perceivability of these two aspects.

When considering the perceivability of the Augmented Reality application two aspects are crucial: The perceivability of the application on an AR device and the perceivability of the AR layer in the urban space. From our perspective, markings are a promising approach to support the latter.

4.3 Technology life cycle

However, the utilization of an AR technology does not take place simultaneously for all humans. One of the most common approaches to understand the technology life cycle (TLC) has been proposed by Rogers [27]. For new technologies in general he has identified five different groups of prospective users: Innovators, early adopters, early majority, late majority and laggards.

Whereas the groups early and late majority, as their name suggests, are quite large (more than two thirds of the people belong to one of these two groups), the innovators (2.5 %), early adopters (13.5 %) and laggards (16 %) are comparatively small. As shown in Figure 9 the technology adoption is Gaussian distributed.

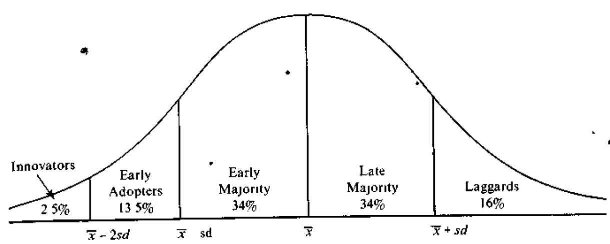

Figure 9: Technology life cycle (TLC) [27]

Thus, usually mainly innovators and early adaptors are attracted by new technologies such as Augmented Reality in the first step. Due to the fact that our installation was visible at prominent places in Hamm, our situation was different: During their exploration of the AR layer in the urban space, many citizens got in contact with the AR technology for the first time in their live [2].

As a consequence, the perceivability of the AR technology in general, and of our AR markers in particular was crucial for the acceptance of the technology and its content.

4.4 S-curve concept

The quantitative distribution of these five user groups during the TLC, leads to the s-curve concept [28]. When analyzing the subsequent adaption of new technologies by the different user groups over time and calculating the product performance by integrating the adaption curve, in result we receive the so-called s-curve.

When additionally considering that specific technologies such as Augmented Reality are replacing existing technologies as well as themselves are replaced by other technologies, the overall picture as shown in Figure 10 contain several interlaced s-curves.

In the next step we will focus on the 2nd technology in Figure 10; the 2nd technology replaces the 1st and will be itself replaced by the 3rd one day. A rather straightforward interpretation for our application might be that the AR technology is just this 2nd technology. However, by diving deeper in, we could interpret the s-curve in a slightly different way: In our project, the augmented urban space, term 2nd technology describes the concrete AR solution, our marker-based AR application.

Due to the fact that we focus on the early and late majorities according to the TLC, when augmenting urban spaces, from this perspective the 1st technology would be location-based AR and the 3rd technology would be marker-less AR. The coexistence of 1st and 2nd technology leads to the necessity to make markers easily perceivable when running through the technological transformation. Due to the coexistence of the 2nd and 3rd technology appropriate substitutions of the familiar marker paradigm, such as the proposed marking concept, are essential.

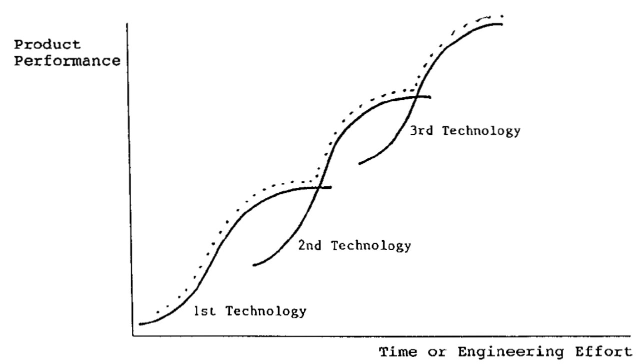

Figure 10: S-curve concept [29]

4.5 Role

These considerations of the TAM, TLC and s-curve concepts help us to gain deeper insights in the present and future role of marker targets for AR applications from an HCI perspective. Whereas from the technological perspective the marker is primarily a auxiliary object which facilitates an accurate estimation of the 6 DOF pose of the human's eye (or of the camera), from the human's perspective the marker plays a different role (which we call *marking*).

This marking makes the Augmented Reality application perceivable in the urban space. Consequently, its strength lies in the capability to make the existence of AR layers perceivable without needing additional technological capabilities. In the urban space the improvement of the technological tracking capabilities has to go hand in hand with alternative approaches to guarantee this perceivability.

An alternative interpretation of the AR marker in the public urban space is to consider the marker as a marketing tool. The marker's capability to draw attention is not limited to the people which are already familiar with the technology. Our considerations on the TLC and our observations show that the curiosity by the marker itself as well as by the people who interact with these markers generates first time users.

The last approach is to focus the marker's role on its capacity to coin the transformation process. Whereas the absence of the AR marker either provides insights about the place (no AR layers exist) or about the technology (only 1st generation location-based AR) at the moment, this view will flip in the future. However, unless we do not introduce new physical artefacts (such as our markings), this interpretation will flip: The absence of AR markers will similarly indicate content poor and technology rich (3rd generation marker-less AR) urban spaces.

5 Discussion

Our insights on markers and markings in the urban space are mainly based on our own experiences from approaching and implementing an AR application which was prominently visible in the urban space during a short term of time. One consideration might be that the markers which have been used during our project, especially because of the requirement regarding the naturality of our markers, are no *real* markers. We would strongly argue against that interpretation of the marker paradigm, because they are triggering our augmentations and make this process transparent to the human. Additionally, our markers follow certain, recurring patterns. As soon as the citizens have interacted with a subset of our markers and identified these patterns, the capability to identify a priori unknown markers increased – according to our observations.

Figure 11: Markings change the physical environment

Nevertheless, the major drawback is that due to our requirements our markers were not that easily perceivable as we wished them to be. As a consequence, we had to additionally modify the physical environment in order to make the AR layer even more prominently visible in the urban space. As a consequence, we used markings and installed a guidance system during our exhibition as shown in Figure 11.

However, this change of the physical environment will struggle with the same challenges as the placement of additional markers – with at least one important difference: Once markings or the guidance system will be removed (either intentional or unintentional) the overall application will be still fully functional and the markers will be perceivable for all humans who have already become familiar with the application. The paradigm we used here is recognition – and as we know from HCI research, this paradigm is much stronger than recall [30].

Figure 12: Changing the AR paradigm by using markings

Whereas the application vanishes when the markers disappear, the disappearance of the markings and the guidance system make the markers just more difficult to find. Thus, in our project we consequently followed the path to use physical markers (which we call *markings*) for the humans – not for the technology, as shown in Figure 12. The humans are looking to a marker on the wall whereas the marking and the guidance system just helps them to find an appropriate perspective.

When Augmented Reality is an upcoming technology for merging the visual and the physical, from our understanding its disruptive character will be not limited to the visual. The physical spaces have to change accordingly. Whereas markers for the sake of technology will disappear we expect an increasing usage of markings – especially when shifting to the 3rd technological S-curve, marker-less AR. In order to make Augmented Reality solutions perceivable in the urban space, we have to leave the application layer – and make our applications perceivable in the physical space as well.

In the ideal case the affordances of objects owning an augmentation layer will become clearer in the future; for instance, by transferring the semantics from the physical space to the augmented one [2]. However, to make this vision become true, we have to go beyond augmenting graffiti, logos and posters in the urban space.

As a consequence, HCI professionals have to assist AR professionals to successfully and repeatedly switch between the AR developer's perspective and the AR consumer's perspective.

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