The World-as-Support: Embodied Exploration, Understanding and Meaning-Making of the Augmented World

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ABSTRACT
Current technical capabilities of mobile technologies are consolidating the interest in developing context-aware Augmented/Mixed Reality applications. Most of these applications are designed based on the Window-on-the-World (WoW) interaction paradigm. A significant decrease in cost of projection technology and advances in pico-sized projectors have spurred applications of Projective Augmented Reality. This research has focused mainly on technological development. However, there is still a need to fully understand its communicational and expressive potential. Hence, we define a conceptual paradigm that we call ***World-as-Support (WaS)***. We compare the WaS and WoW paradigms by contrasting their assumptions and cultural values, as well as through a study of an application aimed at supporting the collaborative improvisation of site-specific narratives by children. Our analysis of children's understanding of the physical and social environment and of their imaginative play allowed us to identify the affordances, strengths and weaknesses of these two paradigms.

Author Keywords
Mixed Reality; Augmented Reality; embodied interaction; embodied cognition; meaning making; Window-on-the-World; World-as-Support.

ACM Classification Keywords
H.5.1. Information interfaces and presentation (e.g., HCI): Multimedia Information Systems

INTRODUCTION
The rich opportunities offered by the blending of the digital and the material worlds have become a mainstream research field in HCI. From a broad perspective, this hybrid space embraces both research oriented toward using the physical world to interact with digital technology (i.e. embodied interaction [11]) as well as studies aimed at digitally augmenting the physical environment through Augmented/Mixed Reality (ARMR) [4,21, 25].

Within this broad panorama, nowadays, the most widespread technological configurations for ARMR systems are based on smartphones and tablet devices. Most of these applications are designed according to the Window-on-the-World (WoW) interaction paradigm. This paradigm provides the user with augmented information on the surrounding physical space by using the device's screen as a layering system that merges contextualized digital content with the user's view of the physical surroundings. In contrast to this approach, we identify the raising of an emerging conceptual paradigm to design ARMR applications for mobile technologies. We call this approach the World-as-Support (WaS) interaction paradigm. This paradigm combines projective augmented reality (PAR) configurations with the possibilities of embodied interaction. Users can use portable devices to augment their physical surroundings by projecting the digital information on the physical world and use the physical world to interact with digital technologies. As we describe below through related work examples, this is not novel in itself from a technological standpoint. However, we believe the current use of these technologies is still in its infancy and our WaS paradigm tries to analyze the potential of this medium.

The two paradigms (WoW and WaS) propose different ways of constructing the relation between physical and digital worlds. As a consequence, we need conceptual and empirical research efforts oriented toward understanding their affordances and their role in mediating user experience and meaning-making. To this end, we first analyze both interaction paradigms from a critical perspective, aimed at unveiling the specific assumptions and cultural values that they entail. Subsequently, we present a study aimed at comparing how the WoW and WaS paradigms can shape the usage and the meaning-making of the physical/digital environment and how they can influence the unfolding of social relationships in collaborative settings. Specifically, in the study, we contrast the use of the WoW and WaS paradigms in an ARMR application aimed at supporting the

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collaborative improvisation of site-specific narratives by children. Our results show that the two paradigms scaffold different ways of engaging and using the physical/digital space in interactive experiences. Furthermore, they strongly affect the unfolding of social relationships and instances for participation and co-construction of meaning. Starting from these findings we will discuss their affordances and design possibilities.

MOBILE TECHNOLOGIES FOR MERGING DIGITAL AND PHYSICAL WORLDS

In recent years, advances in the technical capabilities of smartphones and tablets have spurred the interest in developing context-aware ARMR applications for mobile technologies [5].

The design of these applications is generally based on the Window-on-the-World (WoW) interaction paradigm. This paradigm represents a well-known approach to bridge digital and physical worlds. It finds its root in early works in AR and, technically, it is based on using video displays to merge computer-generated images with a user view of the physical surroundings, usually captured by a camera [25]. In the context of mobile technologies, it employs the device screen to display digital contents over a live video stream of the physical environment [28]. Users can eventually interact through the screen by using digital objects to enable specific functionalities.

This paradigm has been applied in a wide variety of mobile applications (e.g. education [45], creativity [51], cultural heritage [32], tourism [19], gaming [29], etc). For instance, Tien-Chi et al. [45] propose an AR smartphone application to support learning ecological resources in botanical gardens, showing the benefits of these systems in supporting the understanding of site-specific contents. Similarly, [19,32] employ AR mobile technology to make the historical memory of specific places visible and [51] describes several AR systems to encourage different forms of creative play. Despite its benefits, some limitations have also been reported. Betsworth et al. [6] describe how in WoW users must hold their devices in front of the physical world making the system a "digital divider". Müller at al. [28] analyze users behavior in a collaborative task with a tablet-based AR application and report that nearly any participants actually focused on the physical environment during the experience. Also, the authors suggest possible constraints caused by the narrow field of view offered by the tablet. Similarly, specific concerns have also been expressed around the risks of real-life events which can entail dangers while not paying full attention to our physical surroundings when playing with an AR gaming experience (e.g. the reported accidents caused by players' distractions while playing Pokemon Go [29]).

The WoW paradigm represents a useful resource for some specific contexts of usage of mobile AR. However, we suggest that other technological configurations may provide other rich possibilities for blending the physical and the virtual worlds. In particular, while reviewing novel trends in the field, we have identified the rise of new mobile-based technological configurations, which we see as an emerging conceptual paradigm to design ARMR applications. We call this approach the World-as-Support (WaS) interaction paradigm.

The WaS paradigm is grounded in the tradition of Projective Augmented Reality, Spatial Augmented Reality [39], embodied interaction [11], tangible interaction [15] and Full-Body interaction [23]. Important technological advances have been achieved recently in projective technology such as the improvement of pico-sized projectors and sophisticated computer vision systems that detect surfaces and objects in the physical environment [26]. Therefore, on the one hand, it is now feasible to use portable devices to dynamically recognize the physical world (i.e. geometry, surfaces, objects and movements) and projecting physically-aware digital information directly onto it [3]. This feature enables taking advantage of the benefits of Reality-Based Interaction such as *environment awareness* and *social awareness* [16]. On the other hand, by allowing users to interact with digital contents through the physical world [11], it affords the potential of bodily and tangible interaction such as *tangible manipulation*, *spatial interaction* and *embodied facilitation* as defined by Hornecker et al. [15].

In the context of mobile technologies, already a few initial efforts in this direction have been based on the aforementioned systems [6,8,26,44,48] For instance, Molyneaux et al. [26] present a system that combines a pico-projector with a Kinect and IR cameras to create high-quality 3D models of the physical world, project context-aware digital contents on it and enable users physical interaction. Similarly, PHAR [52] offers a framework that allows Android developers to create AR applications based on a smartphone that has an embedded camera-based vision system to recognize physical objects and a pico-projector to augment the recognized object. Instead, Betsworth et al. [6] use a simplified system based on QR codes to know which content the pico-projector should display on the physical elements of a cultural heritage site. Finally, Willis et al. [38, 39, 40] use pico-projectors, motion sensors and a camera-based vision system to animate the motion of virtual characters, [39] enhance storytelling experiences and [40] promote side-by-side multi-users gaming interactions [38].

These projects offer a flavor of the possibilities afforded by the WaS paradigm to think about and design mobile ARMR applications. Nonetheless, to create useful conceptual distinctions between the WoW and WaS paradigms, we must move beyond technology-oriented definitions and consider them as different media with their own specificities. This implies understanding their role in mediating user experience and meaning-making, their underlying socio-cultural assumptions and their affordances.

UNDERSTANDING THE WINDOW-ON-THE-WORLD AND WORLD-AS-SUPPORT PARADIGMS: A THEORETICAL PERSPECTIVE

As all AR technologies, both WoW and WaS systems culturally ground themselves on the appeal of making visible something that is not physically there [25]. Nonetheless, their specific features also entail different ways of mediating the interactive experiences, as much as a broader range of socio-cultural connotations, which can dramatically shape users' sense-making and experience. To dig into these differences, we will examine the relations that are established between the users, the mediating devices and the social and physical environment. This analysis is carried out from a critical perspective [42] to go beyond the focus on technical features and to examine the assumptions and discourses that are embedded in how these systems are designed and deployed.

Constructing the physical-digital relation

WoW and WaS systems propose different ways of constructing the relation between the digital and the physical worlds. In WoW-based systems, the physical environment is positioned as a visual layer in the digital space of the screen (the window). Conversely, in WaS-based systems the digital content becomes a layer that is superimposed directly on the physical space. These two approaches inevitably imply underlying assumptions on the hierarchical structure of the physical/digital relation, by differently framing what actually matters in the experience. At the same time, they entail specific theorizations around the definition of the space of vision and of the place (and actors) for interaction.

The window and the frame

WoW-based systems are based on the well-established metaphor of the window as a single-point perspective [12] for framing, selecting and holding a portion of the environment within the boundaries of the screen [21]. Their configuration draws the user's attention to the frame (screen) by conceptualizing it as "what matters in the experience" and as the space for perception and action. This window for perception entails, in its own logic, both the evocative power of peepholes as engaging means to "see through" [10], as well as the limiting risks of acting as horse blinkers that fragment the field of view which may become too narrow to fully engage with the environment. At the same time, these systems propose the screen as the privileged place for interaction, or, in other words, as the signified space that users can practice [7].

Virtual space: The screen as the mediator

In WoW systems, despite the augmentation of the physical world, the experience of the user occurs completely in virtual space. Therefore, the contents that are displayed on the screen mediate the relation of the users with the physical environment. On the one hand, this configuration may end up shaping the possibilities for physical interaction with the material environment. These are actually reduced to the mediated experience that takes place within the physical limits of the screen and of the built-in functionalities of the device. On the other hand, while most of these systems tend to be aware of their spatial location (e.g. through GPS technology), users are not necessarily completely aware of it. Examples of that can be found in the sad cases of car accidents caused by users playing Pokemon Go or in the study described by Müller at al. [28]..

Individuality & power

ARMR applications based on the WoW paradigm make the digital content visible and actionable mainly by the person who is holding the device. Hence, this configuration affords modalities of usage that can be more easily associated with a personal experience than to a social one. Furthermore, the difference between who can see/know/interact and who cannot, inevitably leads to consequences in the power dynamics offered by this paradigm and the possibilities of using the digital content as a prompt for shared construction of meaning.

Breaking the "fourth wall"

Conversely, WaS-based systems, by projecting the digital content directly on the physical environment, reformulate the conceptualization of the place for vision and for interaction. Borrowing an analogy from theatre, the displacement of the digital content outside the frame of the screen breaks the imaginary "fourth wall" that separates actors from spectators, and representation from life [37]. These systems provide a *non-fragmented visibility* [15] by bringing perception and action out of the reassuring boundaries of the framing-screen, hence creating an ambiguous environment where, eventually, every space can be transformed into a place for interaction. An example of that can be found in the PlayAnywhere system [50], which allows transforming any surface into a playable place through a projector and computer-vision set-up.

Mixed reality: The world as the place for interaction

The configuration of WaS holds the potential of taking advantage of the physical world as the place for interaction [11,15,16]. Examples are found in [8,44], which enable users embodied interactions with the digital contents displayed in the physical environment, employing pico-projectors and computer-vision. Hence, these configurations afford the potential of embracing the richness of materiality and all the possibilities for embodied meaning-making. Furthermore, by reducing the mediation of symbolic representations, it avoids mirroring the Cartesian dualistic bias of privileging symbolic knowledge over the embodied one [30]. These specificities may have a crucial relevance in enabling different forms of awareness, understanding and usage of the physical environment. Furthermore, they can contribute to reformulate the notions of presence and sense-making of the digital content in ARMR experiences [46].

Social encounters

WaS systems make the digital content visible and present-at-hand [11] for a larger audience. Hence, they enable everybody to see how the digital content is being used. As a consequence, they reformulate ARMR technologies as social experiences that can be accessible and eventually actionable by all passersby. These systems offer communication opportunities that are reminiscent of the goals of urban graffiti, which employ the public space to communicate specific messages to a large audience. Furthermore, they expand this possibility by affording different degrees of participation since the digital content can become either an object of interest or of interaction for different participants; e.g. one can just look at the experience while another may decide to interact with it. This collaborative potential is partially exploited by projects such as SidebySide [47] and PoCoMo [43] which enable collocated interaction through the use multiple projectors and by ShadowPuppets [8] which affords the collaboration between the user who is holding the pico-projector and the one that is interacting with the digital projection,

To sum up, in this overview we have pointed out how WoW and WaS paradigms cannot be categorized only according to their technical features. Instead, they need to be acknowledged and understood for the complex network of significations, assumptions and possibilities that they entail; i.e. they are different media altogether despite them both being forms of ARMR. This standpoint provides a better and richer understanding of the adequacy of their specific affordances in different contexts and experiences.

UNDERSTANDING THE WINDOW-ON-THE-WORLD AND WORLD-AS-SUPPORT PARADIGMS: AN EMPIRICAL PERSPECTIVE

Most of the research oriented toward comparing different ARMR systems has focused on assessing their technical robustness or in evaluating their efficacy in terms of optimization of user performance [38]. Examples of this latter are found in [33] or in [39], where different technological solutions are compared in terms of performance (e.g. time, errors, successful completion, etc.) while accomplishing discrete tasks (e.g. pointing, rotating, scaling, etc.). These studies can offer relevant contributions to enhance end-user experience. Nonetheless, as Harrison et al. [14] state, when the understanding of technology aims at going beyond the evaluation of its accuracy and efficiency, there is a need for complementary investigation capable of properly encompassing the experiential and socio-cultural aspects of user interaction [38]. This research strand requires appropriate methodological approaches to explore the signified relation that unfolds between the users, the mediating device and the physical world. Example of these approaches can be found in [27,46] where the authors use several experiential dimensions to compare an AR system or a digital interface for a mobile-phone locative game.

For the purpose of this paper, our objective is to understand and compare the affordances of the WoW and the WaS paradigms to inform both theoretical and design research. Specifically, our goal is to investigate how these paradigms can shape the usage and meaning-making of the physical/digital environment and how they can influence social relationships.

Starting from this necessity, we propose using multimodal analysis [18] to collect, analyze and interpret the multiple resources (e.g. bodily activity, usage of space, gaze, verbal utterance, etc.) that users employ to construct meaning during in situ interaction [17]. From an epistemological perspective, multimodal analysis allows us to consider meanings as constructed by the users in the iterative connection between the meaning potential of an artifact, the user's worldviews and the socio-cultural context [17]. Hence, it permits us to take into account both the affordances offered by the system and their appropriations by users [2]. Furthermore, the application of this approach in research on digital technologies has shown its suitability for the analysis of user interaction with highly multimodal experiences [9,35,36] and its sensitivity to understand how the configuration of the physical/digital environment can shape experience.

THE STUDY: WOW VS WAS

The present study had the goal of investigating how the WoW and WaS paradigms, applied to the design of an ARMR mobile application, can shape the usage and meaning-making of the physical/digital environment and how they can influence the unfolding of social relationships in collaborative settings. Its ultimate objective is to provide a preliminary understanding of the potential of these two paradigms to inform theoretical and design research. For this purpose, we carried out a preliminary study on an ARMR application that supports the authoring of site-specific narratives by children. In the following sections, we describe the employed prototypes, the procedure and the results of our study.

Prototypes

"Espaistory" is an application aimed at supporting the collaborative authoring of site-specific narratives by children. The application has two main goals. On the one hand, it aims at scaffolding children's interest and awareness toward their social and physical environment. For this purpose, it addresses children's capability of employing their environment as a creative and inspirational prompt to create contents [34]. On the other hand, the application aims at facilitating conditions for collaboration and co-creation of content. The application can be used to create fictional narratives or to work on content knowledge related to specific places (e.g. historical sites, their neighborhood, etc.).

For the design, we followed an iterative Design-Based Research approach [4]. First, we derived initial requirements from: 1) the review of traditional methods to

support authoring of stories by children [40] and related HCI works [13,34,41]; 2) the organization of workshops to support children's storytelling and 3) the collaboration with teachers of a local primary school. Subsequently, we developed a preliminary prototype for each paradigm for pilot testing. The prototype only offered basic functionalities. In these initial prototypes, children could create their own contents (drawings or pictures) and display them in the physical environment. The system allowed two different modalities, based on the aforementioned WoW and WaS paradigms, namely:

1. **Window-on-the-World (WoW):** Based on an Android tablet, the system provided a view of the physical environment through the tablet screen as a live feed from the camera of the tablet. The contents created by the children were displayed on the tablet screen as an additional layer (Figure 1).
2. **World-as-Support (WaS):** Based on the combination of an Android tablet and a Philips PicoPix PPX3414 pico-projector bundled in a box and case (Figure 2). The system allowed children to carry around the device and project their own contents directly on the physical environment.

In order to analyze the affordances offered by these two modalities we carried out a study in collaboration with a local school. In this initial stage of research, our goal was not to delve into the strategies that children can employ to construct proper narrative structures but, instead, we mainly aimed at exploring the specificities of the two interaction paradigms.

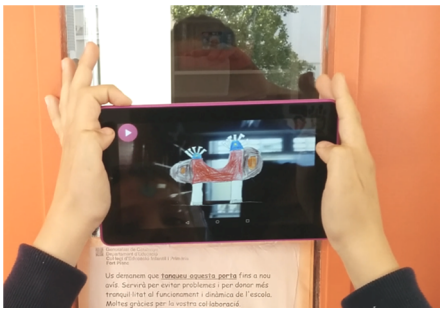

Figure 1. Child playing with the WoW based system

Figure 2. Children playing with the WaS based system

Procedure

The study was structured in two sessions of one hour each and it was carried out on two subsequent days. Participants belonged to two classes of 3rd graders (8-9 years old) of a local middle-class public school in Barcelona.

The first session had the goal of introducing children to the research team and allowing them to create their own contents. During this session, children were divided into groups of 5 to 6 members. We showed them a map of the school and asked them to choose a location that was particularly relevant or interesting for them. Subsequently, they were introduced to the task of imagining a character (e.g. a monster) that could inhabit this place. We encouraged them to draw their characters using traditional crafts material. The designed characters were collected by the researchers and uploaded to the application "EspaiStory".

In the second session, the previously defined groups were randomly assigned to two conditions: (a) the Window-on-the-World Condition (WoWc) or (b) the World-as-Support Condition (WaSc). Each group received the corresponding device (one per group) and was invited to explore the spaces of the school where they decided to locate their character. Each group was accompanied to the selected location by a researcher. Once in the selected location, one child at a time (the "narrator") selected her/his character from the application and visualized it (through the WoW modality in WoWc or through the WaS modality in WaSc). The accompanying researcher prompted the narrator to explain the character by asking these questions: *who is your character? What does it do here?* The "narrator" could freely explore different parts of the space and improvise a personal narrative until s/he was satisfied with it. Then they could pass the device to another group member. The rest of the group *("the spectators")* stood in the area where the narrator interacted with the device. Since our goal was to analyze children's spontaneous interactions. The researchers were instructed not to intervene on children's behavior. The spectators were allowed freedom to interact, intervene or do any other unrelated activity. After all of the children finished their explanations, they were accompanied back to their classroom. The overall second session was video-recorded for posterior analysis.

Data analysis

To research how the two different paradigms shaped children's understanding of the physical/digital environment and their social relationships, we focused on analyzing the relation between the users, their physical and social environment, and the mediating device. The analysis was carried out on the video recordings of the second session of the study using techniques for multimodal analysis [36].

We analyzed the videos according to a three-step procedure. First, we transcribed all videos to get a general view on the experience. This transcription was carried out employing a narrative approach and reported the number of present children, their location, their displacements and verbal and non-verbal interactions. Second, we performed slow-motion repeated visualizations of the videos to

graphically transcribe the different embodied resources employed by each child (narrator and spectators). To carry out this analysis we followed the model proposed by [22] and focused the following resources: *paths of exploration of the space, interaction with the device, gaze directionality, gestures, group disposition, verbal utterances.* The different resources were graphically transcribed in a storyboard-like format (Figure 3), which allows visualizing both spatial and embodied resources as well as the time-based unfolding of the experience. Third, data obtained from the different sources were merged and interpreted. Two researchers carried out the overall analysis. After an initial training oriented toward defining a shared coding procedure, each researcher analyzed and transcribed half of the videos. Subsequently, two researchers interpreted the transcriptions together.

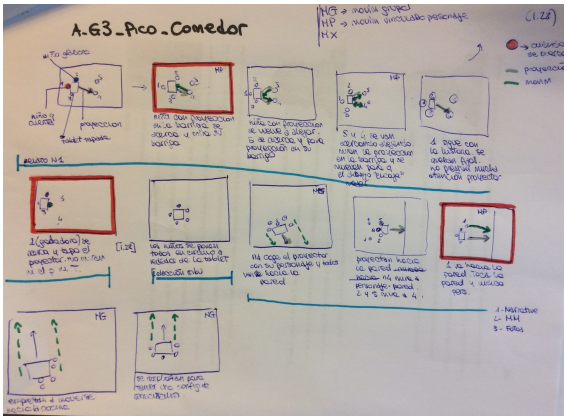

Figure 3. Example of a transcription storyboard

RESULTS

A total of 35 children participated in the second session: 4 groups in WoWc (22 children) and 4 groups in the WaSc (13 children). Results were derived from multiple sources, such as: the amount of explored spaces, children's embodied interaction with the environment, and their ways of employing the features of the space in their narrative improvisations.

Controlling the devices: places for vision and for interaction

To analyze how children interacted with the device, we observed the gaze and the physical interactions of the narrator while controlling her/his own character during the activity. In the employed prototypes, children's opportunities to interact with the character were reduced to the following possibilities: 1) moving the character in the space, by physically displacing the device in the WaSc or by using one finger in the WoWc; 2) resizing the character, by moving toward/away from the projection surface in the WaSc or by two-finger touch-screen zooming in/out on the tablet screen in the WoWc; 3) rotating the character, by physically rotating the device in the WaSc or by using three-fingers rotation in the WoWc.

During the activity, the children showed relevant behavior differences between the two conditions. In the WoWc 36.4% of the children did not perform any physical interaction with the device. The 13.6% interacted using their fingers on the tablet screen and did not move around in space. Instead, the rest (50% of the children) switched between using the built-in functionalities of the tablet (as a touchscreen-based interface) and their bodily displacements in space. In these latter cases, the different levels of embodiment (i.e. fingers on screen gestures and body displacements) covered different functions. The children employed the fingers-screen interactions to play with the character in the portion of the environment displayed on the screen. Once this portion of space ceased to be engaging for them, they physically moved the tablet or completely changed their spatial location to find another spot that was worth being framed and explored. Likewise, during interaction, their gaze was mainly directed toward the screen, with just rapid shifts to the physical world to decide where to move next. Hence, they understood and used the tablet as the privileged place for vision and action (Figure 4) without using space as a continuous place for exploration, navigation and interaction with their characters.

Figure 4. Children focusing on the screen while playing with the WoW based system

In the WaSc, the children adopted different ways of dealing with the device. Most children (84.6%), after selecting their characters, maintained the cover of the tablet closed during the activity and relied only on the projection of the character on the physical world. However, two children choose to use the device with the cover of the tablet open. In the first case, all the control of the device was embodied in the children's full-body interactions with their surroundings; e.g. move toward or away from the surface to make the character larger or smaller, move the device to move the character in space to, for example, simulate it walked. In these cases, their gazes were often shifting between the projected surface, the surrounding environment and the peers who were present as spectators (and dwellers

of that space). Hence, this configuration defined the body/space relation as the privileged place for interaction. Furthermore, it led to a smoother transition between manipulating the character and changing its spatial location, as if they were "accompanying" it toward another spot. Conversely, the children who kept the cover of the tablet open performed patterns of interaction which were similar to those assigned to the WoWc (e.g. switching between the interaction with the tablet screen and their bodily displacement or focusing the attention on the screen). This finding suggests how the presence of the tablet screen absorbed children's attention, interaction and vision within its frame.

Using and making sense of the physical/digital environment

To understand how children explored the physical/digital environment, we first quantified the amount of places that each child explored during the interaction with the device. A Mann U Whitney test showed no significant difference between WoWc and WaSc regarding the amount of explored spaces (U= 143.5; r= 0.48; p= 0.51). Nonetheless, some important differences were reported in the ways children used the space and made sense of it.

Specifically, in the WoWc, 36.4% of the children completely disregarded the physical environment and the interaction during the activity. In these cases, the children showed a lack of interest in exploring the space, experimenting with the character or improvising narratives. These children did not choose a specific location to place their character, did not look at its visual representation and just briefly answered the questions of the researcher without improvising any narrative. Instead, in the WaSc, only one child did not pay attention to the physical space or the visual representation of the character. However, his behavior was motivated by completely different reasons with respect to the children in the WoWc. In this case, the child got so engaged with telling a complex and articulated story (unrelated to any physical space in school) that he completely ignored the space or the visual representation of his character; in fact, one of his peers was occluding the projector with his body but the child was not even bothered by that.

The rest of the children (63.6% in WoWc and 92.4% in WaSc), did employ the space as a meaning-making element in their improvisations. Within this context, we identified different ways of using and making sense of space: 1) Space as a context; 2) Space as a place for sensorimotor exploration; 3) Space as a prompt for narrative improvisation. Table 1 offers a formal definition of their different ways of making sense of space. Their distribution is summarized in Figure 5.

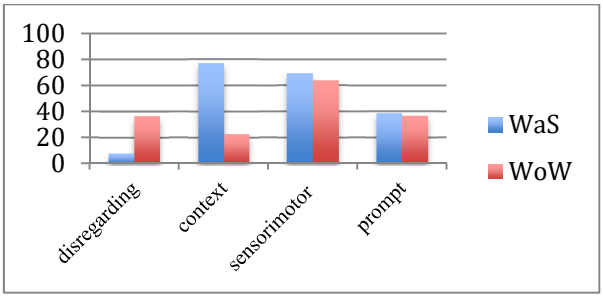

Figure 5. Distribution of ways of using space

Several children started their interaction (76.9% of the children in WaSc and 22.7% in WoWc) by employing space as a context to locate the stories of their characters (e.g. the "spaghetti monster" is in the kitchen because it is looking for spaghettis to eat). This usage of space partially derives from *a priori* decisions since children already chose what would be the habitat of their character during the first session of the study. Nonetheless, the differences between the two conditions can be indicative of the affordances that these different paradigms offer in terms of allowing children "to keep in mind" the role of the spatial location for narrative construction. Furthermore, it is relevant to notice that in WaSc 77% of the children who began their interaction using space as a context, subsequently moved toward other ways of using space. Instead, in the WoW

Disregarding space	The child does not pay attention to the physical space while interacting with the character. The gaze is not directed toward the representation of the character or the features of the space. The narrative does not include any spatial elements (e.g. the child just answered the questions of the researcher but does not pay attention to the space).		WaSc: 7.6% WoWc: 36.4%
Ways of Using space	Space as a context	The child uses space as a context to set the story but does not explore the features of the specific space or use them to build their narratives. The character has a contextual relation with space but space is not used to enrich the narrative, e.g. the spaghetti-monster is located in the kitchen since it looks for food.	WaSc: 76.9% WoWc: 22.7%
	Space as a place for sensorimotor exploration	The child uses the features of the physical space to engage in a sensorimotor play by exploring its material features (e.g. explore how the character "fits" with different backgrounds, textures, etc.).	WaSc: 69.2% WoWc: 63.6%
	Space as a prompt for narrative improvisation	The child uses the features of the physical space as resources to enrich their narrative or engage with pretend play. They use the available physical objects to include a narrative turning point or to transform the available object into something else that fits with the purpose of the story (e.g. a cabinet becomes a secret cave).	WaSc: 38.4% WoWc: 36.3%

Table 1. Categorization of ways of using the space

condition, only 40% of them subsequently shifted toward other ways of interacting. In both cases, these shifts were mainly motivated by the relation established with the spectators who either physically interacted with the character (especially in the WaSc cases) or gave suggestions to the narrator. Instead, in the cases where any shift was observed, the rest of the group did not tend to participate.

On the other hand, the *use of space as a place for sensorimotor exploration* (69.2% of the children in WaSc and 63.6% in WoWc) presented a similar distribution between the two conditions. However, interesting differences between the kinds of exploratory physical play were observed. In WaSc, the sensorimotor exploration mainly related to exploring the features of the environment, i.e. projecting on their peers' bodies, exploring surfaces with different textures, projecting on different and unusual spaces (e.g. ceiling), etc. Instead, in WoWc, the sensorimotor exploration was initially encouraged by the appeal of the image framed and mediated by the camera (e.g. trying to do "nice" framing in a photography-like fashion). Only subsequently, the children started to explore the features of the environment (e.g. go to novel places). These differences pointed out how these two paradigms supported different ways of understanding space (i.e. the space as a place to play with or the space as a mediated image). Furthermore, these results highlight the fascination provoked by the segmentation and separating functions of the framing-screen [20].

Finally, 38.4% of the children in WaSc and 36.3% of the children in WoWc employed the features and stimuli of the space as prompts for including narrative turning points in their stories or to start pretend play. In both cases, this way of using space was strongly shaped by the competencies of the narrators and by the group interaction. Interestingly, in the WoWc, spectators mainly participated by giving verbal suggestions about the location or actions of the character. Instead, in the WaSc, their participation involved both verbal interactions as well as embodied interactions such as directly interacting with the character (e.g. shooting at it, playing with the projection using their bodies) or manipulating the environment (e.g. open a cabinet to allow the monster to steal things). This latter aspect suggests that, in the WaSc condition, the physical/digital space was perceived as actionable also by the spectators.

Shaping social relationships and co-constructing meaning

In order to understand how the two different configurations shaped unfolding social relationships, we focused on variables related to group movements (i.e. group disposition, group displacements and gaze) and on participation in their reciprocal narratives (e.g. verbal utterance, physical interactions, etc). This analysis was oriented toward exploring the different roles that spectators decide to assume during the interaction.

From this analysis, we identified relevant differences between the two conditions. In WaSc, almost all spectators (92.4% of them) tended to focus their attention on the narrator. The children tended to stand in a semi-circle around the narrator and followed her/him in all the displacements in the school. At the same time, the gaze of the spectators tended to move between the place where the character was projected and the child who was telling the story, showing several instances of joint attention behaviors.

Conversely, in WoWc, only 59.1% of the spectators paid attention to the narrator during the activity. In this case, the children also tended to stand in a semi-circle around the narrator and follow her spatial displacements. Nonetheless, some of them showed patterns of discontinuous attention toward the narrative of their peers. Specifically, they tended to get engaged or lost their attention depending on the narrative skills of who was manipulating the character. At the same time, 40.1% of the spectators explicitly showed patterns of disengagement from the activity of the narrator. In these cases, the children did not follow group displacements but tended to get engaged in other unrelated activities while their peers were interacting (e.g. talking about other topics, playing with something else, etc). In the WoWc, this behavior was often associated with narrators that did not perform narrative improvisation and disregarded the physical space.

These differences between the WaSc and the WoWs allowed us to identify different roles that spectators can assume during the activity. Specifically, the following roles were identified: 1) The distracted passerby; 2) The focused spectator; 3) The commenter; 4) The co-director; 5) The co-narrator; 6) The actor. A detailed definition of the different roles is described in Table 2.

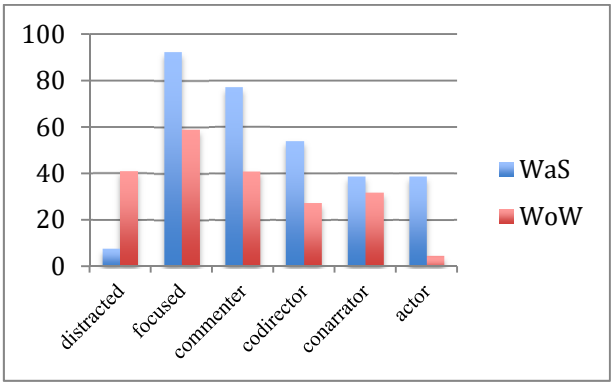

Figure 6. Distribution of ways of participating

As it can be noticed from the distributions of the different roles within the two conditions (summarized in Figure 6), the two paradigms may affect the unfolding social relationships and the instances for participation and co-construction of meaning.

Figure 7. Child playing with the virtual character in WaSc

Specifically, WaSc strongly drew the attention of spectators toward the activity of their peers. This allowed the digital content to become an object of shared interest that can scaffold different forms of cooperative play or social interaction. On the other hand, even if in the WoWc several instances of cooperative play were also reported, their amount was clearly much less compared to the WaSc. Furthermore, spectators' attention and participation was mainly driven by the specific skills of the narrator and not by the activity itself. In this context, it is particularly relevant to notice how in the WaSc, the presence of the virtual character in the physical space fostered physical interactions by the spectators with it (e.g shooting at him (Figure 7), trying to catch him, etc.), hence becoming a playable entity. Instead, in the WoWc, spectators' physical interactions with it were reported in only one case.

In relation to the presence of the character in the physical environment, it is also relevant to notice that, in five cases children in the WaSc also interacted with other passersby that did not belong to the activity (e.g. calling the attention of the school cook toward the character displayed in the kitchen, using a monster to scare kindergarten children, making a zombie attack to the teacher, etc.). Instead, in the case of the children assigned to the WoWc, no out-of-group interaction was reported at all.

To sum up, we can conclude that the two paradigms strongly shaped social relationships and possibilities for co-construction of meaning. In particular, the WaS paradigm offered interesting affordances to allow different degrees of participation both in terms of in-group and out-of-group interactions.

DISCUSSION AND FUTURE WORK

We presented two interaction paradigms for the design of ARMR mobile systems (the Window-on-the-World paradigm and the World-as-Support paradigm) and compared their role in shaping the usage and meaning-making of the physical/digital environment and in influencing social relationships in collaborative settings. Our results show that the two paradigms, applied in the design of the application "EspaiStory", afforded different ways of becoming engaged and inhabiting the physical/digital environment. At the same time, their differences shaped the social relationships and instances for participation and co-construction of meanings that occurred during the activity. These results, by exploring emerging ways of designing ARMR applications, bring forward the findings of [27] who showed that AR mobile-applications promoted different social and bodily configurations with respect to digital mobile applications.

Becoming engaged with the physical environment

Almost all children in the WaSc (92.4%) focused their attention on the physical environment and a high percentage of them (76.9%) employed it as a starting point for their stories. Instead, the children in the WoWc reported a much more scattered distribution. In our study, therefore, the WaS paradigm provided an easier entry path to support children's interest in the environment and to facilitate the task of employing the space to construct meanings. From a broad perspective, this affordance can suggest the potential of the WaS paradigm to design systems that require users to have an immediate engagement with and awareness of their surroundings and better take advantage of embodied interaction. Nonetheless, in both conditions, the relatively low percentage of the children that used the space as a prompt for improvisation (38.4 % in WaSc and 36.3% in WoWc) asks for caution on the limits of our design to

Distracted passerby	The child does not pay attention to the other. s/he becomes disengaged and does other unrelated activities.	WaSc: 7.6% WoWc: 40.9%
Focused spectator	The child pays attention to the other. Her/his attention is focused on the activity of the narrator child.	WaSc: 92.4% WoWc: 59.1%
Commenter	The child interacts with the narrator by commenting on aspects related to the character or location (e.g. "it is super fat!")	WaSc: 76.9% WoWc: 40.9%
Co-director	The child interacts with the narrator by giving suggestions on character actions or location (e.g. "put it in the shower!)	WaSc: 53.8% WoWc: 27.2%
Co-narrator	The child interacts with the narrator by enriching her/his narrative and directly refers to the action of the character (e.g. "and now the zombie goes to the elevator because he wants to eat the teacher")	WaSc: 38.4% WoWc: 31.8%
Actor	The child interacts with the narrator by actively interacting directly with the character (e.g. s/he stands in front of the character and shoots it with an imaginary gun)	WaSc: 38.4% WoWc: 4.5%

Table 2. Classification of ways of participating

facilitate the recasting of spatial elements through symbolic play and the exploration of the relation between what it is and what it could be [1]. This finding requires defining design strategies to more directly support make-believe play and test them across the two paradigms.

Inhabiting digital/physical environments

In both conditions, the children showed different ways of inhabiting and understanding the hybrid spaces provided by ARMR technologies. Specifically, in the WoWc, children's explorations were mainly tied by the appeal of the segmenting and selecting features provided by the frame of the screen. Therefore, space was perceived as a mediated image, a freeze-framed portion of reality. This specificity confirms the appeal of see-through technologies [10] and suggests potential design directions oriented toward explicitly exploring the act of framing as a source for meaning making in ARMR technologies. Furthermore, the idea of space as an enclosed portion of the environment could designate the WoW paradigms as a particularly appropriate approach in the design of ARMR applications that require users to focus on a specific spot. Finally, the use of the screen as a privileged place for interaction supports its suitability for tasks that require performing fine-motor manipulations.

Conversely, in WaSc, children's explorations were not tied to the act of partitioning the physical environment. Instead, they smoothly moved between different locations, accompanying their character through them. From a broad perspective, this finding may indicate that the WaS paradigm may be particularly appropriate to design ARMR applications that require a holistic understanding of the surroundings. Furthermore, in our case, the WaS paradigm, by constituting the body/space relation as the privileged place for interaction, supported the understanding of the physical space as a place where different users can engage in physical play with digital content. This broader accessibility and its social nature can offer relevant opportunities for ludic multi-user activities (e.g. augmented playgrounds).

Shaping Social relationships

In our study, the two paradigms affected the unfolding of social relationships and the instances for participation and co-construction of meaning. In particular, the WaS paradigm facilitated considering the digital contents as objects of shared interest and cooperative play (both physical and verbal). As a consequence, a higher amount of social interactions were reported. Our findings confirm the benefits of embodied interaction to support collaboration [24] and extend them to ARMR mobile technologies. Hence, from a design perspective, the WaS paradigm may be considered as particularly suitable to support collaborative tasks and shared construction of meaning. Possible fields of applications can be identified in the design of learning activities, public events or systems to foster interaction between strangers. On the other hand, children's reciprocal attention and interactions were much more limited in the WoWc. Hence, these findings may indicate that this system can be more suitable in the design of personal and private ARMR experiences, as opposed to group activities.

Limitations and future work

The study offered a flavor overview of the potential and affordances of the WoW and WaS paradigms. Nonetheless, to validate these findings, we need further research oriented toward applying these paradigms in different contexts and with different tasks. At the same time, the study presented some limitations related to the sample distribution and to specific methodological choices. First, the choice of forming the groups during the first day affected the overall distribution of children during the second session (many children assigned to the WaS condition were absent due to personal reasons). As a consequence, an unbalanced number of children used the two systems. Second, both our observation and a posterior interview with the teachers evidenced that the pupils presented important differences in their narrative competencies. This aspect points out the need to more carefully assess individual competencies in future studies. Third, in future research we need instruments to better evaluate children's awareness of spatial features (e.g. ask children to draw their experiences). Finally, future studies should address the analysis of the perceived presence of the virtual elements and evaluate how enabling different forms of embodied interaction in space may affect children's understanding and play.

CONCLUSIONS

In the paper, we proposed the concept of the World-as-Support (WaS) interaction paradigm to address the rise of emerging approaches to design ARMR applications for mobile technologies. We contrasted the affordances of this paradigm in mediating and shaping the understanding of the physical/digital world by users and in influencing social relationships. This analysis was carried out by comparing WaS with the Window-on-the-World paradigm (WoW) on an application aimed at supporting children in authoring a site-specific narrative. Our experimental results suggest that the WaS paradigm promoted a higher level of engagement with space and afforded a larger amount of instances for shared meaning construction and embodied interaction, compared to the WoW paradigm.

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