Environmental Visualization and Exploration in Mobile Augmented Reality Games: Redefining the Spatial Affordances

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Abstract. While spatiality in desktop and console interface video games has been widely studied, not many approaches have been made in the context of mobile augmented reality (MAR), an environment from which popular games such as *Pokemon Go* have emerged. On the one hand, this paper retakes the notion of spatial affordance that Janet Murray introduced for digital environments and proposes a reinterpretation of the concept throughout the integration of the MAR features. On the other, it seeks to approach the impact that these characteristics have on the gameplay experience. For this purpose, 46 mobile augmented reality video games of different genres were analyzed. The study reveals that augmented reality is still a superfluous element rather than a central aspect of the gameplay in most MAR video games, although trends involving new hybrid game experiences have been observed. Finally, we propose a tool for classifying MAR video games according to two axes that assess up to what extent physical space is integrated into the gameplay: gameworld spaces (representational layer) and gameplay spaces (interactive layer, interaction with the game rules and mechanics).

Keywords: mobile augmented reality, game studies, spatial affordance, visualization, 6DoF, gameplay experience.

1 Introduction

Mobile Augmented Reality (from now on, MAR), understood as the real-time combination of physical and virtual elements on a mobile device (smartphones, tablets, handheld game consoles, etc) is one of the most popular and accessible manifestations of augmented reality [1]. MAR involves new ways of experiencing space through hybridization of the analog and the digital [2]. It also affords interactivity, most often through six degrees of freedom (hereafter, 6DoF), understood as the freedom of movement in three-dimensional spaces [3].

While spatiality in fully digital video games has been a widely addressed topic, not much research has been done regarding the spatial affordances in MAR video games. The hybrid and ubiquitous nature of MAR games motivates us to study in more depth the spatiality, as well as its relationship with gameplay experiences. In this paper we make an approach to the spatial affordance in the context of MAR and study its integration into the gameplay experience. In the first sections of this work we review the approaches that have been made so far to augmented reality and the notion of spatiality, hybridization and ubiquity in video games. After that, we detail the goals of the research and the methodology employed, as well as the most meaningful observations of our analysis. Finally, we address the main contributions of our study, as well as possible limitations and future steps to be taken.

2 Theoretical and Technical Approaches to MAR

From the canonical definition of Azuma et al. [4], augmented reality environments were defined as interactive systems that not only combine physical and virtual elements, but must also have a three-dimensional real-time register. This definition has been maintained by the specialized literature throughout its more than two decades. In addition, and as we address in this article on MAR, in these environments the augmented image is executed and/or displayed on a mobile device [1].

Because this hybridization of augmented environments does not always occur with the same degree of virtuality, Milgram and Kishino [5] proposed the mixed reality continuum. The continuum established an intermediate stage between our physical reality and virtual reality environments. Augmented reality lies in between, and consists of inserting computer-generated graphics into our physical space, resulting in an enriched view of our surroundings.

Merino et al. [6] systematically reviewed the trends in papers on augmented reality during the last ten years in the main scientific events on this technology. They found that a large part of the research still assesses technological issues for the implementation and evaluation of AR scenarios. But currently there is also a growing and important trend focused on the users that participate in these environments, as well as on the evaluation and observation of the augmented environments that have also been the subject of our study.

Our work addresses specific issues of augmented reality environments such as tracking (enabling the correct superimposition of computer-generated graphics in a physical context), rendering (recognition techniques), calibration and registration (alignment of 3D virtual objects in a physical context in real time), display (augmented image display device), software tools, user interfaces/interaction (tangible, collaborative, visual, audio, haptic....), 2D and 3D data visualization and/or perception methods, among others [7][8][9].

Finally, when focusing on MAR video game applications, it is necessary to consider that there are some particularities determined by the use of portable display devices: smartphones or portable consoles. These particularities, following Siriwardhana, et al [10], are related to the ubiquity of augmented reality experiences, the computational capacity limited by the devices, the excessive battery consumption, the primordial need for an ergonomic and functional design, or, the presence of random external conditioning factors (light, noise, etc.).

3 Spatial affordance in the context of MAR

In her work on the affordances of digital environments, Murray [11] identifies spatiality, and describes it as the power to represent navigable, enactable and traversable spaces. Linear media such as books and films can show a space through verbal description or image, but only digital environments can present a space through which we can move or perform spatially.

We consider that the hybrid property of augmented reality, coupled, on the one hand, with the particularities of mobile devices as drivers of ubiquity and, on the other hand, with the specificities of the video game as a medium, make it necessary to review the notion of spatial affordance.

3.1 The hybrid property of augmented reality

Augmented reality allows physical and virtual space to intertwine through two main processes: spatial tracking and spatial sensing [2].

Spatial tracking is the process by which the (visual) scene adjusts to the user's movements. To accurately track the user's movements in space, augmented reality systems need to track the six degrees of freedom. 6DoF is known as complete freedom in terms of orientation (along the three axes of pitch, yaw and roll) as well as motion, keeping the orientation fixed (forward or back, to the right or left, up and down) [3].

On the other hand, spatial sensing encompasses the ability of computer vision software to enable mobile devices to "understand " what the embedded cameras see (from surfaces such as walls and floors, to furniture, people and other objects in a particular space). This combination of hardware and software processes has facilitated the development of techniques such as Simultaneous Location and Mapping (hereafter, SLAM). Through this technique, features of the physical space (composition of surfaces, depth, lighting conditions) are used to build in real time a map of the world around the user, so that it is then possible to track the user's pose in relation to the map [12][13].

6DoFs, in this context of tracking and sensing, allows redefining the user's point of view, as the user has control over what she sees. The point of view is generally continuous, allowing the visualization of cutscenes (traditionally considered as the non-interactive sequences of video games) and gameplay sequences from a pose (orientation, position) that the player can change at will.

Unlike fully digital environments, augmented reality can take advantage of the properties and affordances of physical reality such as multisensoriality, as opposed to ocularcentrism [14] and subordination to the laws of physics [15].

As a result of these possibilities, different studies have highlighted affordances of augmented reality linked to spatial hybridization, tracking, sensing and 6DoF. Following Scolere and Malinin [16], augmented reality-mediated hybrid spaces can change the way we perceive the environment by adding virtual information into physical elements (technological and functional affordance). It also can lead to new behaviours and practices (communicative affordances) and act as signifiers highlighting non-obvious possibilities for use and action of the space (hidden affordances) or potential opportunities for action that do not still exist (imagined affordances). According to Steffen et al. [15], linked to tracking and sensing is the possibility of enhancing the positive aspects of the physical environment. On the other hand, there is the affordance of recreating objects by reducing costs and risks. Steffen et al [15] also highlight the possibility of transporting imaginary or implausible elements to the real world (for example, phenomena that do not work under the laws of conventional physics, or fantastic characters and objects in applications of narrative components).

In relation to the 6DoF, the possibility that augmented reality brings to visualize and interact with objects with movements from multiple perspectives is highlighted, both for processes linked to learning and education [17] [18] and to video games [19][20]. While in mobile augmented reality video games touch gestures on the screen allow for easier use, the 6DoF and the visualization and traversability that comprise interactions with 3D spaces through movement make the experience more engaging and offer a better gaming experience [20]. Table 1 lists research that has addressed the affordances of augmented reality in different research fields.

Table 1. Research carried out so far on the affordances of augmented reality.

Affordances	Scope	Authors
Changing the perception of the physical environment adding information to physical elements. Lead to new behaviors and practices. Highlight hidden affordances (signifiers). Test out new ideas or adjustments to the physical space.	Interior Design	Scolere and Malinin (2023)
Decreasing the negative aspects of reality. Enhancing the positive aspects of reality. Recreate existing aspects of the physical world. Create aspects that do not exist in the physical world.	Management information systems	Steffen et al. (2019)
3D visualization. Visualization of what would otherwise remain invisible. Contextualized information. Interaction with specific locations.	Education	MacCallum and Jamieson (2017)
Situated learning. Integration of digital artifacts that can be collaboratively created, shared and explored. Interacting and engaging with 3D digital objects from multiple perspectives.	Education	Bacca et al. (2014)
Visualization Traversability	Gaming	Shin et al. (2021)

3.2 Mobile devices and ubiquity

One of the most popular manifestations of augmented reality is its integration into experiences anchored to a single location. The fixed linkage of virtual content to physical space occurs primarily in three ways. On the one hand, there are experiences designed to be played in the context of specific cities through markers, such as the *Wayfinder Live* game [21] , which was originaly accessible in Melbourne and exported to the city of Tampere. On the other hand, some experiences are linked to an artificial space built as a fixed stage in which to offer the augmented reality experience. An example of this is the AR adaptation of *Façade* [22], deployed in an installation that recreated on the physical plane the apartment of the couple in the video game. Finally, there are AR experiences that can only be experienced in a space because of the load of meaning and sense that it brings because the physical space is already emblematic in itself. This is the case of *110 stories*, an application that allows us to visualize the outline of the Twin Towers in the area where they were actually located before the 9/11 attacks.

The distinction between space and territory is relevant in this context [23]. While space refers to a bounded or geographically delimited place where three-dimensional objects are arranged, territory is a space endowed with sociocultural and symbolic relations with a subjective, ideological character and full of semantized objects (sociocultural space metaphorically and metonymically).

Beyond these cases, the ubiquitous capacity of mobile devices, thanks to SLAM, means that MAR can be deployed in multiple sites, detaching the content from a specific space, so that each space will bring a number of particularities to the hybrid experience [24].

3.3 Approaches to spatiality in video games

Spatiality has been extensively studied in fully digital video games with desktop or console interfaces [25][26][27][28][29]. These studies highlight the linkage and interaction of the user with virtual elements (point of view), the spatial representation (X, Y and Z axes, 2D or 3D graphics and movements) and its impact on gameplay, differentiating the gameworld space from the gameplay space.

On the one hand, the gameworld space is understood as the spatial dimensions represented in the game, whether or not it is possible to interact with them. Beyond navigation, interaction and spatial representation, we consider gameworld spaces are closely related to the sensory (mainly visual) and narrative layer of the game, and to the way the fictional world is shown to the player in spatial terms.

On the other hand, the gameplay space refers to the dimensions in which it is possible to play (interact with the game rules and mechanics) in terms of movements and rotations along the X, Y and Z axes (Table 2). However, spatiality in MAR environments has not been addressed in the same depth.

Table 2. Main concepts of navigation and interaction of the user with virtual elements, together with spatial representation and its impact on gameplay.

Concept	Definition	References
Spatial representation	How the space is displayed to the player.	Fernández-Vara and Zagal (2005), Aarseth (2007), Azémar (2007).
Graphics: 2D and 3D	Technical properties of the video game graphics.	Boullón (2009).
Point of view and complexity of space	Scope of the game world space, and how the player accesses the game world.	Nitsche (2008).
Gameworld space	Spatial dimensions displayed in the game. Sensory and narrative layer of the game.	Fernández-Vara and Zagal (2005), Azémar (2007), Boullón (2009).
Gameplay space	Spatial dimensions in which the gameplay is developed, in terms of movements and rotations.	Fernández-Vara and Zagal (2005), Azémar (2007), Boullón (2009).

Tracking, 6DoF and sensing are essential to the aesthetics of AR [2], and to define the experiences that this new medium offers. These characteristics give rise to a space in which digital elements become dynamic and responsive to the user. Previous studies have pointed out that these aesthetics should integrate, in addition, new gameplay possibilities [30]. That is, physical elements should be integrated into gameplay spaces to elicit new hybrid experiences.

The following diagram shows the main issues assessed as far as hybridization, ubiquity and game spaces concerns, and the conclusions drawn in terms of the spatial affordance in augmented reality devices and applications and games (Figure1):

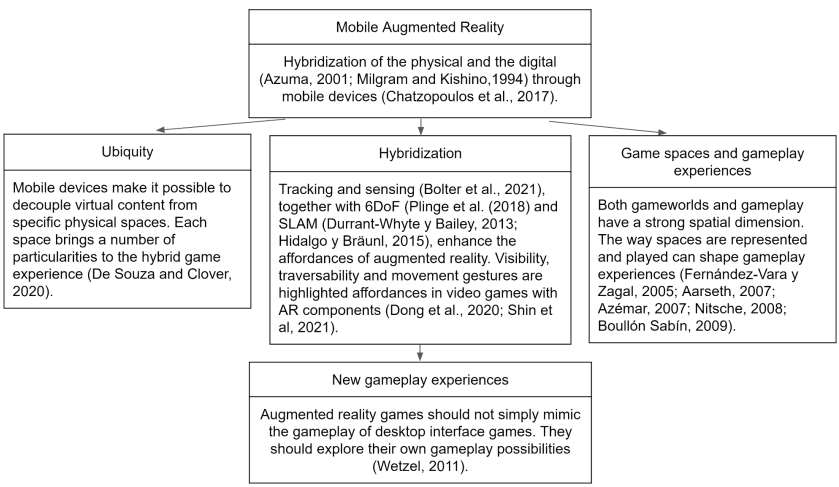

Fig. 1. Conclusions drawn from research conducted in the area of spatiality in augmented reality and games.

4 Research goals

AR presents particular and unique possibilities in the way we learn, perform tasks and interact with the environment [15]. However, the question also arises as to whether AR and its spatial dimensions afford new game experiences and aesthetics. To answer such a research question, we propose to address the following research goals:

- Providing a notion of spatial affordance for mobile AR video games that allows game designers and developers to adapt to new interfaces and emerging technologies.
- Testing whether the physical environment can function as a gameplay space (traversed by analog, digital, and symbolic components).
- Identifying the differentiating elements that spatial affordances bring to the game experience (with respect to desktop or console interface games).
- Comparing the use of spatial affordances in different gameplay experiences in MAR video game cases.
- Identifying the degree to which MAR video games take advantage of the physical-spatial elements with respect both to gameworld and gameplay elements.

5 Methodology

After an extensive bibliographic review [31], we found that there few updated contributions in the field of spatial affordances in MAR. Although, as we have seen above, the production of theoretical approaches has been very fruitful and prolific, there are hardly any empirical proposals that attempt to trace or map the dimensions and particularities of this type of affordances in MAR video games.

At the methodological level, the proposed objectives involve serious technical challenges and require a digital and mixed methodological perspective [32][33], both in method (quantitative-qualitative) and in scope or field of observation (we transit between diffuse realities and imbricated spaces where the analog, digitized and symbolic permeate).

As a research path, we started from the existing theoretical proposals or classifications [11] [19], as well as from a taxonomy developed by the authors in a previous exploratory study [31], in order to serve as a guide to orient, delimit and frame our object of study. First, we proposed an exploratory participant observation with a double objective: i. to empirically test its functioning and serve as a basis for inquiry and ii. to detect the existence of limitations or relevant dimensions of spatiality that we believe can be more deeply investigated.

Regarding the previous taxonomy developed, we started from the concept of affordance proposed by Murray [11] and the four properties that she points out about the digital medium. As a main contribution, we added a fifth property which we addressed deeply (social-emergence affordances). Table 3 shows a summary of the taxonomy of affordances assessed so far.

Table 3. Summary of the taxonomy of augmented reality affordances in the context of gaming, based on Murray's four properties of digital environments, previous research on augmented reality and direct authors' observations.

Kind of affordance	Description	References
Spatial affordances	Exploration of hybrid environments and objects from multiple perspectives through movement gestures. Adaptation of virtual objects to the context (climate, season of the year of the space in which the AR game is played). Visualization of additional information that would otherwise remain invisible.	Murray (2012), Bacca et al. (2014), MacCallum and Jamieson (2017), Steffen et al. (2019), Shin et al. (2021), Scolere and Malinin (2023)
Participative affordances	Manipulation of the represented world.	Murray (2012).
Encyclopedic affordances	Containing high capacity of information in augmented reality formats.	
Procedural affordances	Consisting of executable rules and code.	Murray (2012)
Social and emergence affordances	Cultural emergence (non-expected uses, reappropriation, user-generated content). Social, material and technical restrictions (negative affordance). Social stereotyping (negative affordance).	Puente Bienvenido et al. (2022).

However, on this occasion, not only do we adopt a different focus (spatiality), but in the current proposal, the sample size and configuration are larger, more systematic and operational; and, in addition, the sample is segmented by videoludic experiences (allowing for comparative and more in-depth analyses).

Regarding the fieldwork design, we selected and played between 2012 and 2022[1] a sample of n = 46 video games for mobile devices with augmented reality components. The composition of the sample was mainly based on three different selection criteria to ensure a diverse and structurally representative inclusion [34] based on social dissemination criteria operationalized as; i. number of total downloads that the games have had (n=20); ii. average rating obtained by the video game in download platforms (n=10) Google Play Store and App Store and; iii. visibility in specialized media of informative nature (n=8). Likewise, the final sample was complemented with the additional inclusion of some video games by purposive sampling (n=8) [35]. The latter were selected for their great research interest by incorporating differential elements related to spatial affordances, and more specifically, to the possibilities of visualization and interaction with objects from multiple perspectives. In addition to playing the

[1] Ingress Prime is described as an AR video game although it was disregarded in our study by not finding this technology in the game mechanics.

games, we also viewed gameplay videos and streamings on YouTube and Twitch platforms to enrich our observations.

Once the sample was configured and while participant observation was being carried out (6 months of fieldwork), we proceeded to classify the video games based on an emerging sample segmentation according to the predominant gameplay experience (Fig. 1):

- Board games: video games that recreate the mechanics of board games, such as tower defense or miniature combat games, in which the virtual content is anchored on a flat physical surface. The titles analyzed are: *Balanced Tower AR; Smash Tanks! - AR Board Game; Ticket to Earth; Conduct AR! - Train Action; Stack AR; Knightfall AR; Domino World AR; Genesis Augmented Reality*
- Puzzle: while escape room games propose puzzles in a figurative sense, puzzle video games propose puzzles in a literal sense. The main objective is to recompose figures that are divided into pieces that are out of place, or to reorganize objects or spatial structures in order to unlock progress processes in the game. The titles analyzed with: *Splitter Critter; Amon; ARise.*
- Precision shooting: video games in which the main mechanic consists of launching projectiles from a distance towards characters or objects in the environment, testing the ability to aim. The main theme on which this mechanic is developed is usually warfare, or that which involves eliminating enemies by means of ranged attacks. However, this mechanic is also typical of precision games, such as targets, for example. The titles analyzed are: *Zombie Gunship Revenant; Five Nights at Freddys AR: Special Delivery; Ghostbusters: Afterlife ScARe; Nightenfell: Shared AR; Reality Clash: AR Combat Game; ARGun; Angry Birds AR: Isle of Pigs; The Walking Dead: Our World; RealTag | Multiplayer AR FPS; Black Snow AR: Alien Shooter; Kings Of Pool: Online 8 Ball; AR Dunk : Augmented Reality Basketball Game; AR Basketball Game - Augmented; Father.IO AR Laser Tag*
- Environment exploration / escape room: games in which the main mechanics consist of overcoming a challenge by solving riddles. Solving the riddle involves interacting with different virtual objects distributed in space. The titles analyzed are: *dARk: Subject One; Ghost Phone; The DC: Batman Bat-Tech Edition; Mario Kart Live Home Circuit*[2] *; Temple Treasure Hunt; A&E Crime Scene: AR; Jurassic World Alive; Zombies, Run! 1; Zombies, Run! 2*[3]
- Combat / melee battle: focused on the management of a character giving powers, using magic items or weapons. Unlike the shooter, the mechanics involve melee or close-range combat. The titles analyzed are: *Star Wars: Jedi Challenges; The Machines AR; Warhammer 40,000: Freeblade; AR Robot;*

[2] Although *Mario Kart Live Home Circuit* is a racing game, one of the main gameplay experiences is the players' construction of the tracks and physical environments.

[3] Although our sample included both versions of Zombies, Run! in our study they have not been considered since they are based solely on sound augmented reality experiences.

Cosmic Frontline AR; Kazooloo DMX - AR; Pokémon GO; Harry Potter: Wizards Unite; The Witcher: Monster Slayer.

- Pet simulator: emphasize the link between the player (in the role of caregiver) and the character (in the role of pet). Titles analyzed with: *My Tamagotchi Forever; AR Dragon; Pikmin Bloom.*

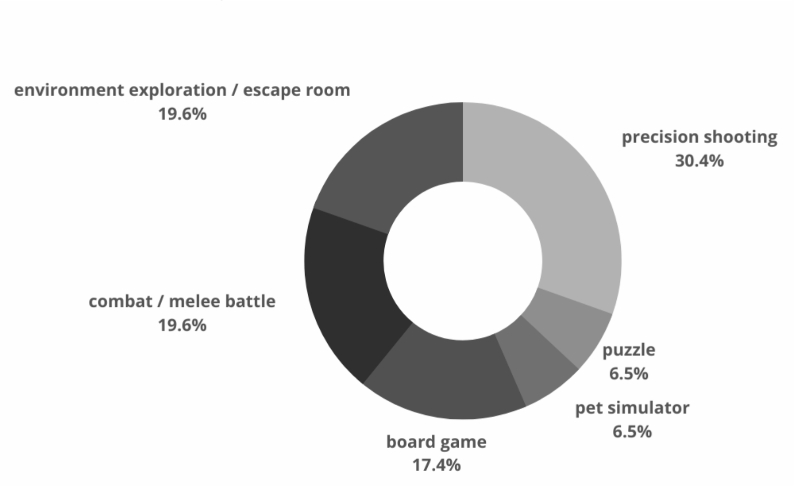

Fig. 2. MAR video game classification according to the predominant gameplay experiences and representation in percentages of the total sample.

Within categories such as shooting and combat we have included games that are more popularly known as geolocated games. The reason why we have put them in different categories is that the AR modes that these games enable encompass mechanics whose dominant experience has more to do with hunting or attacking characters.

The process of classifying the video games into different categories has been carried out considering the dominant experience in them as an assignment criterion. Although a video game can have features of different categories, we have segmented the sample considering which is the most outstanding experience in each one of them.

Despite the biases and limitations derived from not being a probabilistic sample, this is a very significant contribution as it operates as a large descriptive and analytical map or overview, given that most of the empirical approaches in the scientific literature have been carried out through case studies [19] or very small samples. Thus, we have designed a mixed methodological approach with a macrostructural focus that allows the systematic tracking and comparison of a subtype of spatial affordances as a function of videoludic experiences.

The next step consisted of testing and observing each of the MAR video games that had been collected and classified in the sample according to the spatial affordances that appear in the literature considered as the basis of our study and discussed above.

In order to achieve a better analysis of the aforementioned spatial affordances, we have resorted to the notions of gameworld space and gameplay space, which have been widely and systematically studied in the field of video games [25][29].

6 Analysis

6.1 Board games

Video games that mimic the board game experience are mostly characterized by the mapping of a flat surface on which the game's virtual scenario must be positioned and anchored. Except for this base surface, the surrounding physical space is shown as an accessory that does not interfere neither in the gameworld (representational, sensory and narrative layer) nor in the gameplay space (interactions with game rules and mechanics).

As for the players' relationship with the board game space, the possibility of interaction and linkage with the virtual graphics from multiple perspectives (6DoF) is offered, although it does not necessarily represent a variation in the game mechanics nor represents a variation in the players' movement which is static in imitation of their analog counterparts.

As an isolated case, we find *Balanced Tower AR*, where the *Jenga* game is played with a tower of blocks on the X and Y axes, offering a 2D visualization similar to two-dimensional video games, somewhat paradoxical considering the game mechanics that consists of removing the blocks from different angles of the tower. In this sense, the AR version offers limitations with respect to its analog version as it does not explore the potentialities of an augmented environment.

On the other hand, video games that imitate the board game experience include the use of a third-person camera or point of view, as in *Ticket to Earth,* or the use of a zenithal camera, as in *Knightfall AR*. The former reproduces a board with squares that are occupied by avatars of each of the players, while *Knightfall AR* represents a miniatures strategy game in a game scenario similar to the "warhammer" experience where the zenithal view of the entire board or game scenario simultaneously is fundamental for the players.

Regarding the AR visualization of board games, we find some features that participate in the game dynamics. Thus, the use of graphic elements that guide, determine or condition each of the moves is decisive, for example, in *Domino World AR*. This game consists of building rows of dominoes that fall sequentially from the first to the last. Here a series of arrows and lines guide the construction and position of the dominoes on the table in order to knock them down completely. This case demonstrates that gameplay options in an augmented space can be expanded by the use of added virtual elements that offer a more dynamic and interactive experience.

6.2 Puzzle games

To facilitate space exploration, 3D puzzle MAR games offer free camera movement and allow movement from multiple perspectives (6GoF). This is fundamental to *Amon* and *ARise,* where this freedom of navigation through an AR environment is significant within the game mechanics. *Amon*'s gameplay experience consists of a sculpture fragmented into multiple parts that relies on viewing perspective, screen orientation, and player movement to combine 3D puzzle pieces.

In a very similar way, in *ARrise* we find a fragmented game scenario through which a virtual character has to walk. This character only manages to advance and overcome the different levels with a correct alignment of each of the parts of the stage. Specifically, in the case of *Amon*, the visualization of the physical scenery is complementary to the puzzle narrative, offering a hybrid image of the game scenario. Although this is not determinant for the game mechanics in any of the cases discussed.

As an exceptional case, in *Splitter Critters* (AR mode), we find a 2D display mode that limits movement to the X and Y axes, similar to two-dimensional games. Here the setup does not require the player's movement through the surrounding space to get through the levels and, in short, the possibilities of an AR environment are not explored.

On the other hand, the ubiquity characteristics of AR video games allow playing in different scenarios (indoors and outdoors). Although there is no meaningful correspondence between computational graphics and the image of the physical environment in puzzle-like experiences. Especially, we do not find it in the case of *Amon* where the visualization of a hybrid image generates discordant effects of scale or realism between the 3D sculptures and the image of the scenery.

6.3 Precision shooting games

Regarding the category that includes the experience of precision shooting, the interaction and visualization of 3D objects from multiple perspectives is especially relevant. These are video games where the space of traversability is usually expanded [19]. The possible trajectories and the level of difficulty of approaching 3D objects are very present elements when shaping the game experience, enabling movements in the X, Z and Y axes (6GoF), although with some exceptions such as during the fights in *Five Nights at Freddys AR*. The camera point of view is predominantly first-person to favor immersion. In terms of visibility, they use a combination of physical and virtual elements to generate all kinds of barriers and obstacles that can be used as protective parapets, strategic visibility or shaping labyrinthine experiences.

However, in all the games analyzed in this category, both the interface and the various virtual objects operate as totally opaque layers that are superimposed over the physical space, preventing visibility through them and posing a certain danger of accidents (crashes, falls, etc.). For example, in *Zombie Gunship Revenant* navigation occurs most of the time, except for the part where you hunt the creatures over a virtual environment. Moreover, the purple filter simulating a thermal vision camera does not allow visibility of any element of the analog space and, at the same time, the visibility of the available virtual elements is also very restricted. There are also no warnings or advice about not entering dangerous areas while in contact with the game, but it does warn before starting the game that you will need a large space and on a smooth surface to play.

The case of *Ghostbusters: Afterlife ScARe* is also significant. In this game the design of the ghosts simulates a translucent appearance (spectral aesthetics), but, in reality, they are objects that do not allow any visibility through them. Likewise, in some situations, the objects that emerge on the screen (such as towers) occupy almost all the space, which also makes visibility tremendously difficult (despite the fact that several objects adapt their size to the physical space available in which the game is played).

In general, this kind of games encourages low visibility (from extreme cases of very low visibility such as *Reality Clash* to others with a higher degree such as *Next-generation Black Snow AR* or *Angry Birds AR: Isle of Pigs*), but high traversability [19] (with numerous possible trajectories that allow shooting objects through space, possibility to travel long distances and with different degrees of difficulty in approaching 3D objects).

6.4 Environment exploration / escape room games

The category environment exploration / escape room includes all physical and mental adventure games that consist of exploring, solving enigmas and overcoming challenges where interaction -and in some cases the co-construction of the environment- are central elements of the experience.

As in precision/shooting games, in this category the walkability through space tends to be very high, favoring exploration and interaction with the multiple virtual objects available (and even with physical objects as in the case of *Temple Treasure Hunt*). These games maximize the use of space and mobility through the environment (X, Z and Y axes), allowing the approach, interaction and visualization of 3D objects from very different trajectories and perspectives (6DoF), both during game sequences and with cutscenes (as is the case of *The DC: Batman Bat-Tech Edition)*.

Usually, numerous interacting elements are embedded in the spatial margins, offering a more complex and augmented hybrid experience (the backgrounds and boundaries of the game area are exploited from the narrative and, rarely, mechanically).

While in the case of precision/shooting games visibility was limited, environment exploration/escape room games tend to be more diaphanous and different techniques are used to enhance the sensation of exploring the secrets of the territory. For example, in the cases of *dARk: Subject One* and *Ghost Phone*, the ghosts are composed of translucent virtual layers that allow an elevated view of the physical space, avoiding being isolated in the virtual environment and the possibility of accidents. However, the integration of virtual and physical objects, occasionally causes dissonant effects that detract from the experience (compatibility, realism, scale, ect.). Besides, although they tend to use some filters such as green or blue light that sometimes make it difficult to see the analog space, it manages to enhance the immersion (strangeness, ghostly space, tracing traces of blood in *A&E Crime Scene: AR...*).

A special case in this category is *Mario Kart Live Home Circuit*. While most of the games in this category allow the first-person point of view, this Nintendo Switch video game is accessed through a third person camera to control the character who drives. Apart from this feature, this game actually integrates physical elements (from analog cardboard circuit goals that function as markers, to elements of the furniture of the space) in the gameplay space, shaping the game levels and the different obstacles of the circuit. That is, physical elements are integrated into the interactions the player performs with the game rules and mechanics.

6.5 Combat / melee battle games

Regarding combat video games, it is necessary to differentiate between video games in which the user controls a character that can be visualized and those in which the point of view is in first person. Video games in which the player controls and visualizes his own character during combat, such as *AR Robot*, allow observation and interaction with characters and objects from multiple perspectives, although this option is purely aesthetic, as it is not decisive for the configuration of game strategies. Visualization and exploration is not critical to progress in the game. These are games that simulate the mechanics and dynamics of fighting video games with more conventional interfaces in which the objective is to eliminate an opponent by means of different attack strategies and having as feedback the life bars of the characters to know their status and level of progress.

As for the first-person combat enabled by the AR modes of *Star Wars: Jedi Challenges* and geolocated games (hunting pokemons in *Pokemon Go*, or fighting enemies in *Harry Potter: Wizards Unite* or *The Witcher: Monster Slayer*), in most cases the player is not allowed to visualize and move around the environment with complete freedom. The player has to remain motionless and face her opponents or prey head-on, limiting himself to launching attacks by means of weapons, potions or spells. The exception to this mechanic is *Pokemon Go*. Prior to combat, the player is given the possibility to explore and visualize the environment in multiple directions, while the first objective, in the hunting process, is to find out in which corner the pokemon is going to appear. Once the pokemon appears, the possibility of visualizing and interacting from multiple perspectives is restricted, but, unlike the rest of the geolocated video games analyzed, the player retains the possibility of moving on the Z axis. This movement is essential in the game's combat mechanics, and is part of the challenge, as it corresponds to the degree of physical distance the player/hunter maintains with the pokemon/prey. If the player gets too close to the pokemon, it will run away scared and the player will not be able to hunt it.

On the other hand, it is important to note that 6DoF is allowed in these games in non-core game mechanics other than combat. For example, in the video games analyzed in AR mode, it is possible to view the characters from multiple perspectives and take photos of them integrated into real environments. Therefore, it is a photographic composition mechanic, which has little to do with the central mechanics of the game and its progress.

6.6 Pet simulator games

With respect to the virtual pet video game category, exploration and viewing from multiple angles is not part of the core game mechanics, although it can serve to emphasize certain features of the game experience. In *AR Dragon,* actions such as feeding can be performed by scrolling food from the menu to the pet, via the Z-axis. The 6DoF are not locked, the user can move around the scene, but will not be able to see his pet from different perspectives. The pet, unlike other objects that retain their pose (orientation and position), will vary its position to maintain visual contact with the player (its caretaker).

Differently, in *Pikmin Bloom*, it is possible to visualize the pikmins (plants in the process of flowering) from multiple perspectives. One of the premises and objectives of this game is to encourage the action of walking around the city by making the walks more pleasant by means of plants (the pikmins). The player is responsible for this process, and it is considered rewarding for the player to be able to visually appreciate the evolution of the plant.

7 Discussion and results

In relation to spatial affordance in MAR environments, we propose to extend Murray's definition [11] so that we can integrate three essential aspects: the hybridization of analog and digital [2], the ubiquity of mobile devices [10], and the possibilities of enhancing gameplay experiencies beyond replicating those of fully digital video games with desktop interfaces [30].

Beyond "representing" navigable, walkable and enactable spaces, the spatial affordance in MAR environments should integrate the opportunity to:

- "scan" and "understand" physical spaces and their features (shapes, volumes, surfaces, lighting conditions);
- "synchronize" these spaces with virtual objects; and,
- "track" the relationship that the user maintains with the hybrid space composed of physical and virtual elements.

We consider that this affordance is not fully exploited if the tracking does not allow the 6DoF, and if the synchronization of the virtual layer with the characteristics of the analog environment does not integrate the physical space into the gameplay experience, neither at a representational, sensory or narrative level (gameworld space) nor at a mechanical level (gameplay space).

The analysis carried out on the sample of 46 video games allows us to affirm that most of these titles do not take advantage of the spatial affordance, because the gameplay takes place only in the virtual layer. What visually provides us with a very attractive image, does not participate in the gameplay in a meaningful way. We can therefore consider that MAR video games do not take advantage of the potential of augmented environments and unnecessarily overload the computational tasks of mobile devices.

There are some exceptions such as *Mario Kart: Live Home Circuit*, where physical objects can be used in the configuration of the race track. The driver and the car we drive will react to contact with analog elements such as parts of furniture and surfaces. Thus, it is an example to follow for MAR video game proposals.

With regard to the possibilities of visualization of 3D objects, the vast majority of the video games analyzed in the sample offer freedom of orientation (linked to freedom of camera movements) and movement (6DoF). These features are essential in games such as the 3D puzzle *Amon,* which relies on the exploration of space and camera perspective to solve each puzzle.

In general, a lack of correlation has been detected between the virtual graphics and the varying external factors (weather conditions, day/night scenarios, indoor/outdoor environment, etc.), which offers an unrealistic and less immersive image. Here, we highlight *The Witcher: Monster Slayer*, in which different creatures appear depending on whether the user plays during the day or at night, and the weather.

The point of view is fundamental in many of the video game categories analyzed. There is a predominance of first-person view in precision shooters or space exploration/escape room games. In these categories, player visibility is essential to achieve a more visually immersive experience. On the other hand, third-person view has been highlighted in categories such as board games or combat. We consider that in this type of game experience it entails a visual concept in which each player must identify with a characteristic avatar of personified roles.

It has also become evident that three-dimensional graphic representation is essential in all categories, although we found two cases of 2D visualization corresponding to board and puzzle games. Although they aim to be faithful to their analog versions, the potentialities of a 3D space can offer new gameplay experiences not yet explored.

With regard to identifying in which type of video games the physical-spatial elements go beyond representational, sensory and narrative uses, we consider it is necessary to think about the different ways in which these elements are integrated into the game experience.

As an original contribution, we propose a continuum tool for classifying MAR video games according to two observation axes related to the level of use they make of physical space (Figure 3). The first axis represents the extent to which the physical space becomes part of the gameworld, and the second axis refers to the integration of the physical space into the gameplay (experience that emerges from interaction with rules and game mechanics).

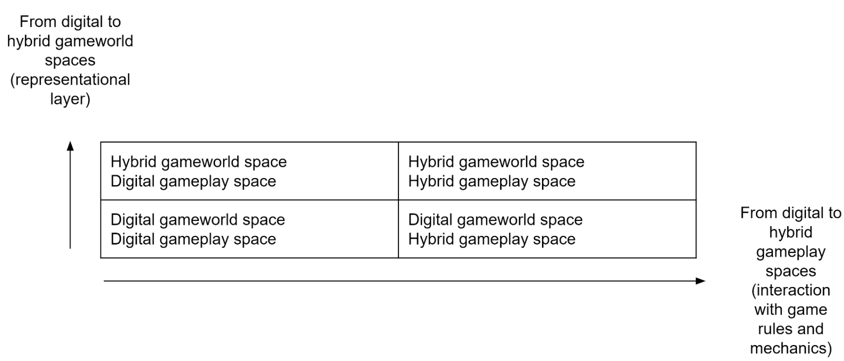

Fig. 3. Continuum tool for classifying MAR video games according to two observation axes related to the use they make of the physical space.

Also, as part of our contributions and results, we show a division on MAR video games according to the level of integration of the physical space into the game experience, and to how this contributes to create new hybrid experiences:

- Digital gameworld space + Digital gameplay space: games in which physical space is merely an anchoring surface for 3D objects. Some video games technically classified as MAR do not make use of the potential of hybrid spatial affordance, as the gameworld remains exclusively digital. Thus, physical space does not operate as an representational, sensory, narrative or gameplay element, but only as a technical resource: *Balanced Tower AR; Conduct AR! - Train Action; Kings Of Pool: Online 8 Ball; or Ticket to Earth*.

- Hybrid gameworld space + Digital gameplay space: games in which the physical space becomes part of the gameworld. Player's visualization and interaction (spatial representation and player freedom of movement) support the narrative experience: *Ghost Phone* or *AMON*.
- Hybrid gameworld space + Hybrid gameplay space: games in which physical space is part of the gameplay space. In this case, physical space operates centrally to represent part of the gameworld, and also is integrated as a game mechanic. Here, interactions occur both with the elements of the physical environment and with computer-generated objects: *Reality Clash; RealTag | Multiplayer AR FPS; or, Mario Kart Live Home Circuit*.

We did not find in our sample any game incorporating digital gameworld space and at the same time hybrid gameplay space.

Finally, as an answer to our research question and goals, about the features of MAR and their possibilities to allow new ways of playing and redefining play, we must consider that it offers several potentialities. However, not all of them have been explored to date; on the contrary, there are few cases in which the physical space is part of the mechanics or narrative of the game, which would provide a multiplier effect on the playability and immersion of this type of hybrid video games.

8 Conclusions

With this research we intended to shed some light on the contributions of MAR to game experiences, but the results were not very satisfactory. Considering spatial affordances, we observed that MAR still presents technical and conceptual limitations in terms of its integration into gameplay. That is, in most of the cases studied, this technology was merely an aesthetic factor, and the potential of hybrid spaces was not exploited. Mainly, we consider that the possibility of taking advantage of the physical space from a narrative and mechanical point of view would be very significant.

On the other hand, the virtual graphics of most of the video games that were part of the sample of our study did not allow interaction from multiple perspectives, generating a less immersive and less realistic experience in this type of hybrid interfaces. We consider that what enriches the experience of MAR-based video games is the possibility of visualizing and interacting with digital objects from multiple perspectives, offering a realistic spatial experience similar to that of the analog world.

Finally, it would be a priority, and at the same time a challenge for designers, to think about the integration of this type of games with the physical environment, in terms of setting, narrative and gameplay space. The technical limitations of this technology and the mobile devices used still represent a strong limiting element, but we hope that in the future these constraints will be overcome to achieve more vivid and hybrid game experiences in augmented reality environments.

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