HÖGSKOLAN
I GÄVLE

FACULTY OF ENGINEERING AND SUSTAINABLE DEVELOPMENT
Department of Industrial Development, IT and Land Management

Analysis of Augmented Reality Games on Android platform

Author
Fekolkin Roman

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Examiner: Julia Åhlen
Supervisor: Peter Jenke

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by

Fekolkin Roman

Faculty of Engineering and Sustainable Development
University of Gävle

S-801 76 Gävle, Sweden

Email:
tbs10rfn@student.hig.se

Abstract

In this paper the research surrounding the Augmented Reality in games on Android platform was performed by testing 108 games from Google Play Market and by analyzing the hundreds of user reviews to determine the level of acceptance and the level of technical stability of the mobile games based on that technology. The Location-based, Marker-based and games based on somewhat different approach were studied and compared by the runtimes, game genres and by the featuring aspects including the presence of multiplayer mode, sound effects and the dimension that the virtual objects were positioned in. The overview of the studied games was presented in this paper. The results, for instance, include that the AR game variation is very narrow in terms of gameplay style and technical issues are very commonly encountered and it makes them very influential to the gameplay experience. The rareness of the multiplayer mode among the AR games was discovered meaning the domination of the single-player game designs.

Contents

1 Introduction

Playing games has always been a significant part of the human evolution, as well as, a defining factor in behavioural qualifier of a person [10]. The industry of game development, similarly to film industry, has a cultural significance that may start to initialize it as new form of art. The sense of relaxation and refreshment of a person's mind, as well as a teaching process, are all the possible outcomes that can be provided by a game session. The games offer an opportunity to relieve the stress of everyday life and to provide the sense of control over the situation where specific goals have to be achieved, by making decisions that actually result in something meaningful.

The games can be roughly categorized into 3 clusters (figure 1) like sports, digital and board games. Each one of the clusters has different organizational structure, different groups of interest (audience) and different environmental specifications in which games can be performed.

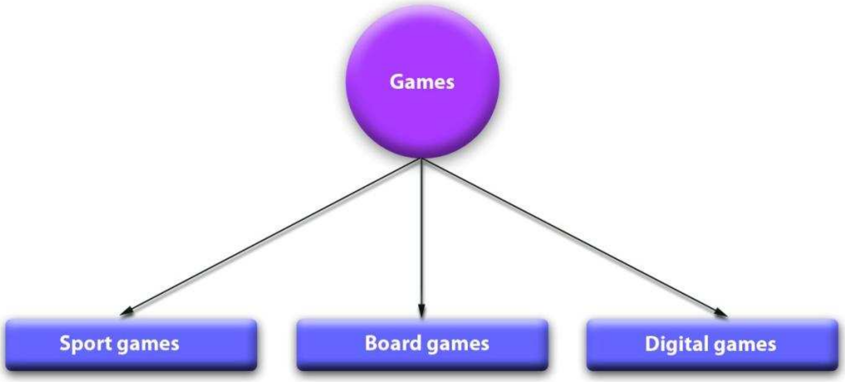

Figure 1: Three structural clusters of game types

The industry of digital games has not done any particular steps towards improving the Human-Computer Interaction (HCI) since 1980s. It mostly depends on the unwillingness of the game companies to risk large budgets invested into the development due to the possibility of unsuccessful acceptance of the game on the market that would not pay off those investments.

Augmented Reality is one of the new technologies that can provide a totally unique HCI by combining the strong sides of digital games and real world games. Before this technology can be widely used by the developers, it has to be proved to have stability, with defined possible limitations and the infrastructure used for building the AR system available to developers. It should also be understandable, in what way the AR technology can be used to become a part of the game process. The game design is a tricky procedure, so sometimes it is difficult to understand the best way of using the technology creatively and appropriately. The gameplay strongly depends on that aspect. Another important thing is the accessibility of the hardware, allowing playing the actual game, for the target audience. Without the proper accessibility the game risks to be a commercial failure.

1.1 Importance of the Study

The proper research of AR started in 90s [3], it has a lot of uncovered potential of further expending the interactivity experience, bringing it to a whole new, deeper level, offering a more vivid sense of presence than ever before [5]. It's a very rapidly growing technology which can be considered as another step deeper into the age of the progressive digital inventions. The games that are based on the Augmented Reality can be used for both entertainment and educational [8] purposes, thus there are many ways of creating really worthy games using creativity to find out the innovative ways of applying this technology. When the study of the Augmented Reality started to grow, initially the games based on AR would require expensive equipment that made the created games not commercially advantageous. But, as the technology developed, the equipment became more available for the broader audience and thus the development of the AR games became more and more attractive for the independent developers [39]. The technological progress makes the ways of implementation and application of AR to become broader, due to the minimization of technical limitations and increase in the variety of the hardware to be used for inventive AR ideas to be realized. Due to the current availability and the strengthened positions of the AR based games on the market, it would be interesting to take a closer look at how the technology can be used to provide AR based interactivity in the games and to see if it offers any perspective in creating a any new perception of the gaming experience for the players.

According to the prognosis from analytics from Juniper Research [24], the share of AR games compared to other areas of AR application (medicine, education etc) will increase up to ¼ of the whole market before year 2015. The analytics from Semico [1] explained in their latest report the role of AR on the market and they stated that AR games will be in popular demand due to rapid increase in technology development. According to the Gartner Hype Cycle in emerging technologies[17], the AR technology is at the stage of increased expectations which means there will be a lot of different applications, both successful and not. Thus, it would be enlightening to research how the AR behaves in the game industry and what kind of game applications are available on the market right now and how well they are accepted by the audience.

1.2 Research Question

How is the Augmented Reality used in games on the Android platform?

1.3 Purpose of the Study

I am interested in finding out how the AR is used on mobile devices. The research will be performed by making an overview of the technical aspects of the current situation surrounding the mobile AR the result of which will be an overview that will clarify what kinds of AR techniques are currently used for mobile AR games and how well the AR games are accepted by users. Since the AR is a newly emerged technology, especially on mobile devices, its aspects are currently not very well uncovered for understanding of how exactly it is used and what kind of approaches are used to achieve the AR effect and how well those approaches work in terms of the technical stability and gameplay interest. The result of the study will give a general opinion about the AR mobile games. This work will provide the general technical information as well as the information about how successful the AR currently behaves on mobile devices. Since this work only focuses on analysis of the AR games available on the Android platform that is why the analysis performed in this work can later be used as a basis for future research of the mobile AR games for both Android and other platforms in order to compare them by technical performance and gameplay solutions.

1.4 Definition of terms

The term Augmented Reality was first proposed by Tom Caudell [11] who was a researcher at a Boeing company in the year 1990. In 1994 Paul Milgram and Fumio Kishino [31] described the Continuum of Reality-Virtuality, a space between reality and virtuality with augmented reality (closer to reality) and augmented virtuality (closer to virtuality) as the intermediate elements (see figure 2).

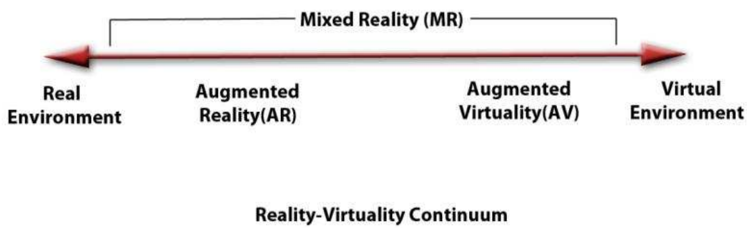

Figure 2: Reality-Virtuality Continuum [31]

There are several definitions of Augmented Reality. One of the definitions was proposed by Ronald Azuma [4] in 1997. He defined AR as a system that:

1. Combines Virtuality and Reality
2. Interacts in the real time
3. Works in 3D

The augmented reality can also be defined as a combination of two initially independent dimensions on one screen.

The dimension of the real world, that surrounds a person, and the dimension of the computer generated world. This interactive technoloegy offers the user to overlay digitally generated 2D or 3D objects on top of the image received from a camera, augmenting or adding them to the real world images [39]. Per se, regardless of the name, the Augmented Reality technology could be applied for both filling the surrounding world with virtual objects, as well as, removing the objects from the real world. The capabilities of Augmented Reality are only limited by the capabilities of the hardware and the software. In the simplest case, to achieve Augmented Reality, four components would be needed:

- Marker – special image, visual identifier
- Web-camera – that "sees" the marks in real time and sends the signal to the computer
- Software – that handles the received signal and combines the virtual objects with the real world image.
- Computer

The user prints a special image (marker) on a paper and shows it to the camera. The software, installed on the computer, should recognize the marker from the image that was received from the camera and according to the position of the marker it will place some kind of virtual object on top of it. The virtual objects could be texts, website links, photos, 3D objects, sounds, video etc. They could either be just observed by users – passive, or they could be interactive.

Head-Mounted Display (HMD) is a display that is commonly built into a helmet or glasses that allows the flexibility for the user to maintain the proper view position produced by the display regardless of the head orientation. HMDs can be binocular- two displays for both eyes, or monocular- one display for one eye only [16]. The first HMD was created by Ivan Sutherland [38]. Originally it was too bulky and uncomfortable for the usage. But as the technology progressed, the HMDs became more mobile. The application area of HMDs is broad. They could be used in different simulations for medicine, military, entertainment etc. Since the display image has to be updated in real time, the high update rate is a very important factor that needs to be taken care of in order to fulfil the proper usage experience received from HMD and provide nice and smooth image generation synchronously with the head movement. The HMD is a somewhat old fashioned type of AR hardware which in the future could be improved by the Google Glass [21].

The markers are crucial components in Marker-Based AR system. Without the detected marker the positioning of the object, that should be augmented, would not be possible. The markers specify the position and orientation of the virtual objects to be augmented into the real world. They work as “triggers” for Augmented Reality and they can be placed on any surface. The role of markers can be assigned to illustrations, photos, logos, QR-codes, product packages and even human body. The markers could be both binary (black and white) printed images, as well as, colored images. The difference between them is in the marker detection/segmentation algorithm used to extract the marker from the image received from the camera.

There was a research performed by Zhang et al [46], where they, through an experiment, compared the efficiency of 4 different marker systems (figure 3) and found no apparent sign of the qualitative domination of one system over the other. So any system can be chosen depending on the developers’ preferences.

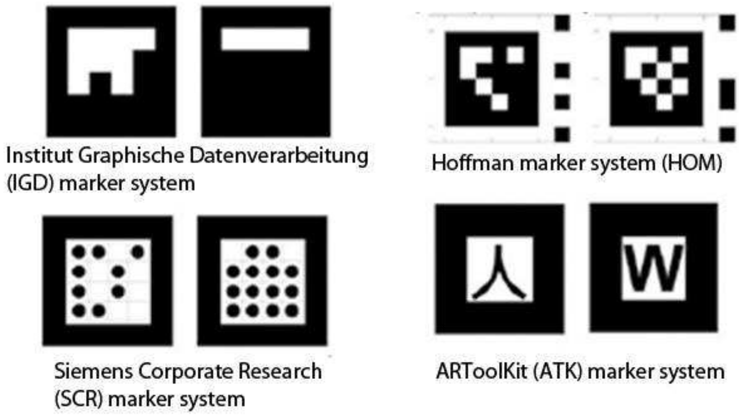

Figure 3: Four types of marker system [46]

Location-Based AR is an approach that uses the virtual object positioning according to the phone’s orientation and position that could be determined by, for example, Global Positioning System (GPS). An example of the location-based AR game called “DroidShooting” [35] can be seen in the figure 4.

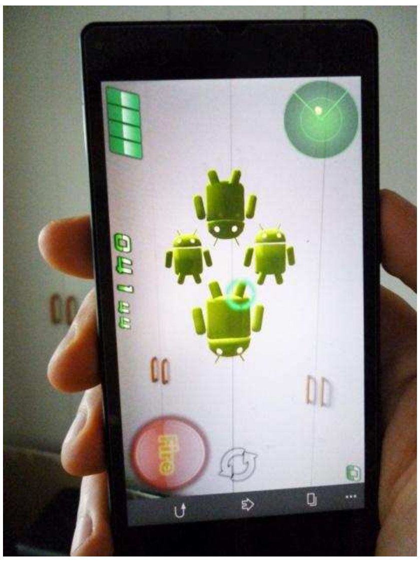

Figure 4: “DroidShooting” location-based AR game.

Marker-Based AR is one of the generally used approaches used for determining the virtual object positioning in space. The position and orientation of the virtual object is determined by the position and orientation of the marker. The marker-detection includes extracting the marker from the camera image by receiving the data from the camera that is later post-processed by the feature detector, whose output is later used for specification of the virtual object position. An example of the marker-based game called “Hoops AR” [7] can be observed in the figure 5.


Figure 5: ”Hoops AR” marker-based AR game.

Other approach – in this paper will be referred to games where virtual objects would be positioned regardless either of the marker or phone positioning properties.

2 Related Work

In this chapter the papers about the AR application methods are briefly overviewed. The types of hardware and the game design solutions are summarized and some of the papers that defined the general AR definition and its structure are presented.

2.1 Overview

In the paper "A survey of Augmented Reality Technologies, Application and Limitations" [40], the authors performed a review of the technologies, applications and limitations in the AR field. The purpose of the paper was to give a starting point for the readers who are interested in the studies of AR field. It was supposed to give the general overview of the different aspects surrounding the AR field. As described in their paper, the AR application area could be clustered into several groups. The groups can be visualized as a tree structure for easier comprehension (figure 6).

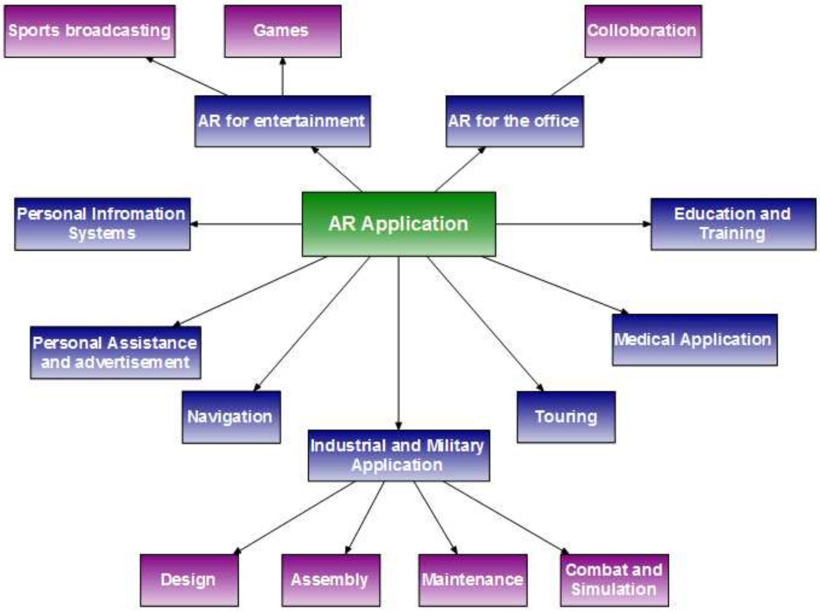

Figure 6: Application areas of AR

The authors described some of the limitations that must be overcome in order to make the AR technology more accepted by the audience. The limitations described by the authors of the paper can be structured as a tree (figure 7), as well.

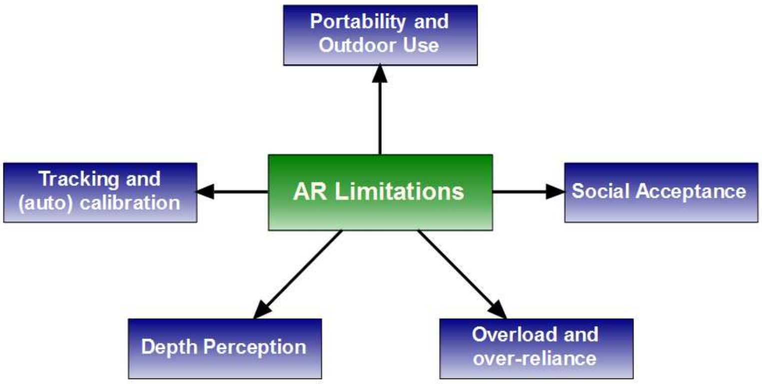

Figure 7: Limitations of AR

According to the paper the AR displays can be divided into 3 categories (figure 8)

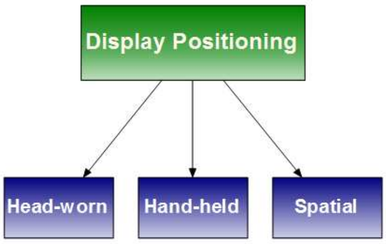

Figure 8: The classification of AR displays

As mentioned previously, the application area for the AR is very broad. In particular, the AR can be used to create games of different genres. The classification of the game genres was presented by Starner et al [36] in their paper.

The games were classified into several categories (figure 9) where each category would need a different approach of using the AR technology.

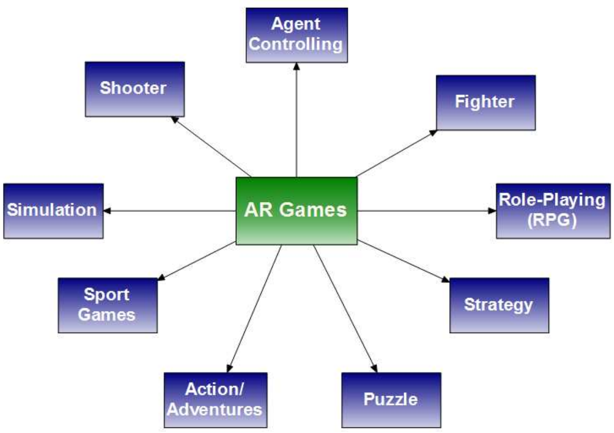

Figure 9: The classification of game genres

There are numerous papers describing different techniques used for application of the Augmented Reality in games. Tan and Soh [39] presented a good summary of what kind of technology that was used in the time interval starting from 2000 up to 2010. In that paper the authors divided the games into 2 categories depending on their purpose and positioned them on the graph according to the game release date and the technology that was used in it. According to their work, the AR equipment changed from expensive head- mounted displays (HMDs) and motion sensor to the less expensive marker-driven detectors and the phone cameras. From that same figure we can conclude, that as the technology became more available (especially from 2007), the purpose of the games became more educationally dedicated rather than just dedicated to fulfilling the entertaining purposes.

However, Lundgren and Björk [29] explored in their paper how the embedded computer technology [43], newly developed sensor devises and ad-hoc networking [19] can be used to broaden the game genre or to create new genre types, as well as exploring the possibilities on enhancement of interaction in traditional games. As the result of their exploration the various game mechanics were identified for expending the mechanic possibilities for game designers. The research revealed also the fact that there is no particular structure of the concepts of mechanics, or in other words, there are no obvious patterns that could be used for classifying the game mechanics which makes it significantly harder to perform a proper analysis of the game design and game processes.

2.2 Games

The computer games usually lack the sense of reality, because the only thing the player has to do is to manipulate the mouse, keyboard or gamepad to perform the actions in the game. The AR technology allows a variety of ways for achieving very realistic interaction between the player and the game.

Andersen et al. [2] in their paper proposed a theory that applying AR technique would enrich and deepen the experience received by the players from a gameplay. As a proof of their theory, they presented a prototype of a multiplayer AR board game called “BattleBoard 3D” (BB3D). For structuring the prototype, they used ARToolkit library. Their game was the result of the inspiration they received from the Star Wars Episode IV movie, where two characters were playing the living chess game with pieces that would actually perform the fighting interaction with each other at certain conditions. To play the game the Virtual Reality (VR) glasses or a regular computer display with a web camera would be needed in order to observe the result of augmentation. In the first case, one player would have to ware the VR helmet and the other player would watch the game process through the display. In the second case, the fixed camera was used and both players had to follow the game process through the display. In order to provide a proper gaming experience for both players, 2 VR helmets and 2 computers synchronised with each other for handling the computation received from each of the VRs, would need to be used by both players. The purpose of their game was to combine of digitally generated game features with the real board game pieces. In that game, the user had to physically move the game pieces that had markers with graphical symbols to which the animated virtual objects would later be attached. The structure of the markers had to satisfy the marker properties required by the ARToolkit. Examples of those markers were mentioned in the first chapter of this work. The gameplay included capturing the chest of the opponent. The virtual objects associated with markers were LEGO figures. The markers for the game were made out of real pieces of LEGO to provide the right physical feeling and consistency for the game structure.

After testing the game with the group of children, they received generally a positive feedback. To increase the re-playability, the downsides like a small variety in character animations and absence of a single player mode against a computer Artificial Intelligence would have to be fixed. Overall, the observed game was an example of the successfully applied AR to a board game.

Another multiplayer AR game called “BragFish” was presented by Yan [45] in their paper exploring the social interaction in AR games. The game was played in a shared space, which allowed multiple users to communicate and affect the game process in a more social way. The gameplay involved navigating the boat around the lake, catching fish and stealing the fish from other player’s boat. In order to play the game, a fixed game plane with markers was required. The Gizmondo handheld device with a camera mounted on the back was the only hardware required for the users to play. Even though the game offered a socially active gameplay, it did not involve any actual physical interaction between the player and the virtual game objects, keeping it only within the screen of the handheld device.

Later on, the authors expended their idea presented in the “BragFish” in another paper. In their paper [23], they explored the ways of making the gameplay more physically interactive, in order to make the gaming experience more vivid and closer to the traditional boardgames. The goal was also to make the game more portable. Considering the requirements, they developed and presented “Art of Defense (AoF)” – an AR handheld strategy board game of type “Tower Defense” for cooperative use. In the game the players were allowed physical interaction with the game pieces. The purpose of the game was for two players to protect the main tower from increasing waves of enemies. For protection, the players would have to build and upgrade the defending towers on the game field. Both players would have to communicate to successfully develop a strategy for defeating the enemies. The intended mobility of the game was provided by small game pieces, adjusted design implementation and a regular phone with a camera to be used as hardware. The structure of the game plane consisted of hexagon-shaped tiles. To explore the game world the user would have to reposition the tiles to move further. For building the towers, the user would have to position a special token on the chosen tile, specifying the direction of attack of the tower. For upgrading, the token would have to be added to the tile with the tower. Both constructing and upgrading the towers needed to be confirmed by pointing the camera and pressing the button.

For implementation of the game, the authors used OpenGL ES programming interface and Edgelib [15] game engine. StbTracker [37] library was used for tracking multiple markers. The described game implementation proved to be effective for improvement of the players’ communication and game experience. Compared to the “BragFish”, the “Art of Defense” became more portable due to the use of assembled game plane and appropriately adjusted game design suitable for mobile devices, making the portability a part of the gameplay.

A non-portable example of AR board game was proposed by Molla and Lepetit [32] in the paper “Augmented Reality for Board Games”. In the paper they converted a well known “Monopoly” board game into an AR domain. Instead of phone cameras and markers, they used a simple display with web camera and pawns that represent the player on the game board to which the virtual objects were attached. The pawns offer a physical user activity and the real feel of the game, which is the main advantage of using the tangible interfaces. As the player moves the pawns around the game plane, the orientation and position of the virtual objects attached to the pawns were calculated, so that the virtual objects would look in the right direction. Each pawn had a unique color and a simple shape, to make it easier to distinguish them in post-processing of object detection. However, the virtual objects associated with those pawns did not have any animation that could enrich the gaming experience.

An interesting approach of creating the AR board game with animated virtual objects was presented by Billinghurst and colleagues [8]. They made an overview of Shared Reality with the Augmented Reality as its interface technology. The AR based multiplayer game with tangible pieces was demonstrated in that overview. The hardware required for the user was a HMD. The gameplay was fairly simple. Its purpose was to match together the cards containing tracking patterns that would later be used for positioning the virtual objects. When the match was successful an animation was triggered involving the two logically suitable virtual objects.

The game process involved also the communication between players when asking for matching cards. The authors tested the game and according to the performed experiments, this kind of AR interface proved to be effective and easy to understand without any requirement for additional gameplay instructions.

Another example of the AR board game with tangible game pieces was presented by Lee et al. [26]. They presented a game where 2 players would sit at the glass table. Both players were given a set of cards where each card had a marker attached to them on the back side. And due to the transparency of the table the markers could easily be detected thought the table surface. To track the markers, the “tracking” camera under the table was used that observed the markers through the reflection in mirror that was positioned under the table under a certain angle. The mirror improved the tracking limitations that could arise depending on the height of the table which affected the view angle of the camera. When the player made the move, by putting a card on the table with the marker pointing down, the second “augmenting” camera, installed above the table, would augment the virtual object depending on the marker properties detected by the “tracking” camera. For the implementation of the game, the authors used OpenGL for rendering, OpenCV for image processing and ARToolkit to position the virtual object according to marker properties. The AR approach described in the paper was strictly non-mobile, due to the special table requirement that was designed specifically for that game prototype.

Unlike some of the previously described papers, the approach presented in the paper “Augmented Reality Chinese Checkers” [14] did not involve the use of any actually physical game pieces. Instead those pieces were entirely digitally generated. In order to move those virtual game pieces, the user would have to move the marker. For the game, the authors developed a special interactive marker prototype that extended the functionality of the regular markers. The game included 3 markers. Two of them were made for defining the size of the game plane and one for the interaction. The marker that was responsible for interaction had 2 buttons, which signalled the user events like choosing and changing the position of the checker pieces. This marker had to be shared by all players in the game depending on whose turn it was. The other two markers defined the game board’s spatial properties like orientation, position and scaling size. The scaling size was defined by the positions of those two markers, placed in the lower left corner and upper right corner. The scaling size could be adjusted by simply repositioning the 2 markers at any time during the game session. The augmented objects had to be observed on the large screen. The observed view could be chosen from one of the 5 cameras positioned above the game board. Those 5 cameras were used as structuring elements of the Passive Detection Framework (PDF). Depending on the choice of camera, the positions of the virtual objects had to be recalculated accordingly.

Another interesting proposal of AR board game was presented by Lam et al. [25]. In their paper they presented a specially developed prototype of the Augmented Reality Table (ART) that would be used for playing the trading card games like “Dungeons and Dragons etc”. The intention of the table was to broaden the regular gaming experience by augmenting the visual and sound effects while maintaining the basic card gameplay process. As hardware for this ART, they used an over-head camera that acted as the only input device and it was positioned above the table. They also used a computer for performing the augmentation and computational processes and the plazma TV aligned horizontally. This TV acted as the table on which the players would actually play the game. Instead of the marker detection they used the Canny edge detector for determining the content and the position of the card. Besides card interaction, the user was also allowed to perform spell attacks by “pressing” the buttons on the “screen” table. The button event was detected in the similar manner as the card recognition.

Piekarski and Thomas [34] offered an interesting way of the outdoor AR interaction in the first-person single-player shooter "ARQuake". They used a transparent HMD, whose orientation and position determined the view. The game statistics were shown on the HMD. For the movements the player would actually have to walk some distance in the desired direction. Due to this interaction, the virtual world aligned with the real world. The game play was adjusted appropriately, removing the actions that would cause some difficulties to be performed (swimming and flying). The walls, floors and buildings were omitted from the game to allow the user see the real structures. For the shooting action - the props or in other words the plastic replicas of the real weapons were used. Due to the lack of bulky hardware and wires, the user could freely navigate in the real world while eliminating the virtual enemies without any hindrances. The "ARQuake" was one of the first AR games that could be used outdoors.

Expending the idea presented in the "ARQuake" from the previous paper, Cheok et al. [12] developed a multi-player game called "Game City" that was set in real world dimensions (e.g real city). In their game, the authors combined the AR and Virtual Reality (VR) in a single gameplay. Since this particular technique was based on the relatively old hardware (from 2002) and the gameplay involved players to move around large distances carrying a lot of hardware in order to fulfil the intended purposes of the game, thus the game sessions might be exhausting. The required hardware included HMD with camera and inertia sensor, GPS receiver, mobile wearable computer for augmentation of virtual objects into the real world, and a power supply to keep the whole wearable system powered up. The game process included 3 stages. First, the player had to collect treasures and clues. To collect those, the players were provided with hints and directions shown on the HMD. After that, the player was guided to a place where he would have to defeat a virtual witch by using a "gun" whose functionality was provided by a gamepad. In order to avoid enemy hits, the player would physically have to dodge the attacks. At the last stage, the player would enter a full VR to find the princess. In the VR, the navigation was provided by the gamepad and the orientation was determined by the HMD. Considering the year of release of the proposed game, the authors used effectively the available, at that time, technology to provide an engaging gameplay.

In the paper "Motivations for Augmented Reality Gaming" [33], the authors developed "Hybrid AR Worms" - an improved version of the earlier implemented "AR Worms" game. The original "AR Worms" was based on the "Worms" [44] computer game. The gameplay involved eliminating the members of the other players' groups until only one group remained. The implementation of their original AR game was done using the ARToolkit, OpenGL and OpenAL. In order to play the game, the players wearing HMDs, had to stand around the table on top of which the virtual game world would be augmented. The controls for the game were provided by the gamepad. To select a worm (group member), the player would have to concentrate/point the HMD's view at the desired worm that needed to be controlled. It was also possible to play the entire game from the first-person perspective, which would transform the game domain from Augmented to fully Virtual. After testing the game with some players, the game design revealed some drawbacks that negatively affected the gameplay. The HMDs and short cables disabled the free movement of the players. The marker trackers had flaws regarding the unstable/flickering appearance of the virtual objects attached to those markers and it affected some game functions making them non-functional. The worms appeared too small to be easily identified or seen by the players. However, the authors took into account the observed test results and implemented "Hybrid AR Worms", improving stability of the original game features and overall functionality. In the updated version the marker system was improved, almost eliminating previously noticed problems. The gamepad was replaced by the Personal Digital Assistant (PDA). The wall projector was used to display the view perspectives and game statistics, making them available for observation for non-participating users. The additional game effects like terrain randomizer, bonus kits positioned on the map and particle system were implemented into the game design.

Besides displays and HMDs, the augmented world could be seen through a projection. An example of such approach was presented by Löchtefeld et al. [30] in their paper. In the paper the authors explored the idea of using the phone projector for achieving the AR by implementing the game called “LittleProjectedPlanet”. They used mobile phone with an in-build camera projector instead of using bulky HMDs and phone cameras for each player. The game was projected onto the whiteboard which would allow multiple players to participate in one game session without the need of a lot of hardware. The authors based their game idea on the Playstation 3 exclusive game “Little Big Planet” developed by Media Molecule [28]. The game process included two modes. In the first one, the player would have to build a level by drawing the primitives/lines on a whiteboard. The second mode included moving an object through the created level from start to finish. One of the important requirements for the game was that the light and surface conditions in the room had to be satisfied in order to provide a good contrast which would make it possible for the edge detector to distinguish the created drawings. The game was implemented in Java, using the Phys 2D engine for calculating the physical behaviour of the object. The hardware included the Nintendo Wii Remote, which played the role of the electronic compass, attached to the camera projector. In nowadays, an alternative to the presented hardware would be a regular smartphone with an inbuilt accelerometer and gyroscope. Considering the previously described papers, the AR can only be seen through some kind of projection or a display that is usually present, for instance, in HMDs and handheld devices. However, the problem with the handheld devices is their small screen size which limits the perception of the augmented world. We can not see on the screen what is not viewed by the device. Cho et al. [13] introduced a special term called “dynamic environment” that they used in their game “Ghost Hunter”. The purpose of the dynamic environment was to expend the perception boundaries when using the handheld device for AR. They developed an approach of allowing the players to feel the game world even when some parts of it were not observed through the device. To achieve the dynamic environment, they developed a special game board with physical elements. The board included small building, lights that would keep the player aware of the position of approaching enemies (ghosts), and tombs that would open automatically when the enemy appeared. The positions of the physical elements could be re-customized, in order to allow the users some variety in the gameplay. In order to detect collisions between monsters and buildings, they used specially generated 3D models of those buildings that were later digitally overlaid on top of the real ones. The authors also developed a special hardware called “AR Gun”. The “AR Gun” contained the display and the camera, and it was connected to a wearable computer. The gun configuration was chosen as an alternative to smartphones and PDAs due to their limited computational capabilities. The solution for the AR design, presented in their paper, was particularly useful when using AR applications on handheld devices. In that solution the users would have to react to actions beyond the screen, making the game more engaging.

There was another example of a dynamic game environment presented in the paper by Barakonyi et al. [6]. In the paper the authors demonstrated the capabilities of the autonomous agents by means of the virtual game characters. They tried to show how those agents can simulate player’s behaviour without the actual player’s participation in the character control. In order to demonstrate that, the authors developed a multiplayer game called “MonkeyBridge”. In that game the player would have to guide one of such agents towards a destination point by placing virtual, as well as, physical (real) objects on the game table.

The virtual objects could be positioned by using the marker. Those objects were randomly chosen from the list of existing predefined 3D models, so the user would have to react according to the object type. The additional physical objects were used for decoration, as well as, for hindering the way of building the bridge easily from starting point to the end point. Some of those objects were mechanically enhanced to provide a proper game feeling. The table surface was covered by a digitally generated ocean to make the gameplay more vivid. The agent character had a proper animation and sound effects for different game situations. When implementing the game the authors used the ARToolkit library and 3DS Max for character modelling and animation. The augmented view could be observed by using a display with web camera or a HMD as an alternative.

The application of AR for education purposes may play an important role in helping people to perceive information in a more effective and engaging way.

One of educational AR applications was described in "Augmented Reality Kanji Learning" [42] paper, where authors presented an educational AR board game for learning the kanji symbols. Two players would have to sit at the table, both given 10 cards and a PDA with the inbuilt camera. The cards were turned with their back side pointed up, showing a symbol. On the other side of the card was a marker. The main game purpose was to find the figure shown on the PDA and find the kanji symbol that corresponded to that figure. The player would have to choose one of the 10 cards and then flip it over. Then, through the PDA, the player would see a 3D object associated with the card's marker. If that object was the same as the required figure on the PDA then the player would gain a point, otherwise the turn was given to another player. The augmentation process and the game's rules determination was performed directly on the PDA which made the game significantly mobile by removing the need for any bulky hardware. The game was implemented by using OpenGL and ARToolkit libraries.

A different type of educational AR was introduced by Ardito et al. [3] in their paper about the use of AR in historical parks. They implemented a mobile AR application that could be run on a cellular phone with a removable memory card. This choice of hardware removed the necessity of having any expensive hardware, but the quality of the augmentation would be affected by that hardware choice. The purpose of their application was to enhance the excursion procedure for students in archaeological parks. At the start of the excursion, the players (students) were given the instructions which included finding some particular place in the park and taking a photo of the QR code positioned in that place. When the photo was taken, a digital model of that place (e.g statue) would be shown on the phone screen. Due to limited computational capabilities of the phones, the application showed a set of sequential snapshots of the model instead of the actual 3D model. At the end of the game, the memory cards were collected by the instructor and then analysed, in order to determine the results of the excursion. The game structure had to be adjusted each time in order to be used in different parks. The game was implemented using Java and it had a XML file responsible for structuring the game and that file had to be modified when adjusting the game for another location.

The different types of simulation training could also be supported by AR. For instance, Brown et al. [9] tested the effect of applying the AR in the military simulation to improve the training skills. In particular, they researched the difference between the training with the AR and without. For that, they developed a special AR system. The training process consisted of 2 stages. At the first stage, the participants had to go through the location, observing the surroundings through the HMD, while carrying the backpack with the computer. The purpose of the first stage of the simulation was to clear the location from the virtual enemies. At the second stage, the same participants had to go through that same location, but this time they had to "eliminate" the real enemies. During this stage, the participants had to be put in the same conditions as in the AR training. They had to wear the backpacks with hardware and HMD on the head, but without the need to look through it. After the participants passed two stages, the statistical results of completion were compared. As it turned out, the AR did not improve the training skills of the participants. The results depended perhaps on the wrongly structured simulation stages. The location layout was the same during both stages which might affect the results of the second stage. Further testing, considering some of the simulation aspects, might result in the different outcome.

2.3 Another less game-related technique

There was a technique presented by Vera et al. [41] that offered an interaction with the surrounding audience with help of the augmented mirror, while maintaining a realistic way of movement of the computer generated character. The movement was based on the detection of the different parts of the player by attaching four different devices responsible for tracking different parts of the body. The Kinect [27] tracked the basic body movements (arms and legs). The tracking of the orientation of the head was performed by the Gyroscope. The microphone detected the motion of the lips and the WiiMote provided the user with the set of facial expressions to choose from. Considering the amount of equipment required for providing that kind of result, it would require some significant financial spending which would most likely make the games based on that kind of technological approach, unattractive on the market.

3 Method

The process of the data retrieval that was performed during the analysis was divided into 2 stages. During the first stage the games were analysed for the presence of the sound effects, multiplayer mode, 3D object positioning, game’s genre and the distribution type. Another major part of the first stage of the games’ analysis included the measurement of the frame rate for each one of the 108 games. During the second stage of the data collection the analysis of the user reviews was performed that included going through the user reviews for each game and separating them roughly into positive and negative categories. The technical complains were collected as part of the negative reviews and their proportion was later calculated in order to see the main reason for negative acceptance. The games’ ratings and number of installs were collected from the game’s description page on Google Play Market.

3.1 Overview

The general questions about the performed research can give some insight into the process that that was performed in this work in order to collect and represent the data. All of the collected data was not biased in any way by any hidden factors that might affect the judgement during the testing. With a personal 16 years of experience being closely familiar with the gaming products of various types, the test results were collected in an objective way. If the game future was present in the tested game then it was noted as such. If it was absent then it was noted appropriately as well.

Who was the study about?

The study was about the users who used the AR based gaming mobile applications. The players are the corner stone in the commercial success of every game, and thus their opinions or feedbacks play a major role in the gaming industry. Since, the AR is a newly emerged technology, thus the acceptance of the games among the users would define the reliability of the whole idea of creation of AR based games. In this particular study the players who use the Android platform were taken into account and studied.

What was the study about?

The study was about the games that used the AR technology. In particular, the study concentrated on the Android platform for mobile games. The development of the AR applications is just emerging and it's a large research field for creative design ideas which would offer some innovative gameplay solutions using the technological advantages of AR. The general overview and understanding of the current situation surrounding AR in gaming on mobile platform was performed. The conclusions were reached based on observations and experimentations with the currently available freeware and payware mobile games that were installed from the Google Play Market.

What and how did I do it?

I performed a detailed testing of 108 games for Android platform. The list of available AR games was made. Then those games were installed on a mobile device. The games were studied one by one. The observed information was recorded. In order to test the games, 3 different mobile phones were used. The information of interest included the general game features like multiplayer mode, sound effects and 3D which was absent in some games. The game genres and commercial status was taken into consideration as well. The result of analysis was used to overview the current situation in the mobile AR gaming field. The analysis of the users' reviews from Google Play Market was performed in order to find out how the AR based games were accepted when it comes to using them on mobile platforms. The information about the acceptance of the gameplay and the current problems that were frequently noticed by the users was recorded. All of the data from the study was recorded into the table and later that data was used to build graphs and charts for later interpretation and conclusion making. All of the graphs and tables were made using the MS Excel, EDGE Diagrammer and Photoshop for visually enhancing and highlighting some of the graph features.

What did I look for?

I looked for the evidence that would proof that the AR can be successfully applied to mobile game while maintaining the interesting gameplay in order to keep users satisfied.

3.2 Hardware

For the testing, 3 different mobile phones were used: Samsung Galaxy Note 2, Sony Xperia Z and HTC One X. Three different devices were needed in order to run all of the applications, due to incompatibility issues that appeared when trying to run some particular application on one phone.

3.3 Android games' analysis

The most important part was actually to find a sufficient number of games to be used for testing in order to allow a more representative representation of the data. The games were found on the Google Play Market [20], using "Augmented Reality Game" as search keywords. After that, the AR games were installed one by one. But before installation, they had to be separated from the occasionally encountered non-AR games. When installing the game, the installer would ask for the permissions that the game needs an access to. Those permissions had to be noted in the table by setting a mark "x". The game's genre was taken from the description page of the each game and it was recorded into the table as well. The commercial status, specifying if the game is freeware or payware, had to be noted in the "Freeware" column by choosing either "Yes" or "No". After the installation, the game was run and tested for technical features. First of all, the approach had to be specified. If in order to play the game, a marker had to be used, then the appropriate mark had to be set in the table in the proper column. If the positions of the virtual objects were location-based, or in other words the positions of those objects were correlated to the position of the mobile device then the mark had to be set in another column. Some of the tested games were neither location-based nor marker-based. In fact those games were hardly even AR, because they were just regular games, but with the camera background, meaning that the data received from the camera did not influence object positioning and the virtual game objects were not actually integrated into the real world. However, the virtual objects were still overlaid on top of the real world images, even though they were not dependent from it in any way and thus those kinds of games would still be considered as AR-based. The games of that sort were not encountered as frequently as the games based on other two approaches.

To better understand the process of gathering data we can take a look at the following example. For example, after testing the payware game called “3D Pool game 3ILLIARDS”, we can conclude by observation that there were sound effects when interacting with the virtual objects, it was set in 3D space where the position of the virtual object was determined by the position of the marker, and there was a multiplayer mode in this game allowing several users to participate in the game process (table 1).

Table 1: Specification of General Information and AR Approach in the table.

	General Information					Approach		
	Genre	Freeware	Sound Effects	3D	Multiplayer mode	Location-based	Marker based	Other
3D Pool game - 3ILLIARDS	Sports game	No	x	x	x		x	

The access to the phone’s features that was required by the game had to be noted too, but in the different section of the table. The information about access could be collected when installing the game on the phone. It will request your permission to allow the application to use some particular phone’s features that were intended to provide the proper gameplay.

In the “3D Pool game 3ILLIARDS”, during the installation the game requested access to the phone’s hardware controls, network communication and phone calls (table 2).

Table 2: Specification of the required access in the table.

Required access					
Storage	Network Communication	Hardware controlls	Phone Calls	Your Location	System tools
	x	x	x		

After all that data for the game was recorded into the table, a next game had to be tested in the same manner. Some of the games could not be run on one phone, thus 3 different phones were used in order to run all of the games. This was one of the major drawbacks of the actual testing process. This particular compatibility problem is perhaps one of the major problems that currently exist on the Android platform, perhaps due to the universality of this platform making it available for different phones with different system configurations to run the same applications. Thus it would be very interesting to compare the AR games from the Android and iOS platforms to see if these technical limitations would be resolved on the Apple devices. It would be interesting to see what platform is more preferable for developers to create AR applications for and to determine which one of the platforms is more dominant on the market.

As an important part of this thesis work the runtime for each tested game was measured by using a special application called “FPS Meter” [18]. This was done in order to determine which of the AR approaches more computationally demanding on the device's hardware. The application that run at the same time as a tested game, calculated and displayed the average runtime measured in Frames per Second (FPS). The average runtime is calculated by adding together the FPS values collected at some intervals and then dividing that sum by the total number of the collected samples.

3.4 User Studies

After running the tests for each one of the 108 games while recording the observed functional and technical aspects into the table, the user reviews taken from Google Play Market's description page for the tested game were analyzed and recorded into the table judging by their affiliation. The affiliation could be either positive or negative. The affiliation types were chosen in such a way due to impossibility to expand the intermediate stages between negativity and positivity which would be impossible to do because the user reviews were analysed without the actual contact with each respondent user whose reviews were analysed. Even though the affiliation assignation might seem too subjective, but the reviews could clearly be distinguished by their affiliation due to the fact that the users did not intend to make a feedback with double meaning. For example if the review was positive it was obvious that the review was positive due to the structure of the sentences that did not contain any positivity about the reviewed game. There were no "not so bad and not so good" or "some parts are good and some parts are bad" reviews and this fact makes the process of determination of the review affiliation type fairly clear. An insufficient number of reviews might give a wrongly guided impression about the games since the same user could complain about the same problem several times when actually that problem is not very common among other users. Thus the larger is the number of reviews; the more representative will be the opinion about the game. But for the purpose of my analysis, the games with at least 5 reviews were considered only.

The table for the reviews contained 4 columns. The columns included percentage of positive and negative reviews, as well as, the percentage of the technical complains and the total user ranking of the particular game. For example, in case of "3D Pool game 3ILLIARDS", after studying the user reviews (figure 10), the descriptive statistics were summarized in the table appropriately.

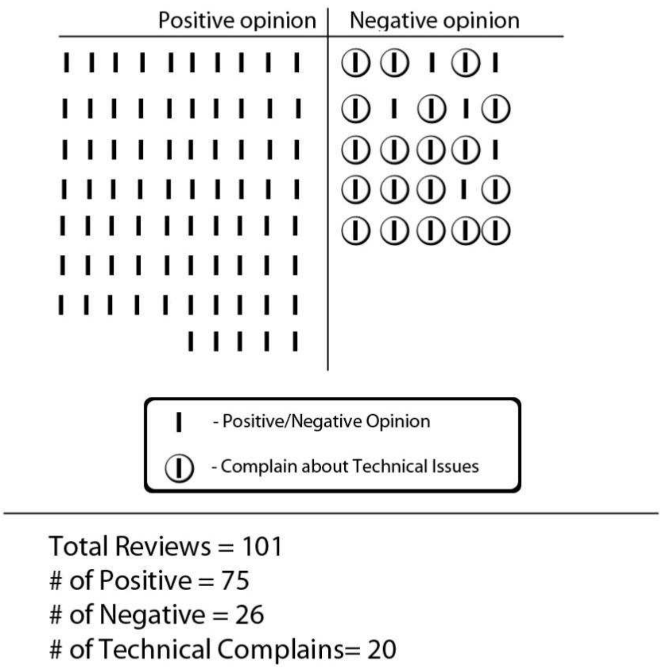

Figure 10*: Counting Positive/Negative/Technical notes for "3D Pool game 3ILLIARDS".*

In the figure the lines represent each review or opinion. Those lines were set on different side dependent on their affiliation. The lines in circles represented the technical issues and they were considered as negative reviews. From that figure, we can calculate the proportion of positive and negative reviews by:

% of Positive = # of Positive / Total Reviews = 75/101 = 0.74
% of Negative = # of Negative / Total Reviews = 26/101 = 0.26

Since the technical complains were considered as part of the negative reviews, their proportion will be taken with respect to the total number of the negative reviews:

% of Technical Complains = # of Technical Complains / # of Negative = 20/26 = 0.77

In case of technical complains received from users, the game had to be run again in order to confirm that the technical issue really existed. This confirmation was done only when there were a small number of reviews and just a few of them had complains. In cases where a lot of complains were noted, no further confirmation was needed. After the user reviews were separated by category or affiliation, the total rating for the game was collected from the Google Play Market's game description page. For the "3D Pool game 3ILLIARDS" game the rating equalled to 4.3. All of the calculated user reviews' statistics were then recorded into the table (table 3).

Table 3: Result of the user review for "3D Pool game 3ILLIARDS".

Opinion		Technical issues	Game Rating
Good	Bad	(technical/total bad)	
0.74	0.26	0.77	4,3

As we can see from the figure, the cell containing the percentage of good reviews was colored in red, which means that the good reviews were dominant in the total number of studied reviews. In some cases the proportion of the good reviews equaled the proportion of the bad reviews (0.50 each) and there was no particular domination of one review type over the other. The determination of the dominant review was done using the following simple algorithm:

```
If (good reviews > 0.50)
        Dominant = Good;
Else if (bad reviews > 0.50)
        Dominant = Bad;
Else
        Dominant = Tie;
```

In some cases the number of pages with the reviews was too large to be analyzed, because each page contained, on average, around 9 reviews. In order to cut down the amount of reviews to choose from, the randomly generated page numbers were used to determine the page of interest. To generate random page numbers, the table of random digits was used.

The process of game and review analysis was performed for each one of the 108 game applications. In some cases there were no user reviews or there were an insufficient number of reviews to be representative for the users' opinion about the game and thus the users' study for those games were skipped. The table with the complete Game and User study can be seen in the Appendix section.

4 Results

The results of my research were recorded into the table. The categorical data from the main table was counted and summarized in the several tables represented by different graphs. Those graphs were used to represent the findings of the research.

4.1 Result of Games' Analysis

The studied 108 games were distinguished by the approach that they were based on. The following table (table 4) summarizes the number of games of different genres for different AR approaches.

Table 4: The game genres for different AR approaches

	Marker-Based	Location-Based	Other	Total
Action	22	27	6	**55**
Casual	10	9	2	**21**
Puzzle	8	1	0	**9**
Sports game	9	1	1	**11**
Lifestyle	2	1	0	**3**
Entertainment	4	3	0	**7**
Racing	2	0	0	**2**
Total	**57**	**41**	**9**	**108**

According to the total number of games per approach (figure 11) we can see that there were 57 games that used marker-based approach. For the Location-based approach there were in total 41 games, while the remaining 9 games belonged to the category that used a somewhat questionable approach that can hardly be considered as AR.

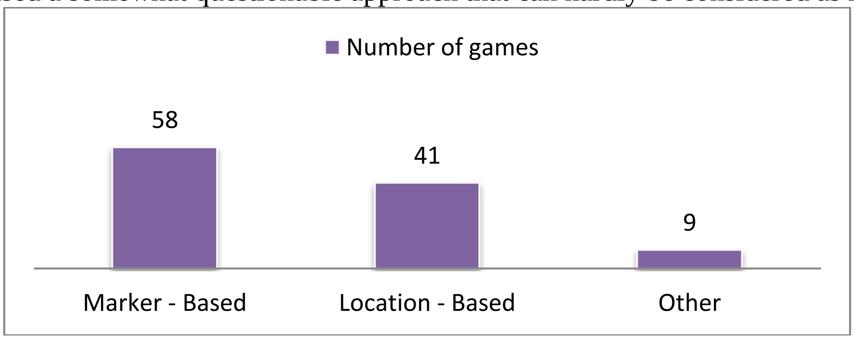

Figure 11: Total number of games per approach.

The total share of each one of the AR approaches can be summarized as a pie-chart (figure 12).

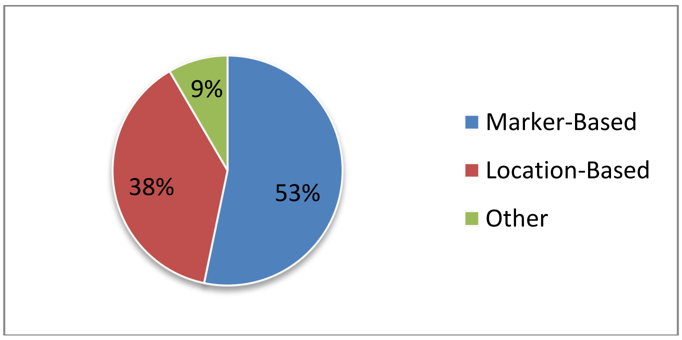

Figure 12: Share of AR approaches

The Marker-Based games appeared to occupy more than half (53%) of the total share of the AR games for Android platform. The Location-Based approach was used by

15% less number of games having 38% of the total share. The remaining 9% were occupied by the games that used other "AR" approaches.

As noted in the table previously, the games were of different genres. Each genre represented a somewhat different style of game. In total there were 7 different game genres one of each was represented by a different number of games (figure 13).

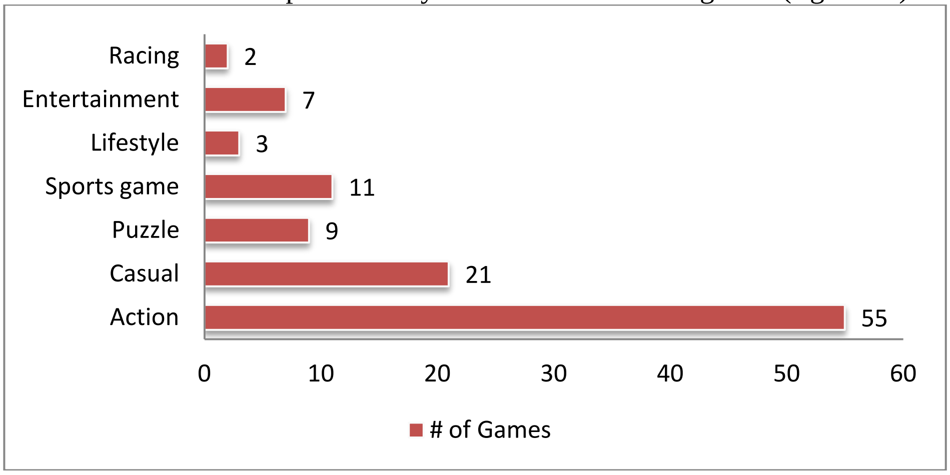

Figure 13: The number of games for different genres

According to the figure, the most common AR game genre for "Action" with total 55 games which made up 51% of the total game genres' share (figure 14) and which was more than double of the number of "Casual" games that counted up to 21 occupying only 19% of total share. The remaining 30% were distributed among the rest of the genres, where 2% went to the "Racing" genre and 3% to the "Lifestyle" games being the least frequent AR game genres on Android platform. Every second game application build by developers were of "Action" genre.

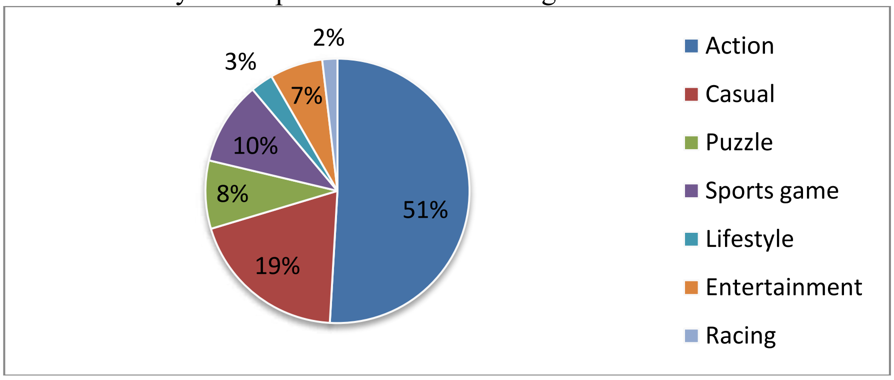

Figure 14: The share of AR game genres

After separating the games by approach and by genre we can see the number of games that represented each approach in each genre (figure 15). The proportion of each approach for each one of game genres can be observed in side-by-side bar charts (figure 16). Judging by the number of "Action" games, we can see that the majority of AR games belonged to this genre regardless of the approach that was used in them. It appears that marker-based approach was more frequently used in almost every genre except for the slight 9% lose in "Action" category where Location-Based games were represented by 22 games which occupied 49% out of total number of "Action" games. In the "Casual" genre the Marker-Based games were just slightly more dominant with 10 games that corresponded to 48% of total rate compared to 9 Location-Based games that occupied 43% of all "Casual" games. For the other game genres we can clearly observe the major dominance of Marker-Based games. Nearly 90% of "Puzzle" games were using the markers and around 80% of "Sports games" were based on marker-system as well. Besides the total proportion, we can see that Marker-based approach was represented by 9 “Sport” games which made it the 3rd largest genre type for this approach. Twice as many (67%) of “Lifestyle” games were using the marker system compared to 33% of location-based ones. The “Entertainment” category was represented by 2 approaches with the 67% rate of marker-based games and 33% rate of location-based games. All of the “Racing” games were using the marker system. The slightly less frequently encountered “Puzzle” genre was represented by 8 marker-based games which made up around 90% of all “Puzzle” games. The least frequently encountered game genres included “Entertainment” genre with 4 representatives and 2 games for each ”Lifestyle” and “Racing” genre. However, this small number of games occupied the larger proportion compared to the number of representative games from other AR approaches. Regardless of the domination of Marker-Based games, the Location-Based games were significantly more frequent than the “Other” approach games that were rarely encountered. We can see that the rate is somewhat equally distributed among the 3 game genres (“Action”, “Casual” and “Sports game”) with the rate of 11% in “Action” genre which was slightly larger compared to 9% rate for both “Casual” and “Sports” genre, while being completely absent in the other genre categories. There were totally 9 games that used “Other” approach with 6 games of “Action” genre, 2 of “Casual” and 1 of “Sport game” genre. In general, we can see that the variation of gameplay type is somewhat biased, being much more dominant in “Action” and “Casual” game genres and being almost completely absent in other genres.

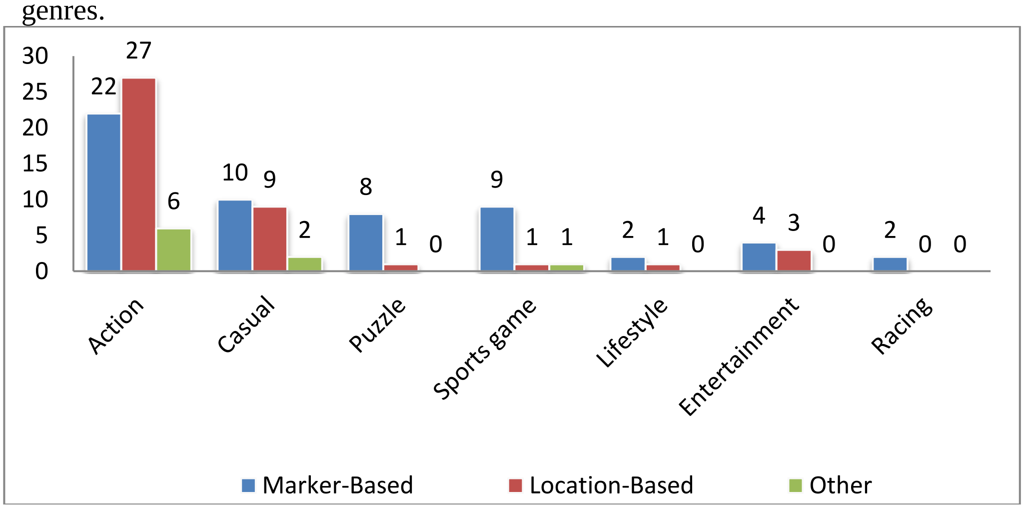

Figure 15: Frequency of games of each genre per AR approach.

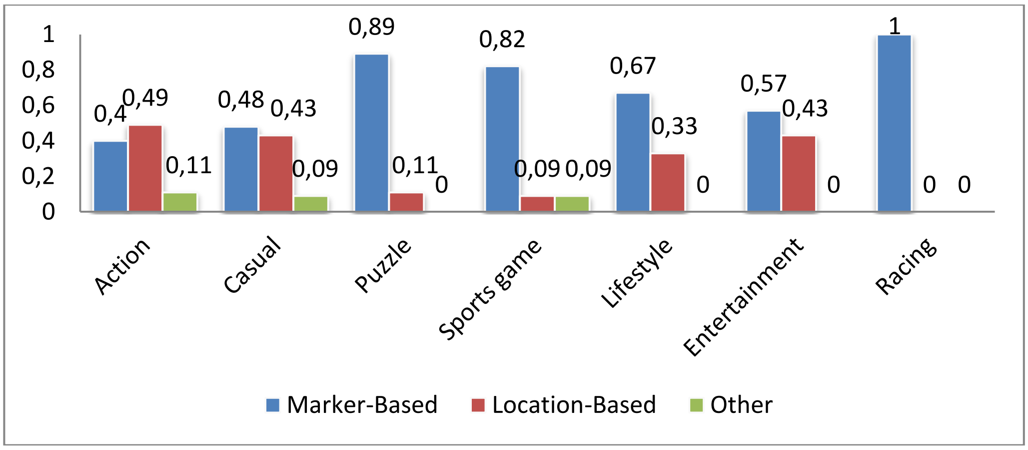

Figure 16: Frequency of games of each AR approach per genre.

To get a more specific overview of the genres for 3 approaches, the pie charts in figure 17 can be observed.

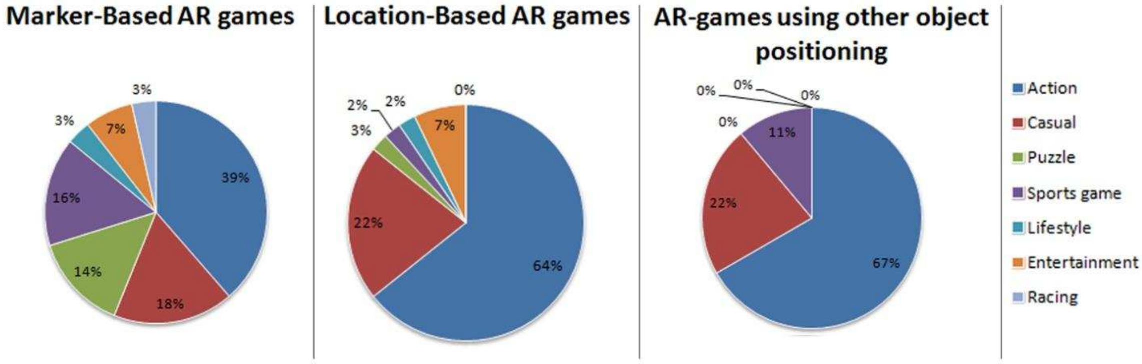

Figure 17: Dominance of game genres per approach

From the figure we can see that “Action” games were the most common for all three categories with 64% for Location-Based, 39% for Marker-Based and 67% of share for other approaches. This genres’ share occupies more than half of the total genre distribution in Location-Based approach being the most frequently encountered game genre in this category. It was nearly 3 times as frequent as the “Casual” games, while the other genres occupied only 14% of the total share. In marker-based games, the “Sports”, “Puzzle” and “Casual” games were almost equally frequent, in total, occupying roughly 50% of the total share of genres for this approach. The remaining share was divided between “Racing”, “Entertainment” and “Lifestyle”. While most of the games that used the “Other” AR approach were of “Action” genre, there were still 22% and 11% of games in “Casual” and “Sports game” genres respectively.
In order to use the phone appropriately to achieve the AR effect, some of the phone features had to be accessed and manipulated by the game application. The required access to the phone features were presented for user confirmation when the user would actually install the games. The information about the requests for access to different phone features was recorded and displayed as a bar chart (figure 18).

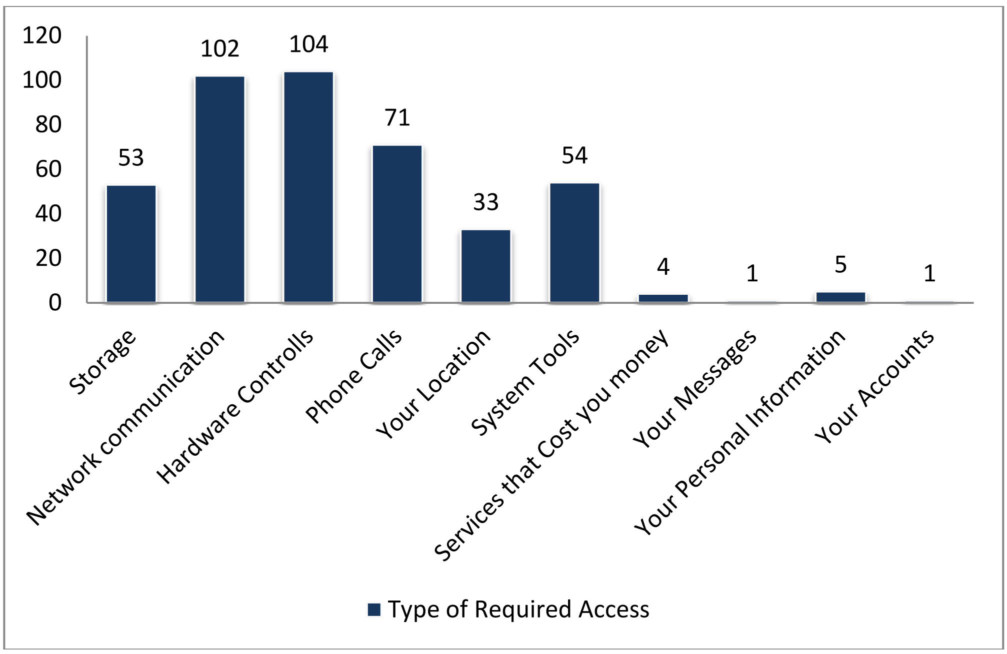

Figure 18: Bar chart that shows the # of games that requested access.

The major part of the studied games, which was counted as 102 games or more than 90% of all studied games, required the access to the "Network Communications" and they required the access to "Hardware controls" which included the usage of camera features and audio settings. The "Phone calls" feature for saving the data in case if the game process was interrupted by the phone call, was required by 66% of games. There were 50% of games that needed to control "System Tools" which allows the modification of network connectivity and screen turn on/off properties all of which in their turn affect the phone's battery life and thus the applications that need this access might be energy draining. Around 50% of games needed access to the phone's storage in order to modify (add/delete) information from the memory card. The GPS location that lets the application to know where the user is provided by the "Your location" permission and it was requested by 31% of the studied games. There were several games that needed access of somewhat "dangerous" phone features. For example, the "Services that cost you money" permission allows the application to make phone calls and it was requested by 4% of games. The "Your messages" permission is similar to the previous one, in terms of that it performs actions like sending messages that would cost you money and this kind of access was requested by only 0.09% of all games which is an insignificant amount. The "Your personal information" is somewhat unusual permission to be requested by a game, since most commonly it's used by messaging applications, however it was requested by 5% of the studied games. There were also 0.09% of games that needed access to the User's accounts.

Some of the permission requests could indeed be harmful to the mobile device or to users personal information confidentiality in one sense or another, so in order to detect if the game application deserves to be trusted the access to the phone features, it's wise to evaluate the user reviews as well as the number of downloads and rating for the game of interest before the installation. Those particular aspects are examined in the section 4.2 of this paper.

Some of the tested games had proper AR effect but in some cases the additional technical aspects or features were omitted, the presence of which would otherwise improve the gameplay experience. In particular the games were tested for the presence of the features like multiplayer mode, sound effects triggered when interacting with the virtual objects and the 3D position of those virtual objects in space. The result of the game tests for three different game features was recorded for each one of the games and summarized in the table (table 5).

Table 5: Table with number of games with features of interest

	3d	Multiplayer	Sound Effects
Marker-Based	55	5	46
Location-Based	34	9	22
Other	0	0	4
Total	89	14	72

In the figure 19 we can see the number of games with one of the features.

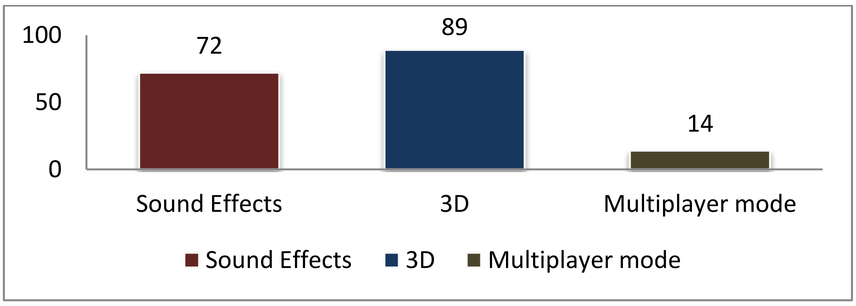

Figure 19: Number of games with features of interest

The proportion of the games with noted features to the total number of studied games can be seen in the figure 20.

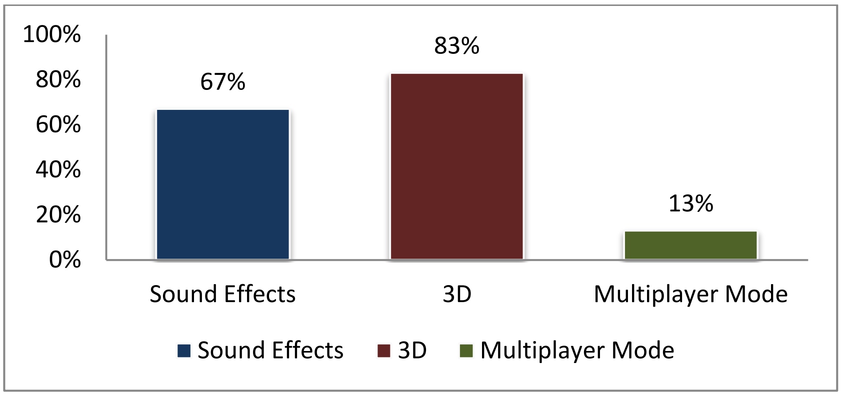

Figure 20: Proportion of games with features of interest

According to the results of testing, we can see that 72 games or 67% of the total number of games had the sounds when the player interacted with the virtual objects giving the game a proper appeal and more noticeable feedback. 89 out of 108 or 83% of the games were noted to have the 3D object positioning. The absence of the 3D mode was noticed mostly in the games that could hardly live up to the AR definition that was previously described in the paper. Most of those games were simply using the camera view as a game background. Some of the games were using the Google map as a gaming ground with virtual objects positioned on top of that 2D map and the users' positions would be determined by the GPS. As noted from observation, only 14 games, which accounted for only 13% of the total number of examined games, had the multiplayer mode that would allow multiple players to participate in the game session either through a network or by taking turns on the same device. We can say also conclude that only 9 out of 10 AR games did not have the multiplayer mode and roughly every 7 and 8 games out of 10 had the sound effects and the 3D mode respectively.

Separating the games with features by approach we can see in what approach-based games those features were most commonly encountered (figure 21) and what is the total share of the games with futures from the total number of the games that used one of the 3 approaches (figure 22).

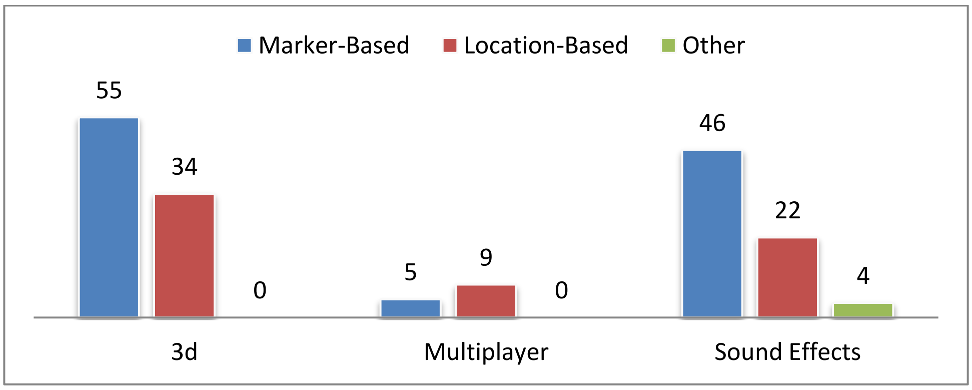

Figure 21: Number of games with features per approach

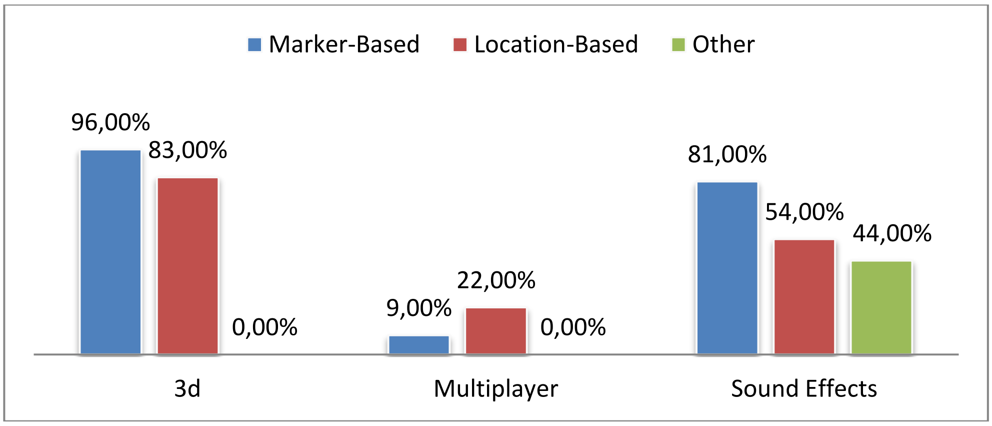

Figure 22: Proportion of games with features per approach

As we can see from those 2 figures with bar charts, the marker-based games has a bigger frequency of having the 3D and Sound Effects features 55 and 46 representative games which make up 96% and 81% from the total number of marker-based games respectively. When it comes to the Location-Based games, 34 games had the 3D and 22 games had the sound effects which were accounted for 83% and 54% from the total number of the games that used this approach. Even though, the games that were based on the Other AR approach had a questionable AR effect, they still had sound effects in 4 out of 9 cases which accounted for 44% of all Other-based games, while the other 2 features were completely absent.

Some of the games had more than one of those features implemented in one game while some of the games did not have either one of them. The number of games having different features was counted and summarized in the table (table 6). Where,
SE = {Games with Sound Effects}
3D = {Games with 3D object positioning}
MM = {Games with Multiplayer Mode}

Table 6: Number of games with features of interest

	SE	3D	MM	SE *U* 3D	3D *U* MM	MM *U* SE	MM U SE *U* 3D	not(MM *U* SE *U* 3D)	Total
# of Games	6	23	2	56	2	2	8	9	108

Using the data from the table, the Venn diagram was constructed for easier understanding of the presence and absence of game features (figure 23).

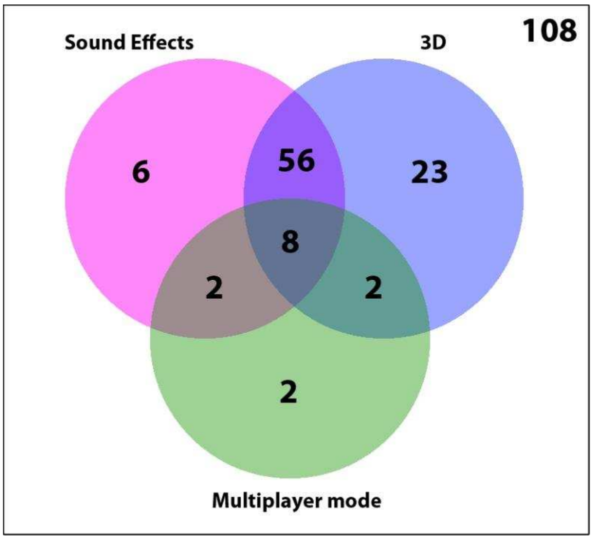

Figure 23: Venn diagram representing Number of games with features of interest

From the Venn diagram we can see that 6 games had only sound effects and no other features. Another 23 games had 3D positioning only. There were 2 games did not have neither sound effects nor 3D, however they had multiplayer mode. Another 56 games had only 3D and Sound Effects. There were also 2 games that had both multiplayer mode and sound effects and another 2 games that had multiplayer mode and 3D object positioning. Considering the total amount of tested games there were a very few games that had all three features present at the same time. There were only 8 out of the 108 games had Sound Effects, Multiplayer Mode and 3D positioning which is only 7% of all games. There were also 9 games that did not have either one of the features where 5 of those games were based on the “Other” AR approach which actually explains the absence of those features due to the poor AR implementation quality of those game applications.

The runtimes for all 108 games were measured and recorded into the table. The result of the measurements can be observed as the two bar-charts merged into one graph for a better comparison (figure 24).

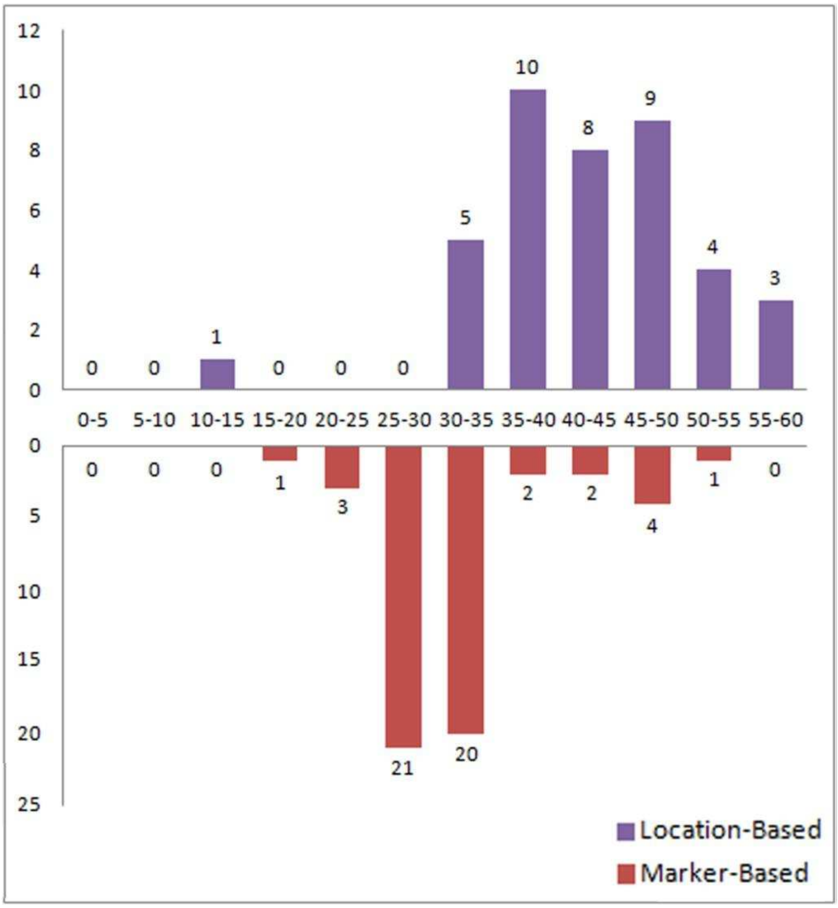

Figure 24: The bar-charts that display the FPS for each game separating them by AR approach

From the figure above we can see that the majority of games that were using the Location-based approach were running at more than 35 FPS while the majority of the Marker-based games were running at less than 35 FPS. There was one outlying Location-based game that showed the lowest result that was observed during testing which approximated to fall within the interval of 10 to 15 FPS.

The games that were tested in this research had different distribution type. They could either be freeware or payware. The freeware are the game applications that are free to be used without any additional cost. Even though the freeware games held the majority, there were some games that had the payware status meaning they were developed as commercial software and they were required to be purchased (figure 25).

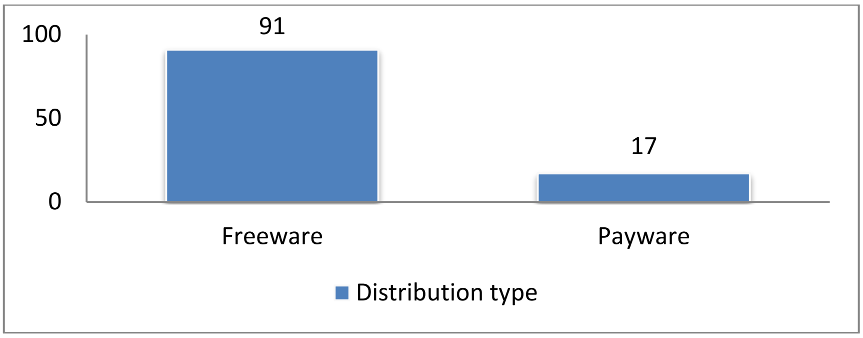

Figure 25: Number of games of different distribution type

From the bar chart above we can see that 91 games were freeware which corresponds to 84% of all studied games. There were 17 games or in other words 16% of all games that were distributed as a payware (figure 26).

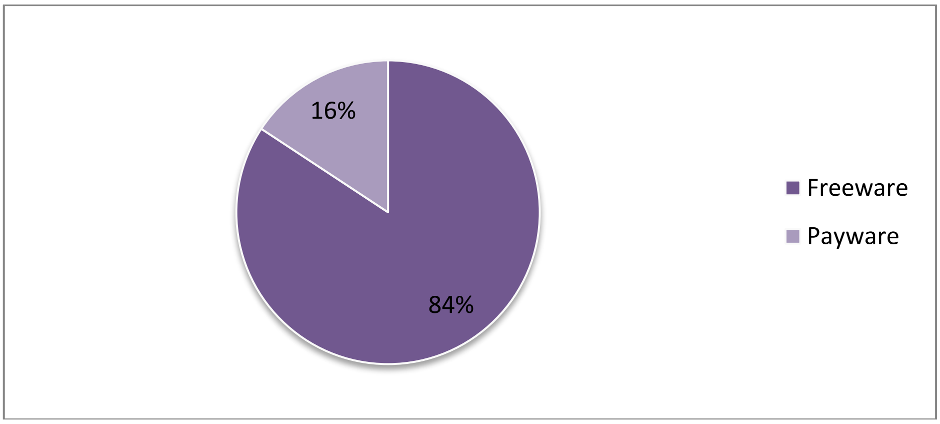

Figure 26: Share of games of different distribution type

Taking a closer look at the payware and freeware games by separating them by the AR approach we can note that every 8 marker-based and location-based games were freeware, while the games that were using other techniques were distributed for no commercial purposes (figure 27).

By taking a closer look at the AR approaches distinguished by distribution type we can conclude that for every 10 AR games that were Location- or Marker-Based, roughly 8 games were freeware which clearly shows the domination of this kind of distribution on the platform. The games that were based on the Other-approach were fully freeware.

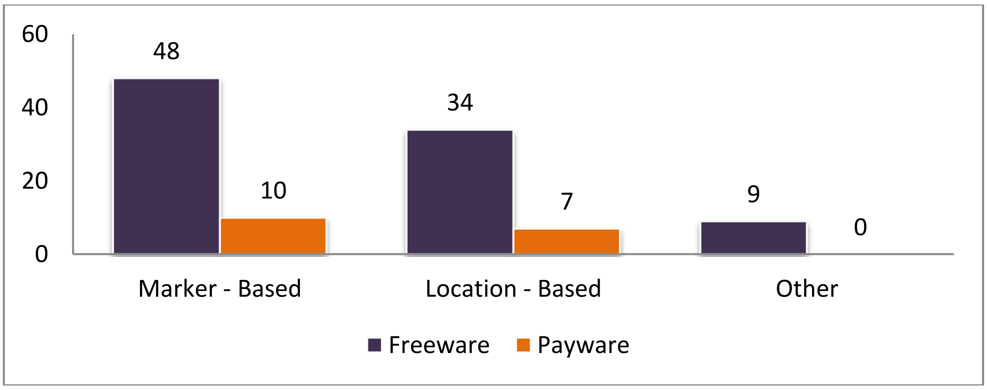

Figure 27: Number of freeware/payware games for each AR approach

When it comes to the payware games there is a specific price for each one of them. The prices for the payware game applications were summarized and analysed (table 7).

Table 7: Overview of payware prices

Prices	
Mean	10,8
Min	7
Max	16,99
Std.dev	3,86
Num	17

The average price of the payware game, judging by the total 17 payware games, was at around 11 SEK with the minimum price of 7 SEK and the maximum price of ca. 17 SEK. The prices varied with standard deviation of 3.8 SEK.

From the bar chart (figure 28) we can see that the majority of payware games' prices were at around 7 SEK with only 3 games having the price of ca. 16 SEK. In the majority the user was asked the smallest possible price for this kind of game applications.

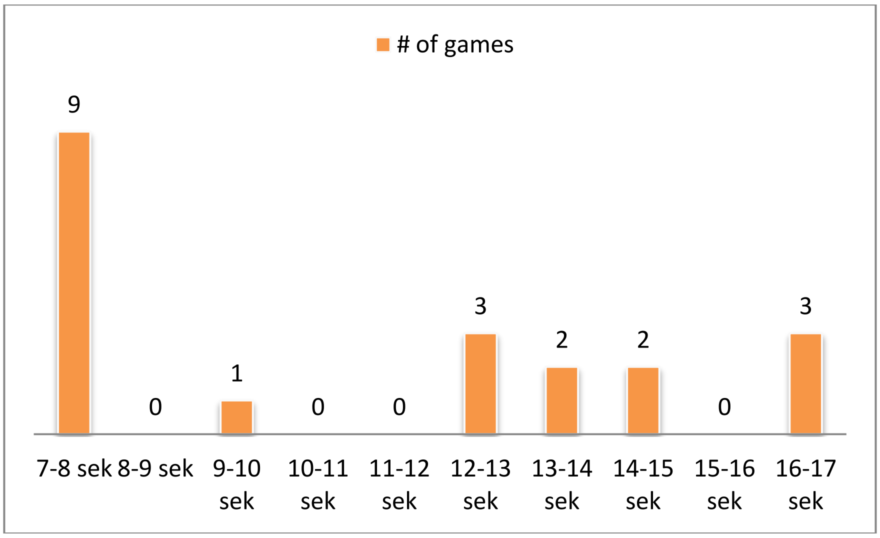

Figure 28: Bar chart of prices

The full table of collected information about games, their runtimes and the AR approaches that were used in them can be seen in the Appendix 1 section of this work. After studying the technical aspects of the AR games and taking a look at the prices we can proceed with examining the results received from the user studies.

4.2 Result of User Studies

The reviews were studied for as many games as possible. To be more specific, only 61 out of 108 games which is only 55% had a sufficient number of reviews in order to calculate a representative proportion. In other words, roughly every second game was not sufficiently reviewed to give an opinion. If the proportion of either review affiliation (positive or negative) was larger than the proportion of other affiliation then the game was considered to be reviewed according to the affiliation that had larger proportion. From the games that actually were reviewed there were 37 positive and 23 negative reviewed games in total, which correspond to 61% and 38% respectively. There was 1 game that had equal number of both positive and negative reviews resolving in a tie situation but for the analysis we disregard this reviewed game, since we are only interested in positive and negative reviews (Figure 29).

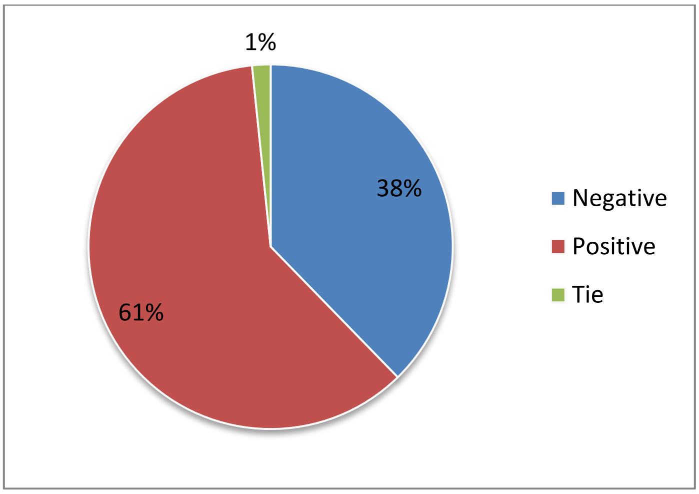

Figure 29*: Proportion of good, bad and "equal" reviews*

By taking a look at the proportion of bad and good reviews separated by the approach, we can see that in general the proportion of good reviews is larger than the proportion of bad reviews for all three approaches (figure 30), however the proportion of bad reviews is significant, since we can conclude that in general only 6 out of 10 games were positively accepted by the users. For the Location-Based and Marker-Based approaches there were 58% and 69% of positively reviewed games, while for the "Other" approach the negative reviews were dominant with 60% of share. Even thought the percentage of bad reviews is very significant, the Marker-Based games still tend to be more positively accepted than other approaches, regardless of the fact that the user have to print the actual marker in order to play the game.

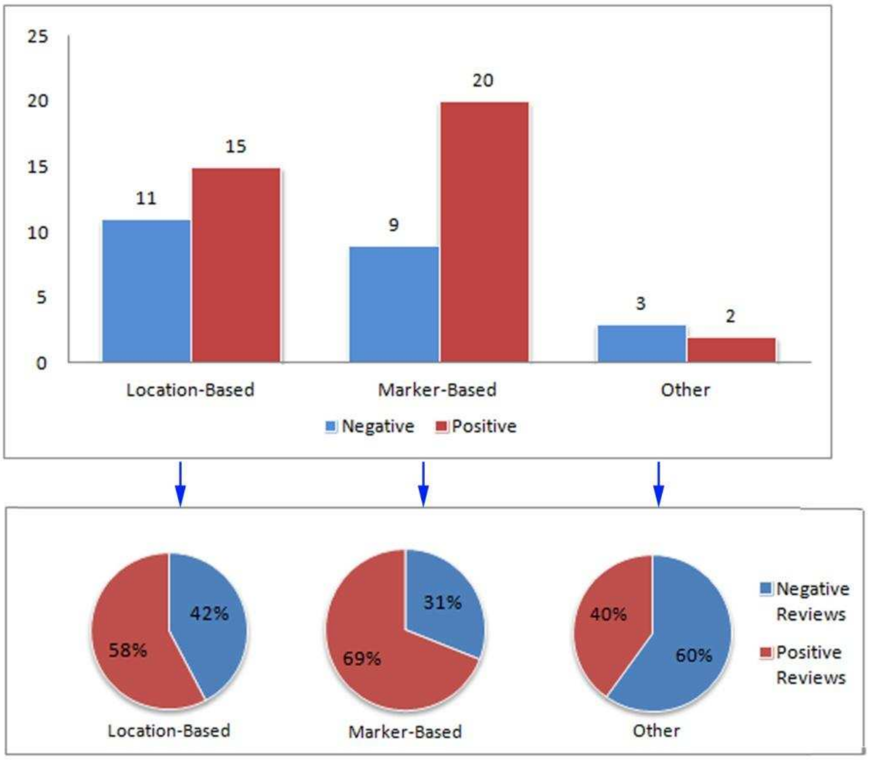

Figure 30: Bar charts and pie charts displaying the proportion of good and bad reviews for each AR approach.

Generalizing the reviews into Positive and Negative categories was done using the comparison of reviews' proportions. So, if the proportion of good reviews was larger than the bad reviews' proportion then the game was considered to be generally positively reviewed, otherwise it would be categorized as the negatively reviewed one. But before generalizing the reviews, their frequencies of appearance were counted (figure 31).

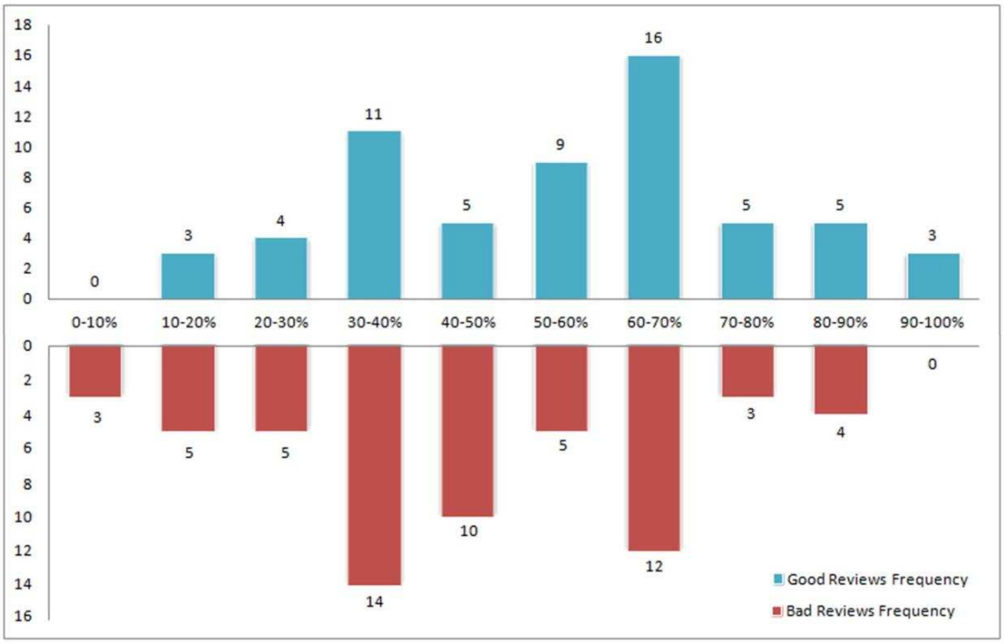

Figure 31: Bar charts and pie charts displaying the proportion of good and bad reviews for each AR approach.

From the graph above we can notice some similarities between percentages of both bad and good reviews. For both review categories the number of reviews tended to be in the intervals from 30-40% and 60-70% of affiliation. Meaning that from 30% to 40% of the reviews for 11 games had a positive acceptance and for the same percentage interval there were 14 games that had negative acceptance. The 60-70% of reviews were negative for 12 games and positive for 16 games. There were 3 games that fell in the 90-100% interval meaning that they were nearly fully positively accepted by the users.

Besides the positive and negative reviews there were also user feedbacks that complained about some technical aspects, whether it was some object positioning problem or compatibility problem that made it impossible to properly run the game. The technical complains were very probable reasons of the bad game reviews and thus the proportion of technical complains to the total number of bad reviews per each game was calculated and represented as percentage intervals as well(figure 32).

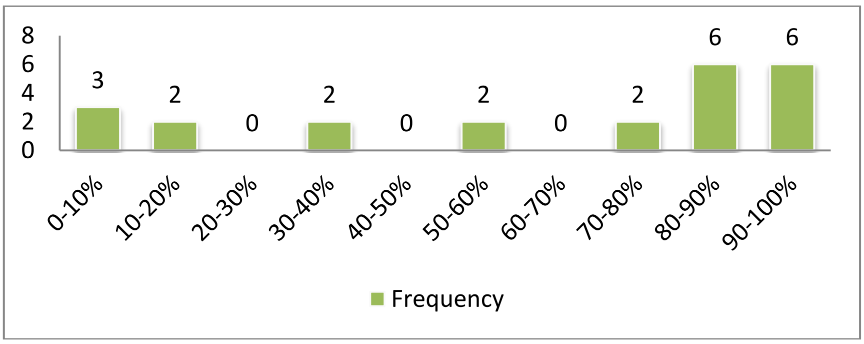

Figure 32: The bar chart that displays the number of games with different proportion of technical complains to the bad reviews.

There were 14 out of total 23 badly reviewed games that had technical complains in the interval from 70-100% which means that more than 70% of those negative reviews were due to technical issues and which correspond to 61% of all bad reviews fell in that interval(figure 33).

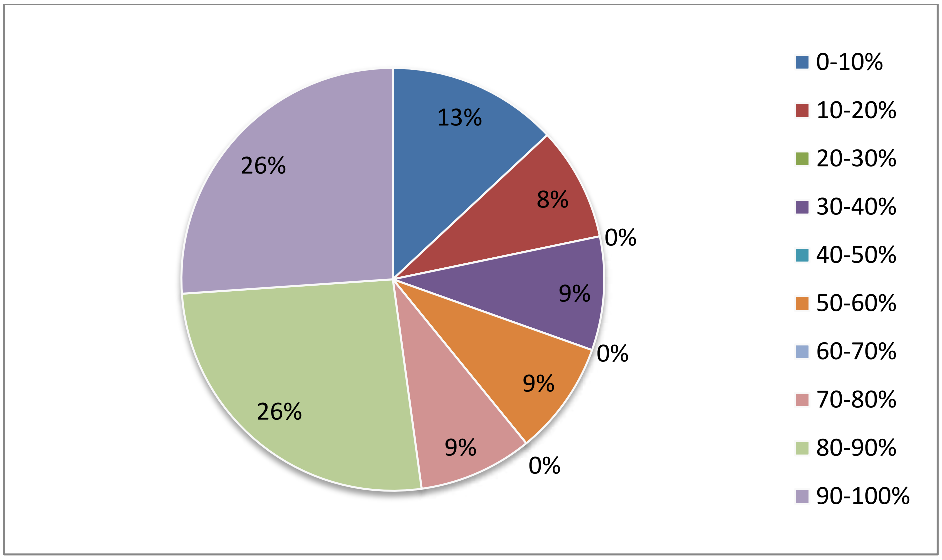

Figure 33: The pie-chart that displays the proportion of percentage intervals of technical complains.

There were 5 games that had less than 20% of technical complains meaning that 21% of badly reviewed games were negatively accepted due to the gameplay issues like the lack of long lasting interest or unclearness of the game process etc.

If we go beyond the negative reviews and take a look at the proportion of technical issues even for the games with the dominance of good reviews, we can see that the bad reviews in their turn still contained a large proportion of technical issues. But these technical issues were detected by fewer users and thus it did not shift the general game affiliation from good to bad. For the purpose of determination of which AR approach was more technically issued, the number of games whose proportion of technical complains to the total number of bad reviews was larger than 50%, was counted and then that number of technically issued games was used to calculate it’s share in the total number of reviewed games for that approach (figure 34).

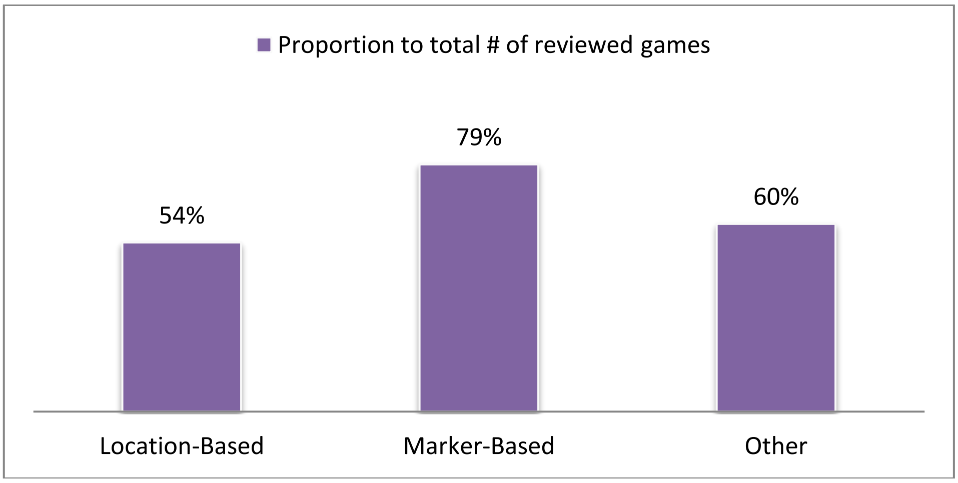

Figure 34: Total proportion of dominant technical issues to total number of reviews per game for each AR approach.

It appeared that the Marker-Based games generally received more technical complains than other AR approaches. There were 79% of all reviewed marker-based games that had more than 50% of technical complains per each. We can conclude that roughly 8 out of 10 marker-based games had technical issues. The much smaller percentage of Location-Based games caused any technical complains from users where only 54% of reviewed games were technically issued to some extent. There were also 60% of reviewed games based on "Other" approach that had technical complains. Considering the data from the bar chart it's clear that the marker-based games are still in need of improving the technical stability.

Another important factor that could influence the users to choose the game was the total number of times the game was installed by other users, meaning that the larger is the number the more popular the game is and the more reliability it gives to other users to try it out for themselves. In the figure 35 we can see the number of games with different number of installs by users.

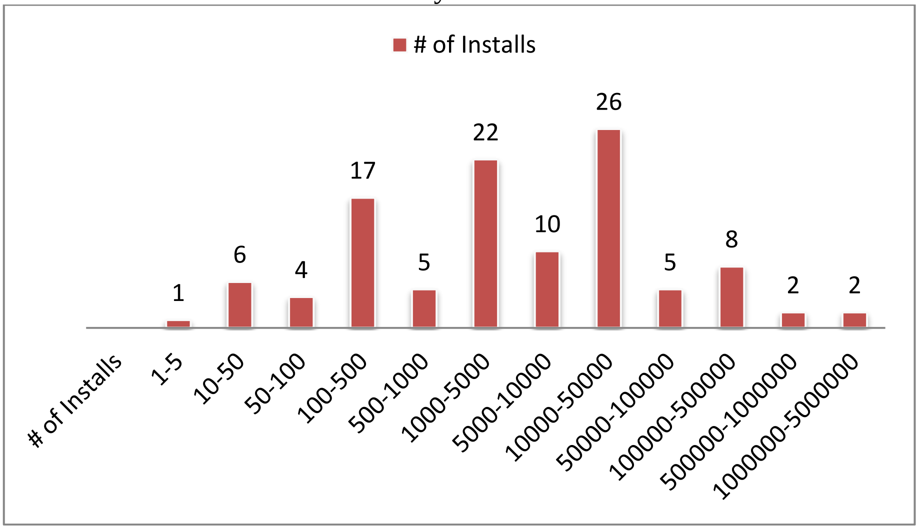

Figure 35: The number of installs by the users.

We can see that the major part or 58 of games had been installed at least 1000 and at most 50000 times. This makes up to 53% of the total number of installs for all studied games (figure 36).

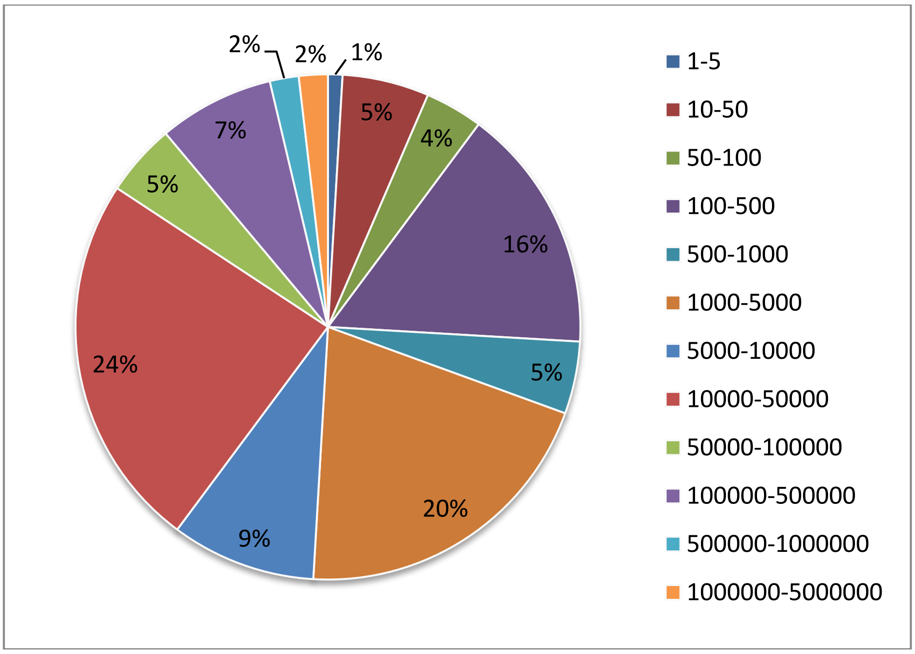

Figure 36: The proportion of installs by the users.

From the pie chart we can see that only 4 games were popular enough to gather at least 500000 installs with the maximum at 5 million installs. Those 4 games occupied only 4% percent of the total number of installs. About 26% of the studied games were downloaded less than 500 times which means that roughly every 3 out of 10 examined AR games were hardly known by users or were of unreliable quality.

The number of installs for both distribution types of games can be seen in the figure 37.

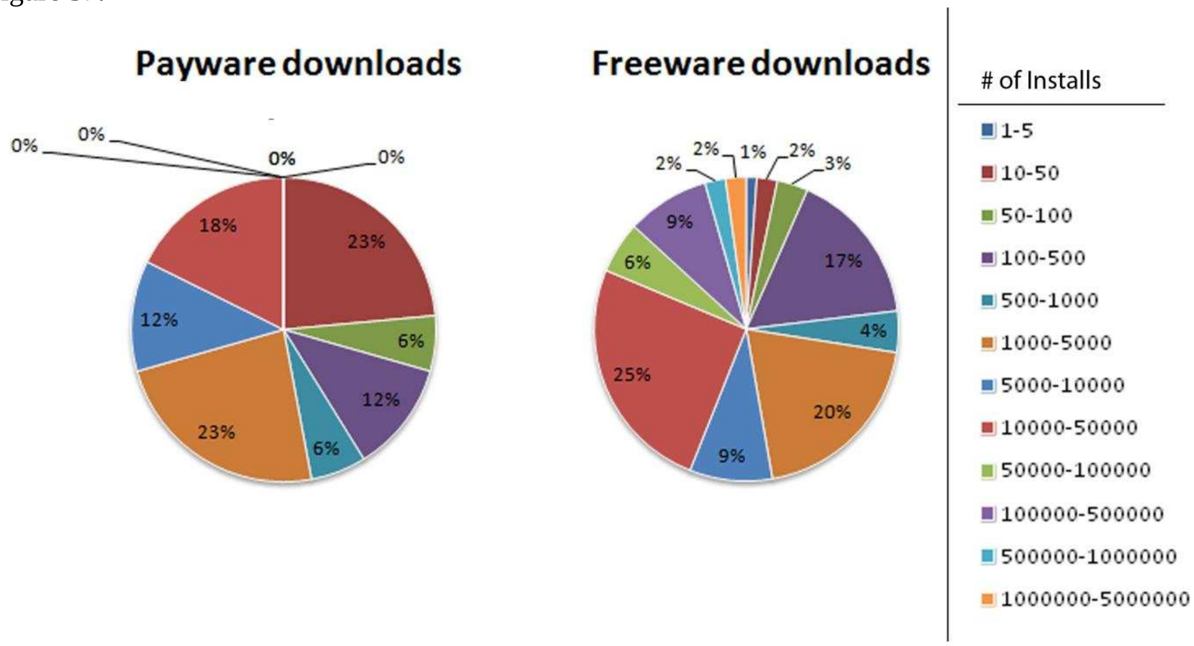

Figure 37: The proportion of installs by the users for each distribution type.

From those pie-charts we can see that for payware games there were no particularly popular games that had the number of installs above 50000. Out of those games 70% had at most 5000 installs only. While, taking a look at the freeware games we can see a larger popularity. For the freeware games there were noticed 2 games that had been installed at least 1 million times. Those games were "Parallel Kingdom" which was a multiplayer online game and "Red Bull AR Reloaded". In its majority, the freeware games were more popular. In 50% of cases the games were installed at least 10000 times and in 25% of cases there were at least 50000 installs while this number of installs was not even detected among the payware games. In only 6% of freeware games there were at most 100 installs, while among the payware games this percentage was 5 times larger being 29% percent of all payware games. The detailed number of installs for both payware and freeware can be observed in the Appendix I. One of the important aspects that might influence the users' opinion about the game is the game's rating that was set by other users. In the figure 38 we can see the most common ratings for the AR games on Android platform. The ratings were only collected from the games that had at least 5 votes. The games with fewer votes were disregarded due to the lack of representativeness. In total the ratings from 81 games were collected.

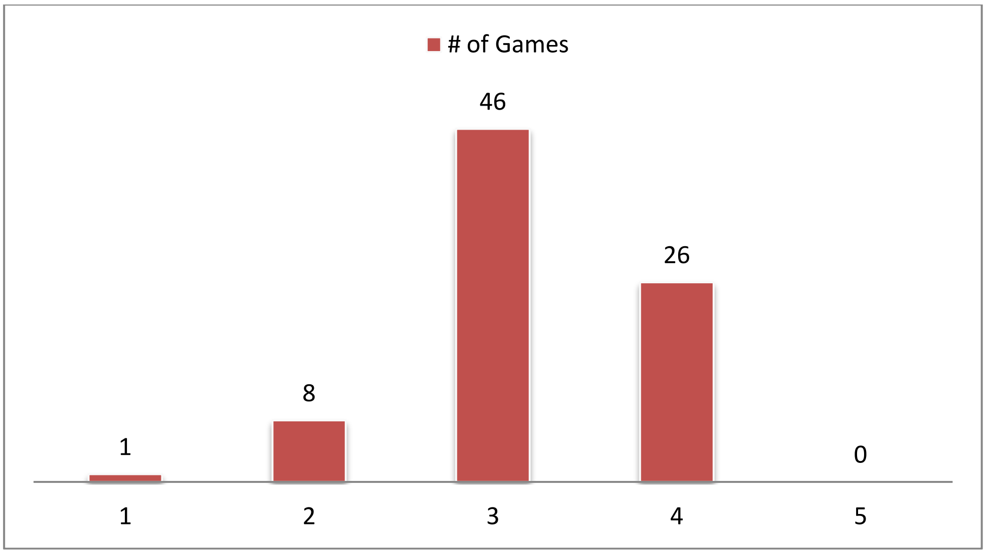

Figure 38: Number of games for each rating.

According to the graph the majority of games were given the rating “3”. While almost half of that amount were given rating “4”. There was one game called “Destroyer AR” which was based on the “Other” approach and that was given rating “1” (the lowest possible) which made up 20% of the total games of this approach and that most likely depended on the technical issues of this game that was based on the Other AR approach. If we take a look at the proportion of game ratings to the total number of rated games per approach (figure 39) we can see that biggest proportion of games for all AR approaches had the rating of “3”. For instance, 60% of Location-based games had rating “3” while only twice as few games based on that approach had rating “4”.

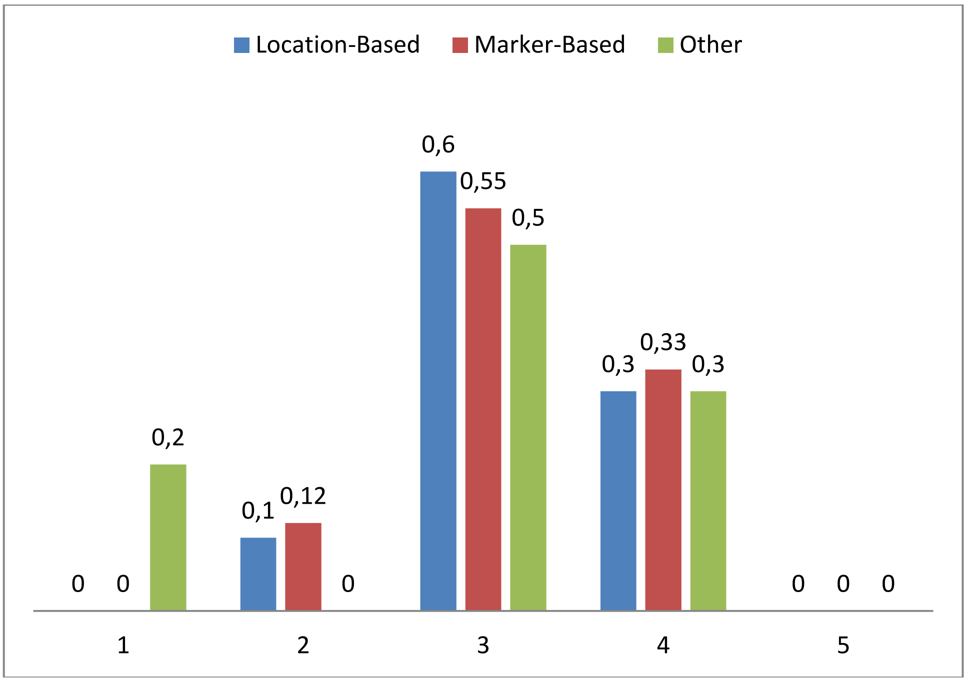

Figure 39: Proportion of games for each rating separated by approach

Since the games were distinguished by different genres, we can take a look at how the ratings were distributed among those genres (figure 40).

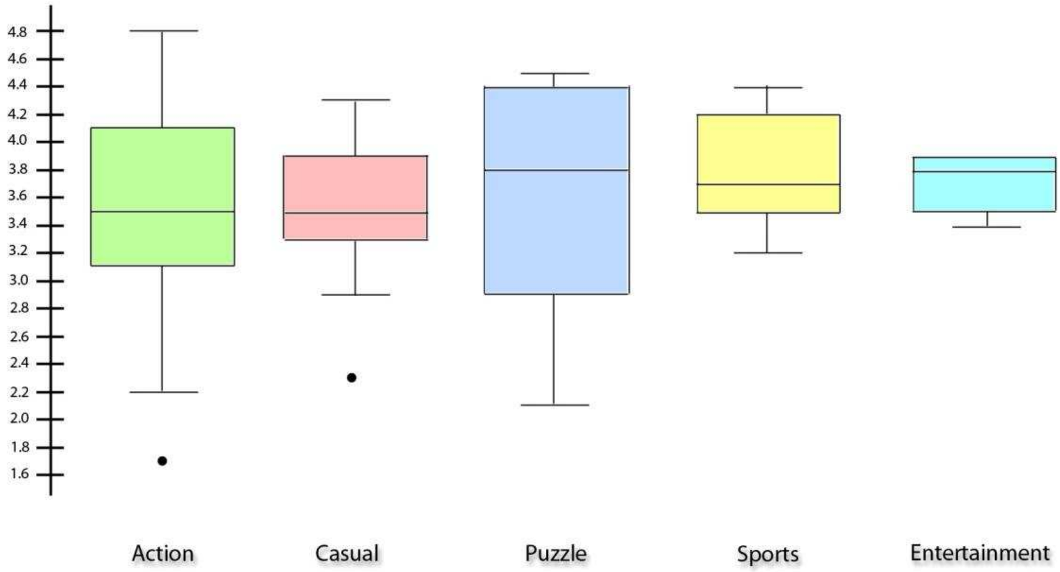

Figure 40: Rating distribution for each game genre.

Both “Action” and “Casual” games’ median ratings were set around 3.5, while the ratings for “Casual” games were much more consistent judging by the spread of distribution. However, both genres had some outlying games with uncommonly low for that genre rating. The outlier for “Action” genre had the rating of 1.7, while the outlier for “Casual” game had the rating of 2.3 which was even higher than the extreme value of “Action” game which laid at 2.2. In general, the main distribution of both “Casual” and “Sports” genres were similar where the second one received slightly higher ratings. For the “Puzzle” genre, 50% of games had the rates in the interval from 2.9 and 4.4 which corresponds to the lowest rating consistency among other genres. 25% of “Puzzle” games received rating lower than 2.9 which is the largest amount out of all genres. The “Entertainment” genre had the most clustered distribution of rating compared to other genres, which depends on the insufficient number of encountered games from this category compared to the studied games of other genres. However, all of the rating for this genre was set above 3.4 with the median rating positioned at 3.8 which is the highest detected median rating among all studied genres.

The representation of game rating for “Racing” and “Lifestyle” games were disregarded due to insufficient amount of user votes that determined the game rating which was less than 5 votes. The complete table with data about user opinions and game ratings and number of installs can be found in Appendix 2 section.

5 Discussion

When the research in the AR field just began, it always required a lot of expensive and bulky hardware which made the games based on that technique non-mobile and inaccessible for the broader audience. Compared to the regular non-AR gaming session where the user interacts by simply pushing the buttons, in the AR games the actual interaction between the user and the virtual world is provided by making the spatial position of the user to become a part of the gameplay. With the increased computational power of the modern mobile devices the possibilities in terms of technological solutions in achievement of completely new style of human computer interaction can become much broader for developers to realise the creative and innovative ideas. The ideas that were analysed in this paper also varied in both approach and the implementation quality.

5.1 Discussion of the games tests' results

According to the test results that can be observed in the figure 12, it was discovered that Marker-Based approach was used in more than 50% of mobile AR games, being the most frequently encountered AR approach for games on Android. The location-based games were somewhat less frequent being encountered in roughly 40% of cases. There were, however, around 10% of games that were "pretending" to be using the AR technique, in terms of using the camera view as a game background, where the virtual objects were not actually integrated into the real world or in other words they were not positioned according to the processed data received from that camera view. They were perhaps more like a misunderstanding of how the AR games should be structured and what goals they should fulfil.

When it comes to the game genres, we can see some tendencies that the AR games have. According to figure 17, more than 50% of all studied games turned out to be of "Action" genre and only around 20% of games were "Casual" genre whereas the "Racing" was almost completely absent from the AR game genres being only encountered 2 times where one of them could not be even called proper AR. That tendency makes it possible to conclude that the game developers do not stray too far away from the general stream of game design ideas. It means that the outreach of the experiments in terms of innovative gameplay is currently very narrow. The more equally distributed frequency among the genres would mean the larger variation of games on the market to choose from. The variety of genres, however, is related to the AR approach that is used in the games. The game genres for Marker-Based games are more diverse according to figure 16, meaning that the gameplay of those games are more spread in terms of design solutions. Even though the "Action" games still occupied nearly 40% rate of the total genres' share, the marker-based games, however, included a somewhat equal share between "Casual", "Puzzle" and "Sports" game genres offering users more variety of game design solutions compared to Location-based games. This perhaps depends on the fact that the usage of marker can open up some creative design ideas for developers due to the virtual object positioning attached to the marker positioning which can be regulated by the player and that in its turn offers more interactivity than the "location" games. In the location based-games the "Action" genre occupied 64%, whereas "Casual" games took other 22% of the total share of games based on this approach leaving only 14% for the games of other genres. So in general, 8 out of 10 games would either be "Action" or "Casual" which does not offer so much variety from game to game. The games based on another "AR" approach was only represented by 3 genres which included nearly 70% of "Action" and the remaining share was divided between "Casual" and "Sports" genres. The drawback of all AR games on Android is their limitedness in the variety of gameplay styles, meaning that most of the games are made in the similar genre which means a very poor variety of gameplay styles from one game to another.

Since on the Android platform the user is the one who allows the application to access the phone features by permitting some of them when required, the information about those requirements was recorded and analysed. According to the results of the analysis depicted in the figure 18, as expected, more than 90% of all AR games required access to the camera that was provided by the "Hardware controls" permission and which in its turn is the main idea behind the AR which is augmentation of the virtual objects to the real world data received from the camera. The access to network communications was required by the majority of AR games and that was used, for example, to download online updates. During the user reviews' analysis performed in this work, it appeared that the users concerned about the questionable permissions that the game asks access to and which might make the mobile device vulnerable or exposed to threats. The main concerns were triggered by the permissions that would allow the application to use the features that might cost money or to access the account data and the data on the internal storage of the phone. Perhaps, some of the complaints about some of those permissions were due to the lack of the understanding of what those permissions actually do and how much influence the applications might get by getting that access. In fact, some of the truly so called “dangerous” features like account data and monetary spending permissions were only encountered in only 4% of cases making them very rare to be encountered at all. During the analysis, the complaints about the permission were integrated as a part of the technical complains about a game and they were analysed as a whole.

The important things that in combination with technical stability and decent gameplay might greatly improve and broaden the game experience could be, for instance, the sound effects, 3D object positioning and multiplayer mode. Those features were chosen to be analysed because in case of 3D it was interesting to determine how many games were actually using the 3D object positioning and if the 2D positioning was considered by developers when creating the AR games and which one of them was more popular. According to the results represented in the figure 20, the sound effects were detected in quite fewer games than it would be expected. It was noted 33% of studied games did not have any sounds which means that 3 out of 10 games were without any audible feedback that would provide the user with the more realistic and noticeable feedback to his actions and the absence of which would make the gameplay sessions somewhat tedious due to the complete muteness. The 3D mode, which corresponded to the virtual object positioning in the 3D coordinate system, was present in most games. The frequency of 3D occurrence corresponded to 83% or in other words, roughly 8 out of 10 games were using the 3D object positioning leaving the remaining share to the 2D AR games and the 2D non-AR games that simply used camera video as a background. The 3D AR games are currently more frequently encountered compared to 2D AR games meaning that the variety of 3D games is much broader than the variety of 2D games. The multiplayer mode was, on the other hand, a very rare feature that could be found in AR games. It was encountered in only 13% of the studied games or in other words only 1 out of 10 games had the multiplayer mode. This actually means that at this stage of game development the AR games are mostly dedicated to the single player use. The gameplay styles were more concentrated on achieving somewhat simple game goals that would not require assistance of multiple users. There were only 8 out of 108 games that had all 3 features detected in one game or in other words, 1 out of 10 games had all three technical aspects which account for only 8% of total share.

By taking a look at those features for each AR approach separately in the figure 22, we can see that marker-based games were more frequently noticed to have those features compared to other two approaches. Especially, if in Marker-based games the presence of sound effects was detected in 8 out of 10 marker-based games whereas only 5 out of 10 location-based games had any sound effects. As expected, the games that used neither one AR approach had neither multiplayer mode nor 3D object positioning, however the sound effects were present in 44% of them. So, in general the marker-based games are more technically advanced in terms of additional technical features than other AR games.

Another distinguishing factor between the AR games for Android was the distribution type that could either be payware or freeware. By taking a look at the figure 26 we can see that the distribution type’s share was equal for both Marker- and Location-based games but in general, the proportion of freeware games was significantly larger than the payware proportion meaning that roughly 8 out of 10 games were distributed without any charge. So, the developers of Android applications were not concentrated on implementing an AR game for commercialization purposes. This fact, in its turn, should broaden the audience due to the increased accessibility of AR applications available for testing without any additional charge and that would probably increase the audience and increase the interest rate in this kind of games.

According to the figure 28 the average price for a payware game was approximated up to 11 SEK with standard variation of 3.9 SEK whereas 50% of payware games' prices were below 10 SEK. The prices for the games varied depending on the popularity of the brand. For example, the price for "The Ghostbusters: Paranormal Blast" was around 13 SEK and which depended on the popularity of the franchise compared, for instance, to the "Lunar Eclipse" whose price was only 7 SEK. The prices for the more popular brands or for the games that were developed by more famous developers were larger due to reliability factor. It means that the quality of the games based on the popular brands would be expected to be better than the quality of the non-famous brands.

The runtimes can simplify the understanding about what approach is more computationally heavy and thus which one of them requires a more powerful hardware. Since the FPS is the speed of refreshment of the image, it plays an important role in the perception of the game process and in particular in the AR games where each millisecond matters. The proper refreshment rate is crucial in order to provide a smooth augmentation of the virtual objects into the constantly changing orientation of the camera's view when the user moves the mobile device around in order to observe the surroundings. Thus the measurement of FPS for each of the game applications was important to compare the refreshment rate for both AR approaches. Since 24 FPS is the minimum for the human to perceive the sequence of images as a moving image. But the closer the FPS is to 60 FPS which is the average FPS the eye can perceive the smoother and more natural is the game process [22]. As we can see from the test results depicted in the figure 24, the optimization issues are especially noticeable for the Marker-based approach where the majority of games were performing at less than 35 frames per second with an average of 31.5 frames per second. If we compare those results to the location-based approach we can see the significant superiority of the location based approach that in the majority of cases performed with more than 35 FPS with an average of 42 frames per second offering a somewhat smoother performance in AR gaming applications.

5.2 Discussion of the users' reviews analysis

The users' opinions can influence greatly the choice of other users whether to play the game or not. However not all of the games have the user reviews to guide the other users choice. Approximately, every second game did not have enough reviews to represent the quality of the game experienced by other users. The games with more than 5 reviews were considered as representatively reviewed in this work. As previously mentioned the reviews were divided into positive and negative categories because the reviews in general were either fully positive or fully negative without intermediate steps that might represent neutral opinion. From the analysis results depicted in the figure 29, it appeared that only 2 out of 3 games were of satisfactory quality in both gameplay and technical performance which is a quite low result. From the overall percentage of positive reviews represented in the figure 30, the main share or to be more precise 55% of all reviewed games was occupied by the marker-based ones. Further on, from the total number of reviewed marker-based games, 70% were positively accepted whereas for location-based games the positive acceptance rate was slightly less than 60%. The user reviews statistics prove that, in general, the marker-based games are more positively accepted offering a more satisfactory gameplay and technical performance compared to the Location-Based games.

When it comes to the user feedbacks about technical stability, the compatibility issue is very common, which makes some of the games completely unplayable on some mobile devices. As we can see from the figure 33, it appeared that the majority of games that tended to be negatively reviewed, mostly had the presence of technical complains. Every 6 out of 10 AR games were negatively reviewed due to technical problems. According to the figure 34 we can see that the main proportion of technical issues occurred in mostly Marker-Based games where nearly 80% of reviewed games based on that approach were mostly negatively reviewed due to technical issues. The Location-Based games appeared to be much less troublesome in terms of technical issues where roughly 5 out of 10 location-based games were overwhelmed by technical complains. The most frequently encountered problem with Location-based games besides incompatibility issue was the unstable object positioning. It was especially actual for the shooter games where the virtual objects would flicker and get stuck somewhere in space, making the game impossible to play. For the marker-based games the incompatibility issue was also not the only issue with that approach.

The unstable marker tracking was very frequently noticed both during testing of the games and the analysis of user reviews. That instability led to the shaky gameplay, meaning that the movement of the camera was very sensitively affecting the proper marker detection, which led to the frequent disappearance of the digitally generated game plane on top of the marker. The problem with marker depended greatly on the screen size of the mobile device. The larger screen size would allow observing a larger game area without the need to constantly move the camera around to see other parts of that area. The screen size would also be more suitable for location based games as well offering the larger area around the user that can be observed at once. This suggests that the AR would perhaps be more suitable for the tablets that have the screen big enough to cover a larger area of interest in the virtual world.

Judging by the results of the performed analysis many of the AR games were still in the experimenting phase, meaning that the developers, by trying to integrate the AR technology into the game, resulted in raw, but mostly positively accepted games. The gameplay styles were somewhat positively accepted because according to the figure 32 only less than 20% of negatively reviewed games were due to the non-technical problems. Those problems had to do almost entirely with the gameplay issues. However, the proportion of unstable and technically flawed games was still large enough to decrease the amount of trust in the AR field and thus repulse the desire of users to slightly stray away from the regular mobile games and try the AR games out as well.

One of the advantages of location-based games over marker-based ones was that the digital distribution of the location based games seemed more simplistic than of the marker-based games due to the absence of needing the physical marker that actually was required to be downloaded and printed in order to trigger the game. For the location-based games, the only thing the user had to do was to install the game and play it basically everywhere without the need of any additional required game materials. However, the marker aspect would, in some cases, make marker-based kind of games non-mobile. Regardless of the complains about the need of marker to play certain games, more than half of the available AR games were based on the marker system, making it the most commonly encountered AR technique (figure 12). However, the marker-based games might be more compact in terms of that the gameplay revolves around the position where the marker was placed, while for the location-based games the user would have to be more physically active making the player's movements as the basic requirement for the game of that type.

The main and the most obvious definer of how well the game was accepted by the users was provided by the overall game’s rating. According to the figure 39, the rating frequency was somewhat similar for both Location-Based and Marker-Based games that resulted in the similar variation of rating distribution. The average acceptance rate for games of all AR approaches was around “3” out of “5” possible points (figure 38).

One of the other defining factors that specifies how well the game is distributed among the users, could be determined by the number of times the game was installed by users. The number of installs in some way defines the popularity of the particular game among the users. The popularity denoted by the number of installs tells us whether the users are ready to pay for this newly, yet not completely discovered game technology, or not. According to the results of the analysis depicted in the figure 36 and figure 37, around 50% of all studied AR games were installed at least 1000 times and at most 50000 times. The share of games that were particularly popular with the number of downloads that exceeded 50000 up to 5 million times were only around 16% of all games, whereas all of those games were distributed as freeware making the maximum number of installs for payware game applications at most 50000 times. Perhaps the small number of installs of payware games depends on the uncertainty that surrounds the usage of AR technology and which leads to the doubtfulness of satisfaction that could be received from the gameplay session by users. The larger popularity of the freeware AR games' might depend on the fact that those games were distributed without any charge, meaning that anyone can try it without any financial spending that might not live up to expectations.

5.3 Overview discussion

As mentioned previously in this paper, the AR technology could be used to broaden the way people perceive information around them. This became especially topical because the AR applications could be accessed on mobile devices that can allow users to increase the amount of information they perceive, depending on the type of AR application of course. However, when it comes to the gaming applications that use AR, the situation is somewhat different. Many of the AR games suffer from the poor design choices that make the gameplay not long lasting, while the implementation in many cases suffer greatly as well. If properly implemented, the AR has a perspective future amongst many fields of study including mobile games. It seems like the proper development of AR based games on Android platform and perhaps other mobile platforms too is just initiating, being at somewhat initial states of creative and successful design ideas, attempting to make steps into the direction that would actually make the AR-based mobile games technically stable and capable of competitiveness with the regular non-AR mobile games. In general, all games are dedicated to fulfilling the entertaining purposes. Those purposes could be fulfilled by the regular non-AR games which have a much larger amount of variation in terms of gameplay styles and the amount of trust they received during the years of their existence. On the other hand, the AR games offer a somewhat different style of gameplay, but the amount of repetitiveness in gaming styles is still too large. At this point of mobile AR's existence the variation of AR games and their quality still remains a large issue to be taken into consideration for the future improvement of the situation in the AR game field.

In this paper the statistical overview of AR games and users' opinions about those games was performed for the Android platform taking into account technical aspects and features of those games. This overview can be used as a basis for understanding of the current situation around AR on mobile platforms. The functional stability of every game was tested and the results were analysed to determine the general stability of AR on Android. Since this paper offers the analysis of nearly all of the AR games, including the most recent ones, for the Android platform, this work can later be updated to see if the current AR situation will obtain a more solid structure and a stable position among the other non-AR games which would make it to become one of the major and widely accepted game types.

To answer the question about how the AR is used in games, we can say that, generally it could be used by applying one of the commonly known AR approaches that use either Location-based or Marker-based techniques. The former one uses object positioning where the objects are positioned according to the users location. The later one determines the virtual object positions according to the marker position and orientation. The games based on each one of those techniques differ in the gameplay styles. It's hard to say which one of the two approaches is better when it comes to the mobile games. Marker-based games have a slightly larger variation than location-games when it comes to the game styles. Both approaches, however, suffer from the technical issues. However, the majority of the studied games seem to be as the initial prototypes of the examples of how the AR can be applied as a part of the game design. There were just a few examples of a sufficiently good AR implementation. The use of AR in games still seems unnatural compared to the regular games. The AR gaming with its technical and design challenges still has a long way to go to become a core member of the game industry.

The previous work that was presented in the scientific papers by other authors was mostly concentrated on the application of AR technology for the more hardware demanding approaches. However those works presented much more creativity in terms of game design solutions and stability of the technical functionality of those games. In my work I concentrate on the AR application that does not require any specific hardware except for the mobile phones with Android OS, which is especially important and timely with the current availability and spread of the powerful mobile devices in the modern society.

However, my work could be improved by adding the analysis of AR games available on Apple devices. It's uncertain if the gameplay variation issue and the technical complains would be present on the devices that use Apple's iOS, and thus it would be interesting to analyse which one of the platforms offer more perspective for developers to create AR games contributing to the AR gaming field of research. The contribution would perhaps depend on the fact that the Google Play Market uses somewhat different distribution policy compared to Apple Store that in its turn is more advantageous for developers in terms of commercialization.

6 Conclusion

In my paper I performed an analysis of 108 mobile AR game applications currently available for Android platform. The general information and technical aspects about the games were collected and analysed. During the study some of the major limitations of the AR games were discovered and the tendencies of the AR game creation were detected. user reviews were collected and processed to determine the general user acceptance of the AR games on Android platform and to find the possible reason for the negative complains. All of the collected data was gathered and summarized as graphs. In this paper only games were taken into consideration thus the non-gaming AR applications were not analysed.

The studied games varied in terms of genre and AR approach that was used in them. The approaches were determined by how the virtual objects were positioned in real world. They could either be location- or marker depended, while some of the examples of questionable AR approach were detected as well. Those games used neither one of the two commonly known approaches. The runtimes for the games of Location- and Marker-based approaches were measured and studied in order to understand the computational demands of the approaches.

Since the target audience of the studied AR games was users of the Android mobile devices, the reviews of the users for the studied games were analysed. Unfortunately, it was impossible to gather enough reviews due to their absence for some games and thus the review information only for 61 games was gathered that corresponds to nearly half of the studied games. The popularity of the AR games was studied by collecting the data about the number of installs for each one of the games. The ratings were collected only for those games that had more than 5 votes that contributed to the average rating. This was done in order to make it more reliable in terms of difference of opinions that might come from different users. The user reviews were generally divided into 2 categories. They could either be positive or negative since the reviews were with a straight meaning and there were no intermediate and hesitating about the game quality reviews. The information about technical complains was gathered as part of the negative reviews and then their proportion to the total number of negative reviews was calculated to determine if the negative reviews mostly depended on the technical issues or some other non-technical aspects that had to do with the overall game design or gameplay interest. . As it turned out the technical issues are very commonly encountered in the currently available mobile AR games on Android platform. In general, the Marker-based games were more variant in terms of game styles but at the same time they were more computationally heavy and technically flawed compared to the Location-based games that offered a higher FPS and less technical complains. Regardless of the different technical specifications of the AR approaches, the games based on them were somewhat equally accepted by the users.

After the analysis of the games it turned out that the multiplayer mode is a very rare feature to be encountered in the modern AR games on Android platform. It means that game design of the current AR games concentrates on the achievement of the game goals suitable for single player use only

This work can be used as a basis for the analysis of the gaming applications that will be released for the Android platform in the future in order to detect if the unevenness in game style variation will be fixed. The general overview of the current situation of the AR games can help to understand how the AR is currently used on Android and if it can become a worthy competitor to the regular non-AR games.

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References

[1] "Revenues for Augmented Reality in Consumer Electronics Industry to Approach $600 Billion by 2016, Forecasts Semico Research." Newsgroup. BussinessWire. N.p., 16 Aug. 2012. Web. 10 Apr. 2013. <http://www.businesswire.com/news/home/20120816006090/en/Revenues-Augmented-Reality-Consumer-Electronics-Industry-Approach>. (Online; accessed 11-May-2013).

[2] Andersen, T. L., Kristensen, S., Nielsen, B. W., & Grønbæk, K. (2004, June). Designing an augmented reality board game with children: the battleboard 3D experience. In Proceedings of the 2004 conference on Interaction design and children: building a community (pp. 137-138). ACM.

[3] Ardito, C., Buono, P., Costabile, M. F., Lanzilotti, R., & Pederson, T. (2007, January). Re-experiencing history in archaeological parks by playing a mobile augmented reality game. In On the Move to Meaningful Internet Systems 2007: OTM 2007 Workshops (pp. 357-366). Springer Berlin Heidelberg.

[4] Azuma, R. T. (1997). A survey of augmented reality. Presence-Teleoperators and Virtual Environments, 6(4), 355-385.

[5] Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2001). Recent advances in augmented reality. Computer Graphics and Applications, IEEE, 21(6), 34-47.

[6] Barakonyi, I., Weilguny, M., Psik, T., & Schmalstieg, D. (2005, June). MonkeyBridge: autonomous agents in augmented reality games. In Proceedings of the

2005 ACM SIGCHI International Conference on Advances in computer entertainment technology (pp. 172-175). ACM.

[7] Big PlayAR, http://www.bigplayar.com , (Online; accessed 29-May-2013).

[8] Billinghurst, M., Poupyrev, I., Kato, H., & May, R. (2000). Mixing realities in shared space: An augmented reality interface for collaborative computing. In Multimedia and Expo, 2000. ICME 2000. 2000 IEEE International Conference on (Vol. 3, pp. 1641-1644). IEEE.

[9] Brown, D. G., Coyne, J. T., & Stripling, R. (2006, March). Augmented reality for urban skills training. In Virtual Reality Conference, 2006 (pp. 249-252). IEEE.

[10] Caillois, R. (2001). Man, play, and games. University of Illinois Press.

[11] Caudell, T. P., & Mizell, D. W. (1992, January). Augmented reality: An application of heads-up display technology to manual manufacturing processes. In System Sciences, 1992. Proceedings of the Twenty-Fifth Hawaii International Conference on (Vol. 2, pp. 659-669). IEEE.

[12] Cheok, A. D., Wan, F. S., Yang, X., Weihua, W., Huang, L. M., Billinghurst, M., & Kato, H. (2002). Game-city: A ubiquitous large area multi-interface mixed reality game space for wearable computers. In Wearable Computers, 2002.(ISWC 2002). Proceedings. Sixth International Symposium on (pp. 156-157). IEEE.

[13] Cho, K., Kang, W., Soh, J., Lee, J., & Yang, H. S. (2007). Ghost hunter: a handheld augmented reality game system with dynamic environment. In Entertainment Computing–ICEC 2007 (pp. 10-15). Springer Berlin Heidelberg.

[14] Cooper, N., Keatley, A., Dahlquist, M., Mann, S., Slay, H., Zucco, J., ... & Thomas, B. H. (2004, September). Augmented reality Chinese checkers. In Proceedings of the 2004 ACM SIGCHI International Conference on Advances in computer entertainment technology (pp. 117-126). ACM.

[15] EdgeLib, http://www.edgelib.com, (Online; accessed 27-April-2013).

[16] Fan, J. C., Jacobsen, J., Ronzani, P. A., & Pombo, S. (2002). U.S. Patent No. 6,452,572. Washington, DC: U.S. Patent and Trademark Office.

[17] Fenn, J., & LeHong, H. (2011). Hype cycle for emerging technologies, 2011. Gartner, July.

[18] FPSMeter, https://play.google.com/store/apps/details?id=com.aatt.fpsm , (Online; accessed 27-May-2013).

[19] Gerla, M. (2005). Ad Hoc Networks. Ad Hoc Networks, 1-22.

[20] Google Play Market, play.google.com , (Online; accessed 24-May-2013).

[21] Google Glass, www.google.com/glass/start/, (Online; accessed 19-May-2013).

[22] Haggard, E. A., & Isaacs, K. S. (1966). Micromomentary facial expressions as indicators of ego mechanisms in psychotherapy. In Methods of research in psychotherapy (pp. 154-165). Springer US.

[23] Huynh, D. N. T., Raveendran, K., Xu, Y., Spreen, K., & MacIntyre, B. (2009, August). Art of defense: a collaborative handheld augmented reality board game. In Proceedings of the 2009 ACM SIGGRAPH symposium on video games (pp. 135-142). ACM.

[24] Höllerer, T., & Feiner, S. (2004). Mobile augmented reality. Telegeoinformatics: Location-Based Computing and Services. Taylor and Francis Books Ltd., London, UK.

[25] Lam, A. H., Chow, K. C., Yau, E. H., & Lyu, M. R. (2006, June). ART: augmented reality table for interactive trading card game. In Proceedings of the 2006 ACM international conference on Virtual reality continuum and its applications (pp. 357-360). ACM.

[26] Lee, W., Woo, W., & Lee, J. (2005, May). Tarboard: Tangible augmented reality system for table-top game environment. In 2nd International Workshop on Pervasive Gaming Applications, PerGames (Vol. 5, pp. 2-1).

[27] Leyvand, T., Meekhof, C., Wei, Y. C., Sun, J., & Guo, B. (2011). Kinect identity: Technology and experience. Computer, 44(4), 94-96.

[28] LittleBigPlanet , http://www.littlebigplanet.com/, 2008. (Online; accessed 18-April-2013).

[29] Lundgren, S., & Bjork, S. (2003, November). Game mechanics: Describing computer-augmented games in terms of interaction. In Proceedings of TIDSE (Vol. 3).

[30] Löchtefeld, M., Schöning, J., Rohs, M., & Krüger, A. (2009). LittleProjectedPlanet: an augmented reality game for camera projector phones. Artificial Intelligence, 15-27.

[31] Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. IEICE TRANSACTIONS on Information and Systems, 77(12), 1321-1329.

[32] Molla, E., & Lepetit, V. (2010, October). Augmented reality for board games. In Mixed and Augmented Reality (ISMAR), 2010 9th IEEE International Symposium on (pp. 253-254). IEEE.

[33] Nilsen, T., Linton, S., & Looser, J. (2004). Motivations for augmented reality gaming. Proceedings of FUSE, 4, 86-93.

[34] Piekarski, W., & Thomas, B. (2002). ARQuake: the outdoor augmented reality gaming system. Communications of the ACM, 45(1), 36-38.

[35] Quest-Com Co.,Ltd, http://www.quest-com.co.jp/ , (Online; accessed 20-May-2013).

[36] Starner, T., Leibe, B., Singletary, B., Lyons, K., Gandy, M., & Pair, J. (2000). Towards augmented reality gaming. In Proceedings of IMAGINA.

[37] StbTracker, http://handheldar.net/stbtracker.php . (Online; accessed 11-May-2013).

[38] Sutherland, I. E. (1968, December). A head-mounted three dimensional display. In Proceedings of the December 9-11, 1968, fall joint computer conference, part I (pp. 757-764). ACM.

[39] Tan, C. T., & Soh, D. (2010). Augmented reality games: A review. Proceedings of Gameon-Arabia, Eurosis.

[40] Van Krevelen, D. W. F., & Poelman, R. (2010). A survey of augmented reality technologies, applications and limitations. International Journal of Virtual Reality, 9(2), 1.

[41] Vera, L., Gimeno, J., Coma, I., & Fernández, M. (2011). Augmented mirror: interactive augmented reality system based on kinect. Human-Computer Interaction–INTERACT 2011, 483-486.

[42] Wagner, D., & Barakonyi, I. (2003, October). Augmented reality kanji learning. In Proceedings of the 2nd IEEE/ACM International Symposium on Mixed and Augmented Reality (p. 335). IEEE Computer Society.

[43] Wolf, W. (2002). What is embedded computing?. Computer, 35(1), 136-137.

[44] Worms, http://www.team17.com/, 1995. (Online; accessed 11-May-2013).

[45] Xu, Y., Gandy, M., Deen, S., Schrank, B., Spreen, K., Gorbsky, M., ... & MacIntyre, B. (2008, December). BragFish: exploring physical and social interaction in co-located handheld augmented reality games. In Proceedings of the 2008 international conference on advances in computer entertainment technology (pp. 276-283). ACM.

[46] Zhang, X., Fronz, S., & Navab, N. (2002, September). Visual marker detection and decoding in AR systems: A comparative study. In Proceedings of the 1st International Symposium on Mixed and Augmented Reality (p. 97). IEEE Computer Society.

Appendix 1: The data from the games' analysis.

The following table contains the data received during the game testing. However, the information about the permissions that the games required access to was removed due to the large size of that information. That information can be send on request. The presence of some feature was denoted as the "x" sign.

	General Information						Approach		
	Genre	Freeware	Sound Effects	3D	Multiplayer mode	FPS	Location -based	Marker based	Other
AR Defender	Action	No	x	x		49		x	
DroidShooting	Action	Yes	x	x		33	x		
Sky Siege	Action	No	x	x		40	x		
Buzz	Casual	Yes	x			37			x
BIFITH-AR	Action	Yes				29		x	
Chick-fil-A Kids & Family	Entertainment	Yes	x	x		30		x	
AR Invaders	Action	No	x	x		48	x		

Parallel Kingdom	Casual	Yes	x		x	10	x		
Zombie Room AR	Action	No	x	x		30		x	
Hoops AR	Sports game	Yes	x	x		32		x	
AR Basketball	Sports game	No	x	x		34		x	
AR Baloons	Action	Yes		x		41	x		
Catch the Fairy AR	Action	Yes	x	x		39	x		
Ghost Detector	Entertainment	Yes		x		52	x		
Lumpeeks	Action	Yes		x		44	x		
AR Wild West	Action	No		x		45	x		
Skeeter Beater	Casual	No	x	x		44	x		
Augmentron AR	Action	Yes	x	x		26		x	
Sokoban 3R	Puzzle	No	x	x		28		x	
Gunman	Action	Yes	x	x	x	45	x		
AR-Racing 2	Sports game	Yes				28			x
AR 3C Capture	Casual	Yes				41			x
iSnipeYou (Lite)	Action	Yes	x	x		32	x		
League of Legends	Action	Yes		x		33		x	
GreedyFish	Casual	Yes	x	x		26		x	
Augmented Scavenger	Action	Yes			x	39	x		
JengAR	Puzzle	No	x	x	x	45		x	
Fly Free	Action	Yes		x		34	x		
ARachnophobia Free	Casual	Yes		x		32		x	
SpecTrek	Lifestyle	No	x	x		41	x		
Squash 'em All	Action	Yes				56			x
Pepsi Sokket Goal	Sports game	Yes	x			54		x	
3D Pool game - 3ILLIARDS	Sports game	No	x	x	x	28		x	
Urban Troops	Action	Yes	x	x	x	54	x		
PhotoShoot - The Duel	Action	Yes		x	x	39	x		
DefendAR	Action	Yes	x	x		25		x	
Drop Defender	Action	Yes	x	x		27		x	
Gold Detector Radar	Entertainment	Yes		x		47	x		
HEADSHOT Gun Camera	Action	Yes		x		53	x		
Zooz AR Shooting Game	Action	Yes		x	x	43	x		
Molecular City	Puzzle	Yes	x	x		32		x	
AR-App - Tin can throwing	Action	Yes	x	x		26		x	
Droiders cARs	Racing	Yes		x		22		x	
NerdHerder	Puzzle	Yes	x	x		34		x	
Warp Runner	Puzzle	Yes	x	x		25		x	

MummyTapBeta	Lifestyle	Yes	x	x		43		x	
Ingress	Action	Yes	x		x	34	x		
Piano AR	Casual	Yes	x	x		28		x	
HiddenAttack (Lite)	Action	Yes		x		49	x		
TaTeTi	Casual	Yes		x	x	29		x	
Auggy! Gamer Edition	Entertainment	Yes		x		40	x		
SlinGame Demo	Action	Yes		x		41		x	
Destroyer AR	Action	Yes	x			38			x
Ball BreakAR	Action	Yes	x	x		27		x	
PopAR Construction Puzzle	Casual	Yes	x	x		29		x	
Swivel Gun! Deluxe	Action	No	x	x		22		x	
Sea Monster	Action	Yes	x	x		28		x	
Biljet AR - AC130 Beta	Action	Yes	x	x		29		x	
Huebner Game	Casual	Yes	x	x		30		x	
Lipton Dip&Win	Action	Yes	x			27			x
apptoyz Alien Attack	Action	Yes	x	x		39	x		
Red Bull AR Reloaded	Racing	Yes	x	x		54			x
AR Targets Lite	Casual	Yes	x	x		30		x	
Android Archer	Casual	Yes	x	x		35	x		
BoostAR	Entertainment	Yes	x	x		29		x	
Ghostbusters: Paranormal Blast	Action	No	x	x		49	x		
Capture! Hearts	Casual	Yes	x	x	x	38	x		
AR-App - Shuffle	Action	Yes	x	x		32		x	
Catch The Oreo	Action	Yes	x	x		58	x		
Pull!	Action	Yes	x	x		56	x		
AR Shooter Shooting Game	Casual	Yes	x	x		38	x		
BILLABOOM	Sports game	Yes	x	x	x	29		x	
Mosquito Killer Camera	Casual	Yes		x		49	x		
Killing Souls	Action	Yes	x	x		33	x		
MushABellies	Action	Yes	x	x		31		x	
BattleFlagerAR	Action	Yes	x	x		29		x	
AR Arsenal HD	Casual	Yes	x	x		43	x		
BugZapAR	Action	Yes	x	x		25		x	
Ultimate 3D Boxing Game	Action	Yes	x	x		30		x	
PopAR Soccer Puzzle	Sports game	Yes	x	x		28		x	
Marco Macaco	Puzzle	Yes	x	x		46		x	
Missile DefendAR	Action	Yes	x	x		18		x	
DmC - The Eye of Dante	Puzzle	Yes		x		32		x	

AR Flick the Bean	Entertainment	Yes	x	x		31		x	
SoccerAR	Entertainment	Yes				48		x	
Lunar Eclipse - Asteroid game	Action	No	x	x		32		x	
Argomoku	Puzzle	Yes	x	x		30		x	
PopAR Picnic Puzzle	Casual	Yes	x	x		29		x	
AR Shootout	Sports game	Yes		x		39		x	
Camera Birds	Casual	Yes		x		32		x	
DROID Combat	Action	Yes	x	x		53	x		
BlueTea Game	Action	Yes	x	x		29		x	
Arma 2: Firing Range	Action	Yes	x	x	x	32		x	
Home Invasion	Action	Yes	x			35	x		
Treasure Hunters AR beta	Casual	Yes		x		39	x		
Castrol Golden Strike	Sports game	Yes	x	x		33		x	
Paintball	Action	Yes	x	x	x	38		x	
VuHunt Go. Share. Conquer. Win	Casual	Yes			x	39	x		
Football Game by Hand and Foot	Sports game	Yes				21		x	
AssassinMaster	Action	Yes	x			35			x
Walking Tracker	Sports game	Yes				36	x		
Diamond Hunt	Puzzle	Yes				45	x		
Valwen	Action	Yes		x		59	x		
TWOTW: Augmented Reality	Action	No		x		33		x	
Armed Cam	Action	Yes				34			x
Evil Hornets AR - $Ed	Action	No		x		46	x		
Paparazzi - Augmented Reality	Casual	No	x	x		31		x	
Catch The Ball	Lifestyle	Yes		x		34		x	
Total	**108**	**91**	**72**	**89**	**14**		**41**	**58**	**9**

Appendix 2: The result of the analysis of the users' reviews.

In the following table the data collected from the analysis of the users' reviews was recorded. The Opinions were represented as proportions. For example value 0.33 corresponds to 33% rate meaning that 33% of all reviews for the game were positive. Where the data was missing due to insufficient number of review, then it was denoted as "ND" or "No data". The number of installs was represented as intervals that specifies in which interval the value falls. For example the interval "100-500" can be interpreted as the game was installed at least 100 times and at most 500 times.

	Opinion		Technical issues	Game Rating	# of Installs
Games	Good	Bad	(technical/total bad)		
AR Defender	0.33	0.67	1.0	3,1	1000-5000
DroidShooting	0.65	0.35	0.75	4,0	500000-1000000
Sky Siege	0.37	0.63	0.84	2,8	10000-50000
Buzz	1.0	0.0	No data	4,0	100-500
BIFITH-AR	ND	ND	No data	No data	1000-5000
Chick-fil-A Kids & Family	0.61	0.39	0.93	3,8	10000-50000
AR Invaders	0.51	0.49	1.0	3,5	500-1000
Parallel Kingdom	0.89	0.11	0.8	4,1	1000000-5000000
Zombie Room AR	0.54	0.46	0.59	3,4	10000-50000
Hoops AR	0.69	0.31	0.78	3,7	100000-500000
AR Basketball	ND	ND	No data	3,5	10-50
AR Baloons	0.35	0.65	0.55	3,2	10000-50000
Catch the Fairy AR	0.32	0.68	0.87	3,2	10000-50000
Ghost Detector	0.58	0.42	0.12	3,6	100000-500000
Lumpeeks	ND	ND	No data	3.0	50-100
AR Wild West	ND	ND	No data	2,3	50-100
Skeeter Beater	0.77	0.23	0.33	3,5	10000-50000
Augmentron AR	0.29	0.71	0.8	2,8	5000-10000
Sokoban 3R	ND	ND	No data	No data	1000-5000
Gunman	0.73	0.27	0.41	4,2	100000-500000
AR-Racing 2	ND	ND	No data	3,6	1000-5000
AR 3C Capture	ND	ND	No data	No data	100-500
iSnipeYou (Lite)	0.44	0.56	0.36	3,6	100000-500000
League of Legends	0.54	0.46	0.59	4,1	10000-50000
GreedyFish	ND	ND	No data	No data	100-500
Augmented Scavenger	ND	ND	No data	No data	100-500
JengAR	ND	ND	No data	4,0	10-50
Fly Free	ND	ND	No data	3,0	1000-5000
ARachnophobia Free	ND	ND	No data	3,5	1000-5000
SpecTrek	0.91	0.09	0.11	4,7	5000-10000
Squash 'em All	ND	ND	No data	No data	100-500
Pepsi Sokket Goal	0.67	0.33	No data	3,2	1000-5000
3D Pool game - 3ILLIARDS	0.74	0.26	0.77	4,3	1000-5000
Urban Troops	0.63	0.37	0.75	4,1	10000-50000

PhotoShoot - The Duel	ND	ND	No data	No data	5000-10000
DefendAR	ND	ND	No data	4,8	500-1000
Drop Defender	0.38	0.62	0.8	3,5	10000-50000
Gold Detector Radar	0.36	0.64	0.0	3,9	10000-50000
HEADSHOT Gun Camera	0.63	0.37	0.55	3,5	50000-100000
Zooz AR Shooting Game	ND	ND	No data	No data	500-1000
Molecular City	ND	ND	No data	2,1	1000-5000
AR-App - Tin can throwing	ND	ND	No data	3,0	5000-10000
Droiders cARs	0.64	0.36	0.2	3,3	10000-50000
NerdHerder	0.81	0.19	1.0	4,5	1000-5000
Warp Runner	0.75	0.25	1.0	3,8	5000-10000
MummyTapBeta	ND	ND	No data	No data	100-500
Ingress	0.69	0.31	0.32	4,2	500000-1000000
Piano AR	0.14	0.86	0.17	2,9	1000-5000
HiddenAttack (Lite)	ND	ND	No data	3,6	5000-10000
TaTeTi	ND	ND	No data	3,3	1000-5000
Auggy! Gamer Edition	ND	ND	No data	No data	1-5
SlinGame Demo	0.43	0.57	1.0	3,3	10000-50000
Destroyer AR	0.21	0.79	0.73	1,7	10000-50000
Ball BreakAR	0.4	0.6	0.11	3,3	10000-50000
PopAR Construction Puzzle	ND	ND	No data	No data	1000-5000
Swivel Gun! Deluxe	0.59	0.41	0.29	3,8	100-500
Sea Monster	ND	ND	No data	No data	100-500
Biljet AR - AC130 Beta	0.52	0.48	0.8	3,1	50000-100000
Huebner Game	ND	ND	No data	No data	50-100
Lipton Dip&Win	0.33	0.67	0.38	3,1	1000-5000
apptoyz Alien Attack	0.37	0.63	0.88	3,1	10000-50000
Red Bull AR Reloaded	0.61	0.39	0.65	4,0	1000000-5000000
AR Targets Lite	0.83	0.17	No data	4,3	500-1000
Android Archer	0.14	0.86	0.93	2,3	100000-500000
BoostAR	0.6	0.4	1.0	3,9	1000-5000
Ghostbusters: Paranormal Blast	0.93	0.07	0.43	4,6	5000-10000
Capture! Hearts	ND	ND	No data	No data	100-500
AR-App - Shuffle	ND	ND	No data	No data	50-100
Catch The Oreo	ND	ND	No data	3,4	1000-5000
Pull!	ND	ND	No data	No data	1000-5000
AR Shooter Shooting Game	ND	ND	No data	No data	1000-5000
BILLABOOM	0.63	0.37	1.0	4,4	10000-50000
Mosquito Killer Camera	0.33	0.67	0.0	3,4	10000-50000
Killing Souls	ND	ND	No data	No data	100-500
MushABellies	0.17	0.83	0.97	2,2	10000-50000
BattleFlagerAR	ND	ND	No data	4,7	1000-5000
AR Arsenal HD	0.64	0.36	0.33	3,9	10000-50000
BugZapAR	ND	ND	No data	No data	100-500
Ultimate 3D Boxing Game	0.6	0.4	0.14	3,9	10000-50000

PopAR Soccer Puzzle	ND	ND	No data	No data	100-500
Marco Macaco	ND	ND	No data	4,4	50000-100000
Missile DefendAR	ND	ND	No data	3,4	1000-5000
DmC - The Eye of Dante	0.29	0.71	0.98	2,9	10000-50000
AR Flick the Bean	ND	ND	No data	No data	100-500
SoccerAR	0.68	0.32	1.0	3,4	5000-10000
Lunar Eclipse - Asteroid game	ND	ND	No data	No data	10-50
Argomoku	ND	ND	No data	No data	100-500
PopAR Picnic Puzzle	ND	ND	No data	No data	10-50
AR Shootout	ND	ND	No data	3,6	500-1000
Camera Birds	0.67	0.33	0.71	3,9	5000-10000
DROID Combat	0.68	0.32	0.68	4,0	50000-100000
BlueTea Game	ND	ND	No data	No data	10-50
Arma 2: Firing Range	0.58	0.42	0.61	3,8	100000-500000
Home Invasion	0.37	0.63	0.59	3,5	10000-50000
Treasure Hunters AR beta	0.2	0.8	0.0	3,8	10000-50000
Castrol Golden Strike	ND	ND	No data	4,1	5000-10000
Paintball	0.87	0.13	0.56	4,3	100000-500000
VuHunt Go. Share. Conquer. Win	0.5	0.5	0.0	3,5	10000-50000
Football Game by Hand and Foot	ND	ND	No data	No data	100-500
AssassinMaster	0.47	0.53	0.71	3,5	10000-50000
Walking Tracker	0.54	0.46	0.67	4,0	50000-100000
Diamond Hunt	0.34	0.66	0.82	3,1	10000-50000
Valwen	ND	ND	No data	4,2	100-500
TWOTW: Augmented Reality	ND	ND	No data	4,8	100-500
Armed Cam	0.83	0.17	0.8	4,3	100000-500000
Evil Hornets AR - $Ed	ND	ND	No data	No data	10-50
Paparazzi - Augmented Reality	0.42	0.58	0.91	3,2	1000-5000
Catch The Ball	0.75	0.25	1.0	4,3	1000-5000