POLITECNICO
MILANO 1863

Augmented Reality technologies to relieve stress and anxiety in hospitalized children

Tesi di Laurea Magistrale in Music and Acoustic Engineering

Author: **Matteo Sartori**

Student ID: 968396
Advisor: Prof.ssa Franca Garzotto
Co-advisor: Dott. Alberto Patti
Academic Year: 2022-23

Abstract

The subjection to medical procedures and hospitalization is often a source of significant stressful experiences for pediatric patients, resulting in feelings such as anxiety, social isolation and uncertainty. In some cases, the hospital environment can rewrite children's daily lives, depriving them of the methods and approaches they normally employ to face risks, fears and unwelcome events. These elements have an unfavorable impact on the quality of the patients' therapeutic experience and increase the likelihood of the onset of further complications. Furthermore, they induce avoidance behaviors on the part of the patient towards therapies and medical staff, with consequent possible delays in adhering to established hospital procedures. Considering all this, the use of augmented reality (AR) or virtual reality (VR) technologies could alleviate these states of anxiety and stress in hospitalized children and facilitate their recovery. This thesis analyzes the implementation of an interactive augmented reality game for pre-surgery pediatric patients.

Keywords: hospitalized children, AR, hospitalization, augmented reality, stress relief, pre-intervention, pre-surgery

Abstract in lingua italiana

La sottoposizione a procedure mediche e ospedalizzazione è spesso fonte di significative esperienze stressanti per i pazienti pediatrici, con conseguenti sentimenti quali ansia, isolamento sociale e incertezza. In alcuni casi, l'ambiente ospedaliero può riscrivere la vita quotidiana dei bambini, privandoli dei metodi e degli approcci che normalmente impiegano per affrontare rischi, paure ed eventi sgraditi. Questi elementi hanno un impatto sfavorevole sulla qualità dell'esperienza terapeutica dei pazienti e aumentano la probabilità dell'insorgenza di ulteriori complicanze. Inoltre, inducono comportamenti di evitamento da parte del paziente nei confronti delle terapie e del personale medico, con conseguenti possibili ritardi nell'adesione alle procedure ospedaliere stabilite. Considerando tutto ciò, l'uso delle tecnologie di realtà aumentata (AR) o di realtà virtuale (VR) potrebbe alleviare questi stati di ansia e stress nei bambini ospedalizzati e facilitarne il recupero. Questa tesi analizza l'implementazione di un gioco interattivo di realtà aumentata per pazienti pediatrici pre-operatori.

Parole chiave: bambini ospedalizzati, AR, ricovero, realtà aumentata, sollievo dallo stress, pre-operazione, pre-intervento

Contents

1 | Introduction

Anxiety and discomfort are common features in the experience of children undergoing hospitalization, a context already inherently imbued with significant stress. These psychological disorders can lead to significant impacts on their overall well-being[13]. Current solutions aimed at addressing the conditions of anxiety and distress exhibited by young hospitalized patients, though, **present some limitations**. For instance, some resources suffer from a lack of engaging entertainment options and are not adequately tailored to meet children's specific needs.
Furthermore, the current methodologies, which often rely on the use of medication or traditional psychological therapies, do not always provide them with sufficient relief.

This thesis endeavors to elucidate the conceptualization, design, and **implementation of an augmented reality (AR) game experience aimed at mitigating anxiety and discomfort in hospitalized children**, immersing them in the enchanting realm of oceans, where they can relax and revel in activities such as tag-finding, cartoon storytelling, environment customization, and AR facial masks.

According to its encyclopedic definition[1], **AR is a system that enhances the real world by superimposing computer-generated information on top of it**. Virtual reality (VR) technologies completely immerse a user inside a synthetic environment. While immersed, the user can not see the real world around him/her. In contrast, AR allows the user to see the real world, but with additional digital elements.

In the preliminary phases of conceiving this application, careful considerations are made towards the integration of highly **engaging musical compositions**, **comic-inspired graphics**, and **user-friendliness**. Such considerations are instrumental in rendering the application inherently compatible with the interactive entertainment needs that children typically yearn for, even within the confines of a stress-laden environment.

Given that children must navigate such a taxing juncture in their lives, gaining access to a fantastical realm offers them a significant opportunity to alleviate the struggles and loneliness that accompany their circumstances.
AR emerges as the quintessential technological medium for this purpose, for it

affords the capacity to transform the immediate environment by infusing it with endearing cartoon characters and lush vegetation. This transformative potential serves as a **powerful tool to normalize and infuse a sense of playfulness into an environment as inherently challenging as a hospital ward**.

The introduced characters regale users with whimsical anecdotes and touching narratives, swiftly establishing a **sense of company and friendship**.

The wholesale removal of the clinical environment, a path that immersive VR technologies may tread, bears the risk of alienating children from the reality they inhabit—an outcome that stands in direct contrast to the project's objectives.

Furthermore, **AR enjoys a distinct advantage over VR with regard to the ubiquity** of required equipment for access to applications. **AR necessitates only a smart device equipped with cameras**, whereas VR relies on specialized head-mounted displays (HMDs).

AR presents partially immersive yet highly interactive experiences that are readily accessible through commonly available devices. Thus, it can be surmised that AR represents an economical and efficacious means of delivering entertainment to hospitalized children. Subsequently, this thesis will delve into the topic of the **metaverse**, evaluating the **feasibility of replicating a similar experience within this burgeoning contemporary realm**.

2 | State of the art

2.1. Extended reality for assisting children

Augmented Reality (AR) games offer emerging potential to positively impact learning experiences for digitally-native children[5]. However, systematic, empirically tested design guidelines for AR serious games are largely unexplored yet. In the research by Li et al. [5] some guidelines have been extracted by developing four AR games with distinct mechanics based on self-determination theory, followed by four user studies:

- 1st study: Conceptualized AR game ideas via participatory design.

- 2nd study: Explored children's reactions to varied interactions and feedback, involving 32 participants.

- 3rd study: Examined social interaction effects in AR games with 24 participants.

- 4th study: Designed an AR game with four versions, immersing children in a fantasy world, tested with 81 participants.

From the studies, it was found that **game narratives motivate and contextualize learning**, enhancing motivation: in AR serious games, narratives drive interaction and learning, influencing experience quality; on the other hand, yet, fantasy environments could hinder learning[5].

Earlier findings emphasized a progress map and **3D elements to boost enjoyment**. The game story version guided players to rebuild a destroyed village. In contrast, the no-story version lacked narrative cues.

Offering task choice empowers participants and the games should respond dynamically to individual task choices without overwhelming cognitive load and autonomy's impact on engagement varies.

In the task choice version, children interacted with the AR world, answering some simple math exercises. Correct answers restored buildings, while the no-tasks choice version followed a system-directed order.

Furthermore, **3D feedback is favored over points and rewards**. 3D feedback is

about feedback provided in three-dimensional space within interactive technologies such as virtual reality or augmented reality. Unlike traditional forms of feedback, which might be limited to textual, audio, or visual signals on a flat screen, 3D feedback involves elements that can be perceived as spatially present around the user. This can include tactile sensations (physical touch or vibrations), visual cues that appear to be within the user's environment, or auditory cues that provide a sense of directionality and depth.

The overall **goal** is to **create a more engaging and realistic feedback experience** that aligns with the three-dimensional nature of the virtual or augmented environment. From the research is also easy to determine that, regarding social interactions, collaboration for motivation and real-time competition for learning efficiency, and interactions with physical objects are suggested.

In another research by Mesa-Gresa et al. [7], VR has been studied as a treatment approach in various health fields, with particular success in **mental health**. Selected children with Autistic Spectrum Disorder (ASD), high-functionality ASD, or Attention Deficit Hyperactivity Disorder (ADHD) took part in pilot VR-enhanced rehabilitation programs.

According to the publicly available papers, 31 studies have been selected in the research, each with a **specific diagnosis target** and a particular focus on one or many therapeutic aims such as social skills, daily living skill, emotional skills, communication ability, attention, physical activity, and phobia or fear.

Not all the studies were conducted following the same rules, for instance some divided the children in experimental (intervention) groups and control groups, while others didn't. 85.15% of the subjects were males and 14.8% were females, this doesn't reflect that about a third of people with ASD are actually females. The youngest participant was 3 years old, and the oldest was 20 years old. The low number of children involved in these studies may mark research in this area as not statistically significant.

30 out of 31 studies stated that **VR can improve some of the aforementioned objectives**. One study resulted in inconclusive results. Only 10 studies considered the improvements significant.

The fact that VR is decisively beneficial to ASD patients still has to be confirmed by further research, but according to the papers we have so far, **VR is a really promising technology in the treatment of children with ASD, HFASD, or ADHD**.

Another three-month study by Zhao et al. [16] in a children hospital in China revealed that children with autistic spectrum disorder exposed to therapy tailored virtual reality content during rehabilitation ended up obtaining **more beneficial effects than the ones that did not experience VR**[16].

Out of 44 children two groups have been created, the intervention group and the control

group. Members of the first group took part in VR sessions along with the standard rehabilitation program, while the others didn't.

Common rehabilitation for children with ASD includes collective class training, sensory integration training that involves simple equipment to use gross motor skills and fine motor training tailored for the specific child's needs.

Even though the conventional rehabilitation program is effective, resulting in higher metrics in cognitive, language comprehension, gross motor, mimicry, social interaction, and emotional expression than before intervention, children in the intervention group got even higher scores.

For children with ASD, it's not an easy process to wear the headsets and immerse in virtual reality as they often demonstrate social withdrawal, anxiety, and fear in unfamiliar environments.

Considering that safety, controllability, and repeated operation are key advantages of VR, **the onboarding process may not result that difficult even for children with ASD**.

The VR experiences had been made keeping in mind the difficulties of children with ASD, each scenario had a different focus area such as cognitive training, emotional expression, social practice, gross motor training, imitation training, language understanding. Picture communication, visual stimulation, and cartoon animation effectively engage children with ASD. Immersive scenarios enhance their receptivity to visual stimuli, facilitating cognitive learning, a type of learning that focuses on acquiring knowledge and skills through mental processing, comprehension, reflection, and problem-solving. Cognitive learning emphasizes the use of higher cognitive functions such as memory, attention, critical thinking, and concept comprehension. It is based on the theory that students are not mere 'sponges' passively absorbing information but actively engage in the learning process through the understanding and application of acquired knowledge.

Social communication is very difficult for children with ASD; thus, the scenarios had the role of **improving social interaction**, too. Nonverbal communication skills and emotional reactions learned in the virtual environment have been gradually brought to daily life with the help of trained nurses.

Some limitations of this study include the fact that nurses where unable to virtually interact with the children while they were in VR and that such a small sample size may not correctly represent the impact of such a change in rehabilitation techniques.

A study by Goharinejad et al. [4] demonstrated that **the use of VR, AR, and mixed reality (MR) powered technologies in their treatment**, specifically to children with ADHD. The age range of the participants was between 4 and 18 years old, 73% of them

– in studies where sex was specified – were males.

Medication and cognitive-behavioral therapy (CBT) are usually the preferred therapies, but they present various limitations. Psychopharmacological treatment is not always effective, while CBT requires several sessions with therapists specialized in ADHD. It is possible to affirm that currently used therapies for children with ADHD, while being expensive and time-consuming, **do not always result in tangible improvements**.

Recent technological progress led to various trials in which VR, AR, and MR have been implied in treatment for children with ADHD. Some aimed to **improve concentration**, some to better educational success, while others had a focus on the diagnosis or the symptoms assessment of ADHD. **Immersive applications help patients learn daily life skills and behaviors, enhancing concentration and memory abilities**.

The most used technology is VR through head-mounted displays (HMDs), commonly called VR headset, which also stands out as the most effective non-traditional mean to deliver the Continuous Performance Test (VR-CPT), a tool used to measure the ability to maintain sustained attention. Several studies conclude that **VR-CPT is more efficient and precise than its traditional counterpart, CPT**.

VR-enhanced behavioral therapy, offering safe and immersive experiences and scenarios, might better ADHD behavioral symptoms, enhancing motivation and treatment adherence. It is important to note that, due to the low cost and ease of use of VR headsets, **children with ADHD can also access their VR treatment without having to leave their homes**.

With this much evidence **it is possible to affirm that VR and other immersive technologies represent an effective and viable companion to ADHD standard treatment**.

Based on the work by Ficarra [3] nowadays patients are more aware of what's happening to their health when they are undertaking medical treatments. This implies an evolution in the relationship between nurse and patient. It is frequent that medications, care plans, and daily activities are questioned by the ones that receive them to the medical staff.

Immersive technologies, being used as informative devices or as a distraction, may play an important role in **patient engagement** and empowerment.

In the fourth chapter has been seen also that VR, AR, and MR are making their way into pediatric emergency departments (PEDs), where they are employed to tackle anxiety, stress, and fear in children undertaking psychologically traumatizing procedures. Situation anxiety in children is a serious problem, which must be taken into account by healthcare professionals.

Trust and respect are fundamental values for establishing a healthy bond between the

children and the medical team, being able to distract young patients from noxious stimuli results in calming them and making them more accepting of the medical treatments.

Distracting children from their struggling is a task currently carried out by television, books, video games, and similar common entertainment means. Evolving those into a more modern and engaging solution like the one represented by highly engaging **immersive technologies may completely change this process**.

Immersive technologies are usually perceived by children as familiar, as they've already experienced traditional video games.

The process of onboarding, treatment and session closure of VR, AR, or MR experiences for hospitalized children may be described and summarized as following:

1. Identify patients compatible with this kind of treatment;

2. Assess their health metrics;

3. Obtain the device;

4. Explain its functionalities;

5. Launch the experience;

6. Monitor the experience;

7. Assess the patient's health metrics after the experience;

8. Return and clean the device.

In the book is also said that **immersive experiences are also contraindicated for patients with claustrophobia, dizziness, history of seizures, motion sickness, and nausea**.

It is described also that VR, AR, or MR technologies are being applied into higher education, too. Students now require more interactive and appealing means of learning. Applying these immersive technologies to nursing classrooms means that future healthcare workers are able to experience in first person what happens inside a hospital, and inside the human body.

Lastly, being able to simulate emergency scenarios and medical operations through VR, AR, and MR could be a revolutionary and cost-effective solution for University courses in the health field.

Another article by Mott et al. [8] discusses the challenges of managing severe pain and anxiety in pediatric burn patients during dressing changes and explores the **potential use of augmented reality as an analgesic tool**. In particular, the study is focused on young patients between 3 and 14 years old.

Traditional pain management techniques, such as opioids, often prove inadequate in alleviating pain during these procedures, which can lead to avoidance behavior and treatment resistance in young patients.

Pain perception has a strong psychological component, and cognitive techniques have been used alongside pharmacological approaches to manage it. These techniques include patient distraction, breathing exercises, positive reinforcement, and the use of age-appropriate imagery. However, their effectiveness tends to diminish with repeated treatments. Virtual reality is introduced as a promising intervention for pediatric patients, with studies showing up to a 50% reduction in pain scores in adult burn patients using VR systems.

Unlike VR, AR involves overlaying virtual images onto the physical world, offering a less immersive but still multi-sensory experience to distract patients from the painful procedure.

The research involved 42 children undergoing 56 dressing changes, with participants randomly assigned to either the AR group or the control group. Analgesic medications were administered prior to dressing, and clinical measures, including pulse rates, oxygen saturations, and pain scores, were recorded at regular intervals.

Results indicated that the AR group experienced significantly less pain during dressing changes, especially in cases where the procedures took longer than 30 minutes. Parental assessments of their children's pain levels also favored the AR group.

Moreover, respiratory rates in the AR group remained almost flat over time compared to the control group, indicating reduced negative emotions associated with dressing changes. Some limitations are also discussed in the article, such as the need for improved device support, in particular for young children, and the potential for age-specific software programs to enhance the AR experience fitting their specific needs.

Additionally, the AR device's effectiveness in multiple treatments and its potential to decrease analgesic effects over time are subjects of ongoing research.

In the end, the study represents the largest randomized controlled trial of an AR-type device in pediatric burn patients and demonstrates its effectiveness in reducing pain and anxiety during dressing changes. Also, AR is highlighted as a portable, cost-effective, and user-friendly tool that could find applications in various pediatric patient groups, including those undergoing multiple painful procedures. The authors also acknowledge their involvement in patenting the AR device and its **future commercial potential**.

2.2. Augmented Reality for pediatric patients

The implementation of portable augmented reality games, particularly those incorporating a sandbox mode, as a strategy to alleviate stress among pedi-

atric patients and their families during the pre-operative preparation phase has proven to be an effective approach[11].

These games provide an enjoyable and engaging experience for both the child and their family, while simultaneously creating a safe and reassuring environment that empowers the child, giving them a sense of mastery over the circumstances. Consequently, this **contributes to a reduction in stress levels**.

Additionally, **the game serves as a distraction for the child**, allowing them to temporarily set aside thoughts of the impending surgical procedure and relax. Finally, educational resources are made available to the child's family, assisting them in **comprehending the process and preparing for the surgical intervention**[11].

Furthermore, one of the principal limitations associated with previous research and the application of therapeutic video games, particularly those incorporating virtual reality and augmented reality, to alleviate stress among pediatric hospital patients prior to surgical procedures is the **financial burden** entailed by these technologies[12].

The expenses related to these technologies can be substantial, and procuring and operating the requisite equipment and software may pose challenges, particularly for hospitals with budget constraints and there is also the possibility of children becoming excessively immersed in virtual or augmented reality, potentially hampering their cooperation with pre-surgery preparations. These things have to be taken into account when considering the integration of therapeutic video games within pediatric hospital settings [12].

A possible solution related to the costs could be using smart devices – like smartphones or tablets – instead of expensive devices like Microsoft HoloLens or other smart glasses.

In the article by O'Connor et al. [10] it is investigated if the use of Augmented Reality (AR) could provide education on the technique of using asthma inhalers to children, their caregivers and healthcare professionals.

Asthma is a very common condition, also among children, and correct inhaler technique is crucial for effective symptom management and for preventing long-term complications. Traditional methods of inhaler technique education have shown poor adherence rates, with many children not following the correct steps correctly. Therefore, there is growing interest in technology-based solutions to improve asthma education, considering the increased use of digital devices among children.

The research focuses on the use of augmented reality, making it an engaging and immersive learning tool. The objective is to evaluate the acceptability of AR for asthma inhaler technique education using a theoretical framework of acceptability.

The study involved a group of participants, including healthcare professionals, asthmatic children between 8 and 12 years old, and their caregivers. Qualitative data was collected

through individual interviews and a thematic analysis was conducted using the theoretical framework of acceptability.

The results indicate that **AR is generally well received as a delivery mechanism for education** on the technique of using asthma inhalers. **Participants reported positive perceptions of its effectiveness and ease of use**. They found AR engaging, accessible and innovative.

However, some barriers have been identified, such as the need to maintain children's interest during educational videos. Participants suggested including gamification elements and animations to improve engagement.

Additionally, concerns have been raised about the loss of face-to-face interaction with healthcare professionals. In order to address this issue, future iterations of AR solutions could include chat functions for communicating with the healthcare providers.

In the end, this study demonstrates that AR is an acceptable technology to address this issue. The findings highlight the potential for technology-based solutions to improve asthma management and education. The study provides valuable insights for the development of AR-based educational resources, highlighting the importance of addressing user involvement, technical challenges and interaction with healthcare professionals. Future research should focus on the feasibility, usability and broader implementation of AR solutions in asthma management, potentially also benefiting other age groups, such as adolescents.

In conclusion, the article demonstrates that **augmented reality is an acceptable technology for delivering asthma inhaler technique education to children**, and to the medical staff. The study provides valuable insights for the development of AR-enabled educational resources, emphasizing the importance of addressing user engagement, technical challenges, and interaction with healthcare professionals.

In an article by Logan et al. [6] it is said that digital health technologies have rapidly integrated into acute and chronic pain treatment, with the goal of reducing pain while enhancing patient engagement and breaking access barriers. Two standout technologies in this evolution are virtual reality and augmented reality.

VR and AR have effectively eased acute pain during medical procedures, providing distraction and entertainment to users. **This technology holds great promise for pediatric pain management** due to its technological appeal and the creative engagement of young patients.

However, the effectiveness of virtual reality in reducing chronic pain intensity is evident, but its long-term effects remain uncertain. Few studies have delved into functional outcomes in chronic pain, with some positive results observed in specific patient groups.

Chronic pain studies often emphasize presence, embodiment, and interactivity, with im-

mersion playing a lesser role. For instance, virtual reality-assisted muscle training for spinal cord injury rehabilitation has shown improvements in physical function.

Additionally, virtual reality has the potential for exposure-based therapy in adults with chronic pain, building on its efficacy in treating anxiety disorders.

In the realm of pediatric pain management, VR and AR show promise, although research primarily consists of small-scale pilot studies.

Nevertheless, the adoption of virtual reality in pediatric healthcare faces **challenges, including safety concerns, customization of headsets, infection control, and cost considerations**. Overcoming these obstacles necessitates adequate reimbursements and safety protocols.

Customized products can prove effective, but striking a balance between specificity and broad applicability ensures validation through research experiments.

The selection of research design and measurement tools plays a crucial role in assessing virtual reality interventions. Various types of studies may be suitable depending on research objectives.

While standardized patient-reported outcomes are essential, it is also crucial to consider specific virtual reality parameters to comprehensively evaluate the impact of these technologies.

Collaborative efforts between academia and the industry should be transparent and goal-oriented, with results published in peer-reviewed journals to promote evidence-based VR technology in the healthcare sector. To advance in the field, the consortium aims to create a resource repository, define standardized outcome measures, provide training and connections, and continue developing and evaluating virtual reality interventions.

In conclusion, according to the article, **VR and AR represent promising tools for alleviating pediatric chronic pain, although the field is still in its early stages**. Collaborative endeavors are essential to harness their potential, establish standardized outcome measures, disseminate knowledge, and conduct rigorous research. This integration will enhance the quality of life for young patients grappling with chronic pain issues. Comprehensive, large-scale studies are necessary to gain a deeper understanding of the potential of the immersive technologies.

A systematic review by Urlings et al. [15] offers an extensive overview of the current landscape surrounding the utilization of AR in the realm of patients education. The findings underscore the significant potential harbored by augmented reality as a **powerful tool** for the enrichment of their education.

Notably, the outcomes underscore the positive trajectory, revealing **tangible benefits in terms of knowledge acquisition**, heightened patient satisfaction, and the augmen-

tation of usability.

It is noteworthy that applications that predominantly pivot on AR as their core functionality exhibit superior performance in contrast to those where AR merely constitutes an auxiliary component. However, the existing body of research is distinctly characterized by its assortment of participant demographics, diminutive sample sizes, and the specter of potential biases. These inherent limitations collectively serve as a deterrent to the attainment of unequivocal conclusions when seeking to ascertain a meta-study perspective. One crucial point to remember from this discussion is the importance of making things the same and using clear ways to measure results in future research projects. This is especially important when trying to figure out exactly how much **AR helps with patient education**. Additionally, it's important to investigate and find the best devices for this purpose.

Patients being actively involved in creating and designing augmented reality apps is a very important step. **This involvement is fundamental in ensuring that these applications are not only effective but also user-friendly and accessible**.

Moreover, an in-depth examination of the implementation dynamics of AR interventions within clinical settings is an imperative avenue of inquiry, pivotal for the maximization of their pragmatic utility.

In summary, AR unquestionably showcases promise as a transformative force in the realm of patient education. Nevertheless, it is incumbent upon the research community to embark on a trajectory characterized by high-quality investigations. Such endeavors must navigate the extant limitations deftly, with a view to **making sure the optimal role that AR can assume in strengthening patient knowledge and engendering heightened patient engagement**.

The review, by laying a robust foundation, serves as an indispensable precursor for future studies ready to contribute substantively to the evolution of AR within the realm of healthcare education.

2.3. Applications already in use in the hospital setting

An instance of digital solution **aimed at mitigating anxiety and discomfort** in pediatric patients during medical therapy is TOMMI[2, 14]. This gamified virtual reality experience, developed by the startup Softcare Studios, has been purposefully designed to assist young patients in effectively managing stress during medical treatments. TOMMI accomplishes this by fostering collaborative sessions involving the patients' parents and

streamlining the workflow of medical personnel.

TOMMI serves a primary function in enhancing patient comfort and overall satisfaction, particularly useful in the context of dental procedures. This is attributed to the unique diversionary effect created by **immersing children in a virtual reality environment**, which significantly diminishes anxiety and pain levels, thereby ensuring a heightened sense of ease and contentment among patients and their families. Notably, empirical evidence supports the assertion that TOMMI has contributed to enhanced treatment efficiency. This stems from the fact that patients exhibit greater cooperation, thus facilitating dentists in executing their routine tasks with **increased ease and efficiency**, ultimately leading to time savings and **improved intervention quality**.

Moreover, the capacity of TOMMI to **divert children from distressing emotions** associated with therapy and medical interventions also serves to reduce the necessity for sedatives and **pain relievers**. In essence, the application affords young patients a temporary respite from the confines of the hospital environment, granting them access to virtual spaces within the application.

As is common with other virtual reality experiences, TOMMI entails immersing oneself in a virtual realm through the **utilization of a headset**, which is provided and configured by the medical staff.

The headset utilized is multi functional, featuring integrated audio capabilities through small speakers and a jack connection for personal headphones. Additionally, the headbands are composed of removable fabric, facilitating ease of sanitization. The headset adheres comfortably to the face, thanks to a soft plastic material membrane.

The ensuing interactions, and hence the navigation through the purpose-designed, immersive virtual world, are facilitated via an ergonomic **remote control** equipped with touch input and a trigger; the interactions in the virtual world happened thanks to the magic wand controlled by the controller.

A pivotal attribute of this application is its user-friendliness and immediacy, as it merely requires a few seconds to power up and commence usage. This streamlined usability greatly facilitates patient management both before and after treatments. Consequently, TOMMI has been selected and implemented in numerous healthcare facilities, including the SS. Annunziata Hospital in Taranto and the Pediatric Oncology Department at the Polyclinic of Catania.

Furthermore, TOMMI offers an intriguing feature by **collecting diverse patient data** that can be subsequently **monitored by the hospital** or clinic staff and physicians. This data serves to **enhance patient tracking** and enables the customization of therapy to align with individual patient needs.

3 | UNG model

3.1. Definitions

The **UNG Model** is a modeling language used to link all the people related with a project with their needs and goals in a certain context.

The people involved in the project are called **stakeholders**.
There are three different types of stakeholders:

- **primary users**: people who would have frequent hands-on the system

- **secondary users**: people who occasionally use the system

- **tertiary users**: people who are affected by the system introduction, or influence its adoption

The primary and secondary users are also called **end users**.

In the UNG model, **a goal is what the user is expected to achieve by effect of using the system**. Examples of goals are, for instance, improvement of a task or a process or a human capability, while **a need refers to a lack of something necessary**, desirable or useful for the different users.
Needs are more general and abstract than goals; the former are properties of the users, while the latter are properties of the system.

The context refers to **where, when, and how the technology is used**, so there is the need to define the temporal, organizational, social and physical context's parameters.

- The **temporal** context refers to when the app is used, for example during playtime sessions;

- The **organizational** parameter refers to which step of a user process or activity technology is going to be used, for instance during school;

- The **social** one refers to who and how much are the involved people during the use, for example there can be two active users and a secondary user;

- The **physical** context is obviously where the technology is used, for instance a museum or a park.

Thinking of the realization of a project, is not so rarely to encounter **constraints**, which are additional conditions that must be considered during the realization.
A constraint is an element which cannot be changed for any reason. Examples of constraints are time, technology, financial and human resources, and important desires or deficits of the user. All of them must be captured since the beginning to stay in the right track.

3.2. Hospitalized children scenario

Assuming the development of an **augmented reality game for children in a private clinic**, it is essential to define all the parameters mentioned earlier.
Drawing upon the previously elucidated definitions, a potential UNG model pertaining to this specific case is presented in Figure 3.1, as showcased.

The stakeholders involved would be as follows:

- The main stakeholder: the **children around 5 and 7 years old**.

- Secondary stakeholders: the **hospital staff**.

- Indirect stakeholders: the **children's parents**.

- Third stakeholders: the **clinic owners**.

The primary needs of the children would revolve around having fun and relaxing to alleviate anxiety and stress while ensuring that the clinic experience is not traumatic. For the medical staff, their needs would center on supporting and streamlining the doctors' work to make the process as smooth as possible. Parents would be focused on minimizing their children's worry, and clinic owners would aim for technological development.

As for the goals, **children would need to engage with visually stimulating content on the screen and perceive the hospital environment in a more carefree and enjoyable manner**. Parents' main goal would be to ensure their children are as relaxed as possible, while clinic owners aim to attract more patients.

In terms of the context, the scenario occurs before the child's surgery at the clinic, with an expected **usage time of roughly twenty to forty minutes at most**.

The experience will be individual, meaning each child will have their tablet, and the

play mode will be single-player.

Considering constraints, it's important to remember that **the child is in a new and potentially distressing environment**, with limited familiarity and reference points. The rooms may be small and possibly crowded. Finally, resources such as tablets are available in a fairly limited number, and battery duration is a critical factor to consider. These children may experience stress and anxiety in the dressing room and waiting room due to limited activities and the anticipation of surgery.

Figure 3.1: The figure above shows the UNG model of this case study.

4 | Implementation and functionalities

As previously introduced, to address the current problems of children undergoing hospitalization, it was decided to develop an augmented reality application that can help them in their pre-intervention process, relieving their anxiety and stress.
The UX design and implementation of this application are explained below.

4.1. UX Design

This AR experience consists of two strictly subsequential primary experiences designed to be enjoyed at the Fondazione De Marchi clinic in Milan.
The children will be accompanied to the stretcher and will go through multiple floor levels, and so two elevators need to be taken.
In order to develop the application, it was kept in mind that the child who uses it will always be monitored by the hospital staff who will therefore refer the patient firsthand.

The theme of the application is based on the concept of ocean exploration. The children will travel the seabed aboard a submarine, meeting and getting to know different marine creatures, with which they can interact.
During the experience, the user will meet a range of sea animals, including a seagull, a clownfish, a turtle, a killer whale, a squid, and a seahorse. These encounters are enabled by the implementation of AR through the scanning of images depicting the aforementioned animals.

Creating an augmented reality application for children implies crafting an essential interface which is immediate and with a simple design. Therefore, the buttons for carrying out the interactions are all very large and all the icons are colored to have a contrast that makes use instant for the user, who is in any case digitally native.

To enable the interactions with this AR application, other tools are provided to the users and the caregivers:

- a pamphlet provided to the parents with detailed instructions to enjoy the game to the fullest;

- a plastified booklet with pictures;

- decorative elements placed throughout the hospital corridors, in particular in the path that goes from the hospital bedroom to the surgery room.

Taking into account that during the utilization of the AR game the children have to be laying down for the transportation for safety reasons, the decorative elements, i.e. the stickers, will be placed mainly on the high parts of the wall, in order to be able to be clearly seen by the children when they are sitting on the hospital gurney, and also inside two elevators of the hospital. It is important to note that those stickers match the images on the laminated booklet.

4.1.1. First experience

In the first part of the experience, the child will be put on the hospital bed, which is decorated with submarine photos in order to try to simulate their access on board.
Once the children are ready, the hospital staff give them the tablet where the application is installed.
A virtual assistant called Olly – a little octopus – will appear and guide the user through simple input and introductory messages, saying to them to start scanning the images and stickers they find around the corridors and the elevators.
As further consideration, the octopus assistant will be always ready to help the children, remaining always interactable in the foreground, so they can receive help simply tapping on it. Olly, will also give out words of encouragement or tell jokes.

Figure 4.1: The figure above shows Olly, the virtual assistant.

After completing the initial introductory part, the screen will be devoid of content, except for the assistant icon, and the tablet will display what the camera is pointing at. The user is now ready to start scanning the various images.

The user will start by scanning a photo of a submarine to simulate their entry. Once the photo has been scanned, Olly will welcome the child on board.

The second image that the user needs to scan is the submarine porthole placed at the feet of the gurney and only visible from the inside. By capturing it, the user interface is transformed adding a porthole, giving the children the idea of being inside the submarine. In fact, the submarine's window is used to show the surroundings via the camera. On the left side will appear six unfilled shapes as well, which will be colored once the user scans the relative animal. An example is shown in Figure 4.2.

Figure 4.2: The figure above shows the main screen of the first experience.

At this point, the user will encounter the animals and they will start to immerse in the ocean, starting from the first corridor.

Once the first animal has been scanned, a 3D model of it will appear in the center of the display, simulating that it is beyond the window glass. This procedure will be the same for scanning other sea creatures as well.

When an animal appears, it will greet and say something about itself to the child, while making some animations. The dialogue can be listened through the speakers of the tablet. Subsequently, the animal will disappear and the user is now ready to scan the other photos.

After meeting the first animal, the first elevator is encountered and inside there will be placed sticker of a shell house. By scanning it, the first of two minigames will immediately start.

The decision to include a mini-game during the elevator ride was made to prevent the child from getting bored while waiting to reach the other corridor.

During the minigame, the user will see an image of a fish with some continuously-generated wounds, who need to be touched in order to be healed. Tapping on them, the wound will

be then replaced with a band-aid and will disappear after few instants. Once a wound is healed, the score of the user will increase.

While the user is playing with this minigame, the elevator goes to the other floor. A stopwatch will start as the minigame begins, and it will last until the elevator has reached its destination. Each minigame is calibrated for the duration of the journey. Furthermore, before arriving at the destination, a button will be shown in the user interface which - just in case - will allow the user to exit and move on to the next scene.

When the user arrives at destination, they will exit the game and starts exploring the new corridor.

In the second corridor the users will find other three images of the marine creatures to scan. Again, the animals will be displayed to the users saying hello to the children and telling some facts about themselves.

At the end of this corridor users will find another elevator as well, the second and last. Upon entering it, they will find another image to scan, which will start the second minigame as in the previous case. This minigame is the same as the first one, only the image of the animal to be healed changes.

Arrived at the third and last corridor, the user will be able to capture the last two animals, which will tell something about themselves like the previous ones.

After having scanned all the animals, all the shapes will have been colored, as shown in Figure 4.3.

Finally, and child will find the last sticker of the first experience, representing a coral branch. Scanning it, the user will be directly switched to the second experience.

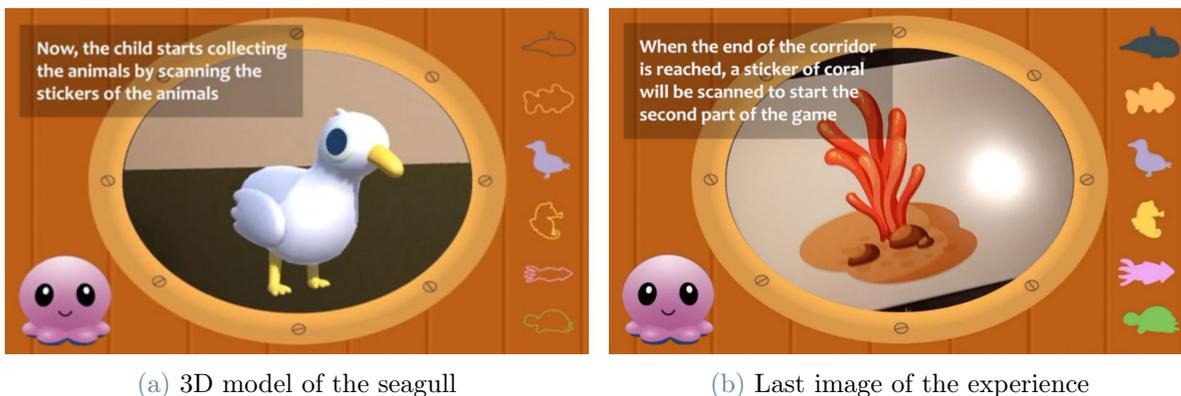(a) 3D model of the seagull   (b) Last image of the experience

Figure 4.3: The figures above shows how the shapes of the sea animals will be colored once they have been found and scanned; in the first image only one animal has been found, while in the second one all of them have been scanned.

4.1.2. Second experience

The second experience includes a variety of activities aimed and designed to lower stress and anxiety of the children with primary goal to make them relax while they still are on the stretcher in the waiting room of the clinic.
The activities include both exploring a virtual world and interacting with different non-player characters with which children can interact with enough degrees of freedom.
The game has a strong emphasis on player choice and emergent gameplay, meaning that players can shape the course of the game by making decisions and taking actions that have consequences in the game world, making the children feel in control over the situation and their stress decrease.

When the users begins the second experience, the assistant welcomes them back and gives them some instructions to play this part of the AR game.
Thanks to the AR the child will see 3D fish swimming around him in the virtual world

With the use of physical markers, with the same images with respect to the previous game experience, children can activate virtual characters to play with or hear a story from them. When the child moves the camera, the virtual models in the environment stay in their programmed positions. This would allow the child to interact with the virtual models as if they were real.

The user can perform the following activities:

- Exploring the game environment looking around the virtual world by simply moving the device using a first-person perspective as exemplified in Figure 4.4.
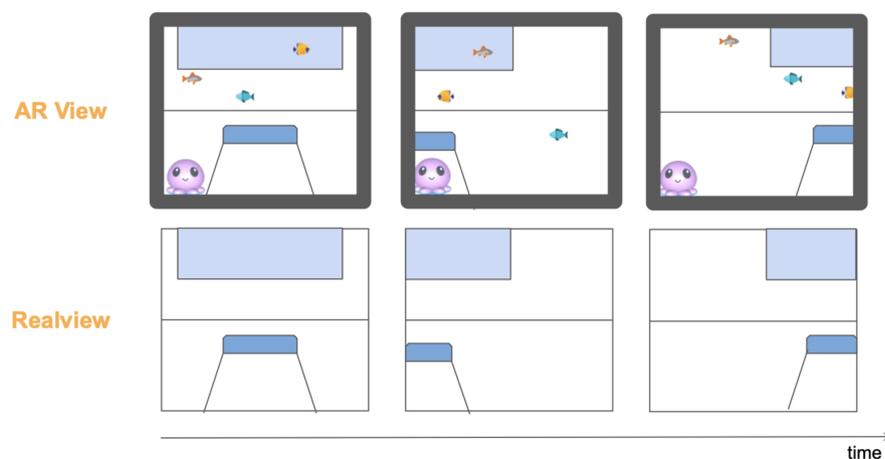

Figure 4.4: User looking around the environment

- Decorate the seabed environment: the user would be able to manipulate and decorate the surroundings with various elements typical of the ocean environment, like corals and seashells, in real time. Their 3D models will be placed on the screen view in a fixed position in the real environment by tapping anywhere on the screen, as shown in Figure 4.5. The game includes a different shapes that can be placed close or far in the environment, as per the child's discretion. The shapes are generated randomly, which adds the element of surprise to the experience, making it more interesting.
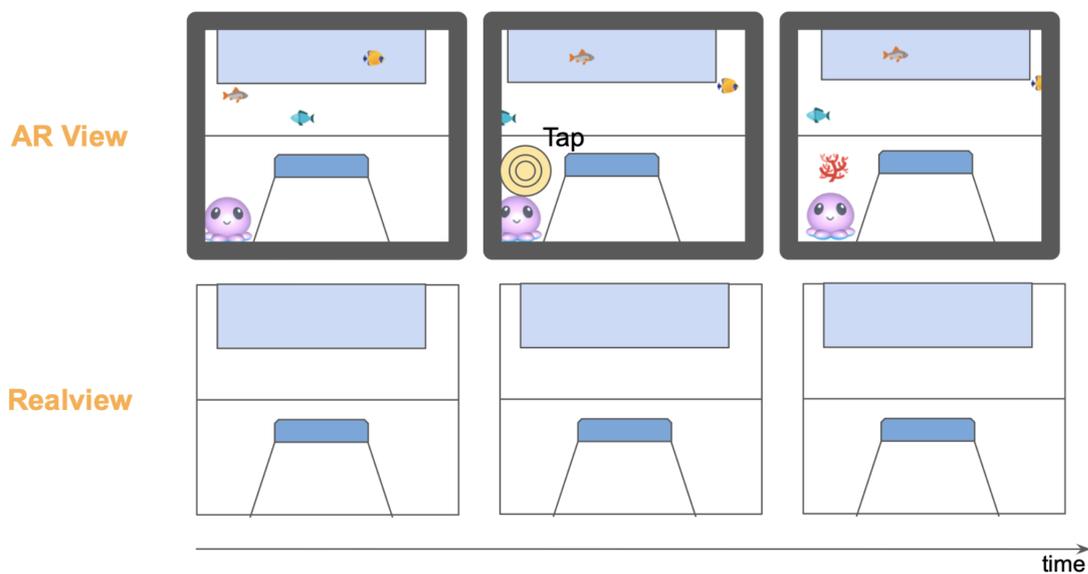

Figure 4.5: Placing objects in the real environment

- Interacting with the animals and listening to stories: the user would be able to interact with the sea creatures by scanning the physical markers, i.e. the stickers, in the real world. This will trigger the appearance of the related animal in the virtual world; if the users tap an animal, it starts talking. At the end of the dialogue a popup will be shown, asking the users if they want to hear a story. If the users agree, the relative video will start playing, as shown in Figure 4.6.
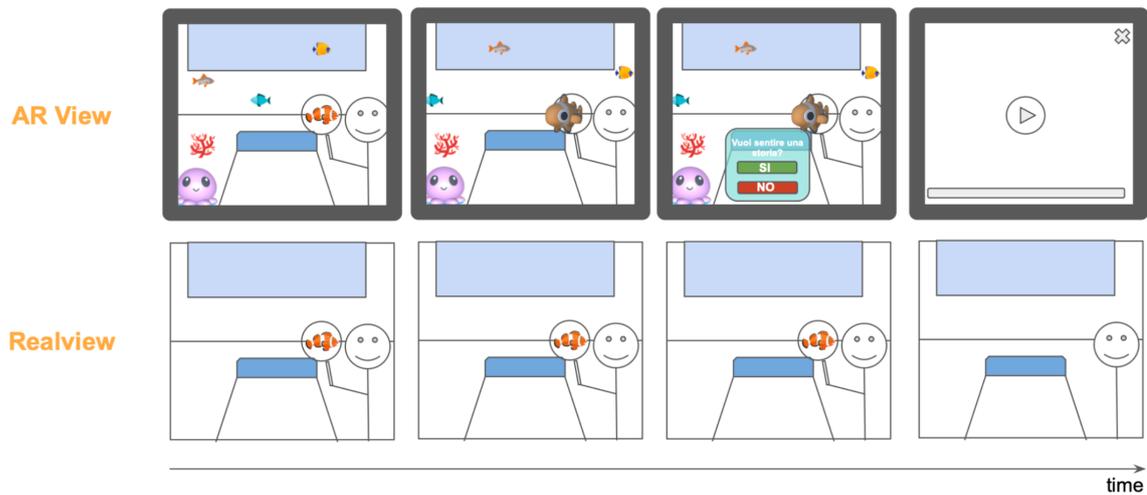
Figure 4.6: Interacting with the sea animals

- Wear a virtual AR face mask through the use of the device's selfie camera, simply switching the camera to the front one. There are two different face masks the child can choose, both of which are 3D face filters and based on an oceanic setting; the first one is a classic scuba mask, while the other one is a diver's helmet. The user can tap on a specific mask and it will appear on the face of the child. The mask follows all movements of the user's head, as depicted in the Figure 4.7.
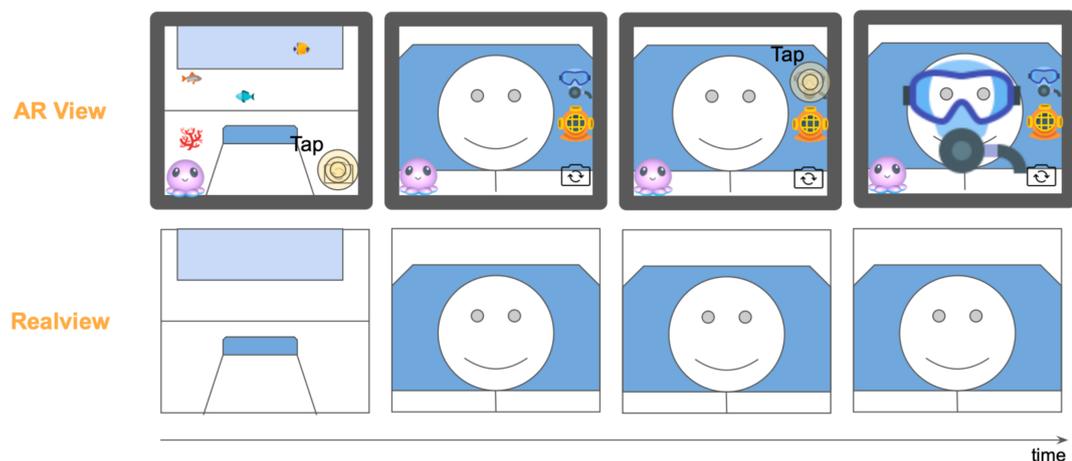

Figure 4.7: Applying the face mask

In this second game experience the user can always choose what to do between these activities, in fact, the scene can be switched every time.

Furthermore, the app can be quit at any time and can be easily resumed by skipping the first part of the experience.

Figure 4.8: The figure above shows all the stickers of the sea animals which need to be scanned in both the experiences.

4.2.   Software architecture

This AR application for hospitalized children has been implemented with Unity 2021.3.14f1, using AR Foundation with ARCore for the augmented reality features. All the scripts are written in C#.

It is a self-contained mobile game and this architecture imply several advantages. Primarily, it obviates the requirement for an Internet connection, as all requisite resources are comprehensively encompassed within the application itself. Additionally, this design mitigates bottlenecks during its execution, ensuring that the application remains operational even in environments where access to an Internet connection is unattainable, for any reason.

In the realization of the AR experience was took into account to design it for Lenovo Tab M10 Plus tablets, so the app is compatible with just Android and not iOS nor iPadOS.

4.2.1.   First experience

In the first experience the user interface (UI) is a canvas, containing an image for the window frame, images for the filled cutouts of the animals and a button.

At the launch an introductive tutorial is shown to the user in order to be used as a tutorial; the dialogs are handled to disappear when the screen is touched by the user until the last dialogue is read; then the real experience in the corridor will start.

All the images start without being immediately visible on the screen when the app is

launched. When it is time for these images to appear, a C# script changes their transparency quantity, making them visible.

All the 3D models of the animals are instantiated on application start, but none of them is active. Since they are already instantiated, the script uses methods to make them visible when needed. When the user scans a photo, the related animal will appear modifying its attributes. The linked audio source will play and after 8 seconds the object will be hidden.

Regarding the assistant, which should be available every time, its button is always visible. This is possible thanks to another script to display it. When the user taps Olly, a random audio track will play as well.

The status of the objects gets changed and set to active when they are intended to be visible and set back to not being active when they are not needed to be visible anymore. Scripts are present to handle this.

Image recognition: A ReferenceImageLibrary is present, and it contains all the images that are to be tracked.

The image recognition is implemented to manage four different tasks:

- Modify the UI;

- Set an already instantiated GameObject as the child of a TrackedImage and render it active;

- Set an already instantiated GameObject as the child of the ARCamera and render it active;

- Switch between scenes;

Monitoring the ARTrackedImagesChangedEventArgs, different behaviors are adopted depending on if its arguments are added or updated.

In the first case, this happens the first time the image gets into frame. A foreach differentiates between cases to identify which image has just been scanned, and then calls the right method accordingly. These methods get called once and only once, the moment the image gets into the frame.

For example the Add methods set the GameObjects as children of the TrackedImage and make them visible. The method to change the interface and all the scene switchers are in this case, as they only need to be called just once. In the second case, this happens at all instants, after the image has been framed the first instant. It is used to track the status of the tracked image, whether it is currently being framed or not. To manage this the Update methods checks if the image status has just changed and is now inactive. If that

is the case the GameObjects are set to not active, effectively making them not visible anymore.

In the end, regarding the two minigames, there is a progressive stopwatch for each one set based on the time duration needed by each elevator to complete its ride, and it will increase until it reaches this exact time value.

4.2.2. Second experience

In the second experience the things are a bit different, because the view is not mainly two dimensional as in the first one, but it's a full 3D environment.

In order to implement all its functionalities the following Unity AR components are used:

- AR Plane Manager: this component is responsible to detect the horizontal and vertical planes, providing methods to interact with them.

- AR Raycast Manager: this one provides methods to detect if a tap in the screen intersects an AR object. This is useful to place objects inside the AR world.

- AR Face Manager: this AR component is responsible to detect and track faces, providing listenable methods which send updates about the tracking status and the exact local position in the AR world.

- AR Tracked Image: this last component is used to recognize and track images in the real world, providing listenable methods that constantly send updates about the tracking status and position in world coordinates.
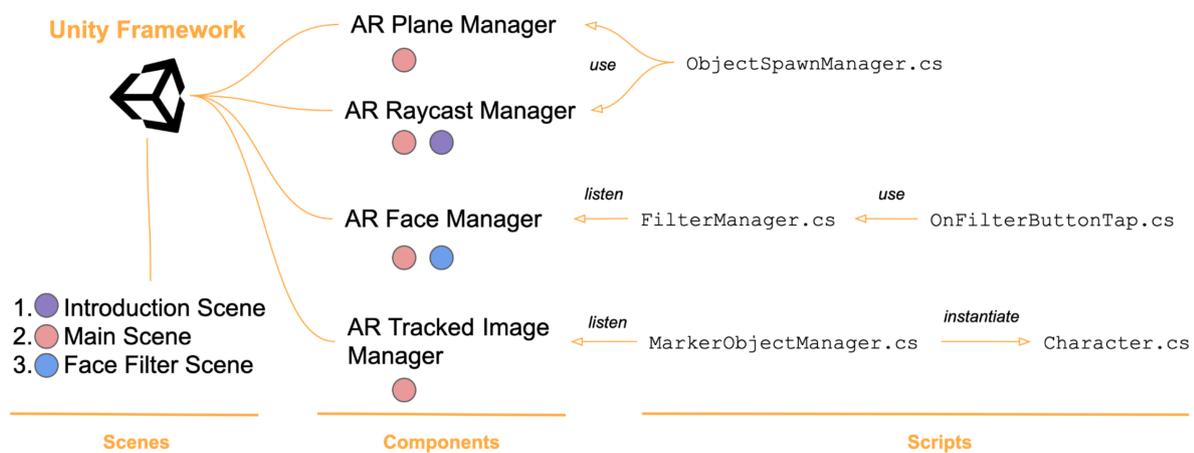

Figure 4.9: The figure shows how all the components and scripts interact with each other.

In addition to built-in features provided by the Unity Framework, some custom scripts are implemented in order to extend and personalize the functionalities starting from the previously mentioned components.

To conclude, the main scripts are the following ones:

- ObjectSpawnManager.cs: it is responsible to spawn objects on planes when the user taps the screen. It takes as input a list of prefabs that are the object that can be spawned. When the user taps on a point in the screen, it uses the AR Raycast Manager component in order to check if the selected point is a plane that AR Plane Manager has already detected. If this is the case, it picks a random prefab from the input list and instantiates it in a position that corresponds to the intersection between the ray and the plane. There is an additional control to prevent two objects from being instantiated too close to each other.

- FilterManager.cs: it is responsible for placing virtual AR masks on the user's face. It listens for updates from AR Face Manager and adds, updates, or removes the face filter GameObject accordingly.

- OnFilterButtonTap.cs: this script is attached to each facemask GameObject used in the UI as a button to change the face mask. It takes as input the AR Face Manager component and the GameObject of the mask. It implements the OnMousDown() method and calls a method of the FilterManager.cs in order to change the facemask with the one it owns.

- MarkerObjectManager.cs: it is responsible for recognizing markers and instantiating the character accordly. It takes as input a list of GameObjects that are available characters named with the same name as the marker image. It listens for updates from AR Tracked Image Manager components and adds, updates, or removes characters GameObject from the input list based on the recognized marker name.

- Characters.cs: this script is attached to each character GameObject and manages its life cycle that is composed of three possible states: Ready, Talking, and TalkingEnded. It takes as input the dialog GameObject and the name of the story video (.mp4) associated with the character. It implements the OnMousDown() method that starts the "Clicked" animation from the Animator of the GameObject. On the "Clicked" animation is attached the OnTapBehaviour.cs scripts that get the AudioSource components from the character GameObject and start the audio. In the Update() method, the state of the character is updated according to the AudioSource status, the current character status, and the visibility of the GameObject. When the audio ends, the status is updated to TalkingEnded and the dialog is activated.

If the user taps the Yes button, the video is taken from StramingAssetPath based on the name and played on the full screen using the device's native player.

- Assistant.cs: it manages the current state of the virtual assistant. It takes as input a list of AudioClips for each character helping, a list for the environment helping, and a list for filter helping. It also takes a TextAssets that contains a list of phrases that will be shown synchronized with the audio. The selection of the help and the phrase is based on the status that can be Character, Environment, Filters, Idle and on an incremental index.

5 | Study on the possible transposition in a metaverse

5.1. Definition and types of metaverse

A **metaverse** is a shared and online virtual environment where users can interact, socialize, and collaborate in real time[9].
It also provides the user with the tools to **create and customize** their avatar and the virtual environment, giving them the ability to **express their creativity** and individuality.

Three characteristics are required to be considered a metaverse:

- **Interactivity**: the metaverse must allow interaction between users and virtual objects within the environment, as well as provide tools for creating and modifying these objects.

- **Persistence**: the metaverse must be constantly accessible and maintain temporal continuity, so the actions of the user must remain stored and persist over time, even when users are not present.

- **Scalability**: the metaverse must be capable of hosting a large number of users simultaneously and enable the expansion of the virtual world, for example through the addition of new locations or functionalities.

After an in-depth analysis of the most well-known metaverses, it is possible to organize them into six categories according to their main characteristics:

- **Sandbox metaverses**: users can create and edit the virtual world and design and build objects or even entire cities. One example of this type of metaverse is The Sandbox.

- **Social metaverses**: they are focused on socialization and communication between users: they can chat and interact with each other in the virtual environment. Ex-

amples of this kind of metaverse are VRChat, Somnium Space, Neos VR, Sinespace, Rec Room and Second Life.

- **Game metaverses**: they offer games where the user can play and interact with other players in the virtual environment. Example of this type of metaverse are Roblox, Fortnite and Minecraft.

- **Enterprise metaverses**: these platforms allow employees to interact and collaborate with each other in the virtual environment. They are used by companies for collaboration, training or simulation. An example of this kind of metaverse is Microsoft Mesh.

- **Educational metaverses**: these are metaverse platforms used for education and training. Users can participate in lectures, seminars and workshops. Examples of this type of metaverse could be Minecraft Education or VirBELA Campus.

- **Open metaverses**: they are open platforms which allow users to create and manage their virtual world. These platforms offer more freedom and control to users over their metaverse experience.
  The main difference with the Sandbox metaverses is that the latter kind of platform is more focused on creating and editing content within the metaverse, while the Open metaverse is more focused on creating and managing the entire virtual environment, with the complete user control over their own metaverse experience. An example of this kind of metaverse is OpenSimulator.

The major metaverses are Roblox, Minecraft, Fortnite and Meta Horizon Worlds.
It is also possible to find cryptocurrency-based metaverses such as Decentraland.

5.2. Metaverse for hospitalized children

Thinking about the creation of an ad-hoc metaverse for hospitalized children with which they can relieve stress, this can be identified as a mix between Social metaverse and Game metaverse, thus having both the components of socialization and interaction between users and the presence of mini-games where kids can work together to complete levels or various tasks.

The Open and the Enterprise metaverses are obviously out of place, and the Sandbox metaverse could be too complex for the little ones or have as a result a world with many objects positioned without a criterion.

The Educational metaverse would still be viable but could be perceived as boring. In order

to avoid this problem, it could be integrated with a Social and Game metaverse, where the notions are given, for instance, through minigames. Alternatively, you can consider having an optional separate space that has an educational theme where an interested user can access, but even here you should carefully evaluate which themes or topics to deal with for different ages.

5.2.1. Pros

The main **pros in designing a metaverse** for hospitalized children are:

- **Knowledge sharing**, for example through virtual lessons or quizzes

- Promotion of **collaboration** through virtual collaboration

- **Reduction of isolation**, allowing them to connect with others

- **Integration with therapies** and treatments, facilitating the recovery process

- **Personalization** of experiences, based, for example, on their ages or personal interests

- **Mutual emotional support** by sharing experiences and offering support during their healing journey

- **Improvement of emotional well-being** and hospital experience by providing a virtual environment that encourages interaction, learning, and mutual support

- Sense of **belonging** by having shared experiences

- Accessibility and **inclusiveness** by offering a virtual environment that is easily accessible and welcomes all young patients, regardless of their abilities or circumstances, thus creating an inclusive space where each child can actively participate.

- **Development of new skills**, like cognitive and social skills

- Safe and **controlled environment** due to the presence of moderators

- Opportunities for personal growth and **self-development** (self-esteem and empathy)

5.2.2. Cons

On the other hand, building a metaverse for pediatric patients can bring these following **cons**:

- **Significant costs** of devices, related to the headsets and the controllers

- Possibility of eye strain, **motion sickness**, induced nausea, and headaches resulting from extended use

- Recommended **minimum age** of 12 or 13 years by most manufacturers of headsets

- Need for a broadband **internet connection**, limiting accessibility in some areas

- The **virtual experience may not be suitable for all children**, depending on their individual needs and health status and preferences as well

5.3. Further challenges, risks and considerations

There are several **crucial considerations** and **challenges** associated with implementing technology for children.

First of all, it is **resource-intense** developing customized user interfaces, and involving numerous professionals will determine the **increasing of the costs** and the complexity overall.

Moreover, there is **difficulty in the utilization for children with cognitive impairments** and using virtual reality is challenging due to the more complex features of the contents or the interfaces.

In addition, there is also the need to strike a **balance between virtual and real life**, and to avoid the risks of social isolation or a metaverse addiction. Another important consideration is that experts will have to create **tailored experiences for children of different ages**, satisfying the needs of each age range and creating an adequate experience for each one: for example, it may be unsuitable for some children based on their personal preferences.

Developing such experience, it is also important to evaluate the **local laws** and all the regulations related to the use of this technology and safeguarding the privacy and the security of the users is fundamental.

Furthermore, it is also required to supervising and moderating in order to prevent inappropriate behaviors and to ensure a positive and supportive environment for all.

Last but not least, dealing with the technology will lead to the periodic need to make all the various updates and **optimizing the software** to be cutting edge.

5.4. Possible improvements of the metaverse

Although not brand new as technology, metaverses and virtual reality technologies in general are still in a state of development that has **not yet reached their full potential**. This means that there is room for improvement on both the software and hardware fronts, with the goal of making these technologies increasingly efficient and as realistic as possible. For example, advancements in graphics and processing capabilities can lead to more immersive and responsive environments, while improvements in VR headsets can provide a more comfortable and accessible experience for users.

One valuable aspect to consider in the development process is **actively involving children** and their inputs, including UX and UI design. By soliciting their feedback and taking into account their preferences, the metaverse can be tailored to meet their needs more effectively and deliver an optimal user experience. This could include refining the types of activities offered within the metaverse or **adjusting the level of interactivity to suit different age groups and skill levels**.

Moreover, it is essential to continuously monitor and evaluate the impacts of the metaverse on children's hospital experiences, particularly in the **long run**. Ensuring that the metaverse continues to offer tangible benefits involves collecting and analyzing various types of data. This data could encompass aspects such as quality of life, mental and physical health, and academic and social outcomes of children who have used the metaverse during their hospital stays. For instance, surveys or **interviews with children and their families**, as well as medical staff, could provide valuable insights into the effectiveness of the metaverse in **improving the hospital experience**. By examining these outcomes and adjusting the metaverse experience accordingly, developers can continue to enhance the benefits and overall experience for hospitalized children.

6 | Conclusions and future developments

The application of **augmented reality undoubtedly represents a highly relevant element in the context of caring for hospitalized children**, providing them with essential tools to alleviate anxiety and stress, two of the primary challenges faced by these young patients. It should be emphasized that the current generation of children, having grown up in a digital era, largely possesses the necessary skills to use digital devices, including tablets, with ease and competence. Therefore, the notion of offering them this technological support is fully justified.

Naturally, the **availability of funds constitutes a crucial variable in this equation**. If the hospital facility is capable of allocating the financial resources required to provide tablets to children, then this option can prove to be extremely advantageous. It is also noteworthy that within this consideration, children with Autism Spectrum Disorder (ASD) are included. As previously highlighted, **communication based on visual elements and images has proven highly effective in engaging children with ASD**[16]. The immersive scenarios offered by augmented reality, in particular, have the capacity to make these young patients particularly receptive to visual stimulation, a factor that significantly facilitates the cognitive learning process.

With respect to the **metaverse** it can be said that, in the event of an implementation, it is necessary to evaluate whether the access to the metaverse will be provided exclusively for the children and teenagers hospitalized in the clinic – and possibly for medical staff who need to carry out specific recreational or educational activities – or if it will be open to children from multiple clinics. **Expanding access to children from different clinics could facilitate the exchange of experiences and foster a sense of community among hospitalized children**. However, in the second case, the possibilities for interaction with other users would be greater, leading to increased complexity in terms of moderation and management. This would, in turn, result in **higher development and maintenance costs**.

When carefully weighing all of these considerations, it is important to analyze the pros

and cons, including factors such as **potential scalability**, adaptability to various age groups and conditions, and ease of integration with existing hospital systems. Additionally, one must consider that **the technology is not at its final stage** and will continue to evolve. As such, it is crucial to plan for ongoing updates and improvements to ensure the metaverse remains **relevant and engaging** for its users.

Considering only the advantages, developing a metaverse environment for hospitalized children to reduce stress and enhance their experience could be a **viable solution with an adequate budget**.

However, specific drawbacks such as motion sickness are really important in this hospital scenario, where children are already facing their own challenges. Taking into account these factors, one might consider that a metaverse may not be the top choice when deciding to create a gaming experience for children in the hospital. If the goal is to provide an interactive experience for users, it could be more suitable to develop, for instance, an online game rather than a virtual reality application.

Regarding the future, this AR experience for children can definitely be improved, for instance fixing any bugs that are present and optimizing the code, even if **at the moment is stable enough and ready to be used in the hospital** endowed with Android tablets and with enough space and proper rooms to play the game.

Furthermore, due to the high scalability of this application, more features could be implemented, for example adding new models and new related stories, new minigames to provide different activities to the users and maybe also adding some cooperative activities so that children can play together.

To conclude, in light of the above considerations, the use of augmented reality through tablets constitutes a valid and highly beneficial option for hospitalized children, including those with ASD.

However, **it is essential to ensure that such an approach is implemented appropriately, with careful planning and supervision, in order to maximize the benefits derived from the use of this innovative technology within the field of pediatric care and to alleviate anxiety and stress in pediatric patients**.

Bibliography

[1] Augmented reality. In *Encyclopedia of Multimedia*, pages 35–36. Springer US, 2008. doi: 10.1007/978-0-387-78414-4_91. URL `https://doi.org/10.1007/978-0-387-78414-4_91`.

[2] Tommi, Nov 2021. URL `http://www.tommigame.com/`.

[3] B. Ficarra. Virtual reality, augmented reality, and mixed reality. *Emerging Technologies for Nurses: Implications for Practice*, pages 95–126, 2020.

[4] S. Goharinejad, S. Goharinejad, S. Hajesmaeel-Gohari, and K. Bahaadinbeigy. The usefulness of virtual, augmented, and mixed reality technologies in the diagnosis and treatment of attention deficit hyperactivity disorder in children: an overview of relevant studies. *BMC Psychiatry*, 2022. doi: 10.1186/s12888-021-03632-1.

[5] J. Li, E. V. D. Spek, J. Hu, and L. Feijs. Extracting design guidelines for augmented reality serious games for children. *IEEE Access*, 10:66660–66671, 2022. doi: 10.1109/ACCESS.2022.3184775.

[6] D. Logan, L. Simons, T. Caruso, J. Gold, W. Greenleaf, A. Griffin, C. King, M. Menendez, V. Olbrecht, S. Rodriguez, M. Silvia, J. Stinson, E. Wang, S. Williams, and L. Wilson. Leveraging virtual reality and augmented reality to combat chronic pain in youth: Position paper from the interdisciplinary network on virtual and augmented technologies for pain management. 2021. doi: 10.2196/25916.

[7] P. Mesa-Gresa, H. Gil-Gómez, J.-A. Lozano-Quilis, and A. José-Gil-Gómez. Effectiveness of virtual reality for children and adolescents with autism spectrum disorder: An evidence-based systematic review. *Sensors (Basel)*, 2018. doi: 10.3390/s18082486.

[8] J. Mott, S. Bucolo, L. Cuttle, J. Mill, M. Hilder, K. Miller, and R. M. Kimble. The efficacy of an augmented virtual reality system to alleviate pain in children undergoing burns dressing changes: A randomised controlled trial. *Burns*, 34(6): 803–808, 2008. doi: https://doi.org/10.1016/j.burns.2007.10.010.

[9] S. Mystakidis. Metaverse. *Encyclopedia*, 2(1):486–497, 2022. doi: 10.3390/encyclopedia2010031. URL `https://www.mdpi.com/2673-8392/2/1/31`.

[10] A. O'Connor, A. Tai, M. Brinn, A. Hoang, D. Cataldi, and K. Carson-Chahhoud. The acceptability of using augmented reality as a mechanism to engage children in asthma inhaler technique training: Qualitative interview study with deductive thematic analysis. 2023. doi: 10.2196/40231.

[11] A. PATEL, T. SCHIEBLE, M. DAVIDSON, M. C. J. TRAN, C. SCHOENBERG, E. DELPHIN, and H. BENNETT. Distraction with a hand-held video game reduces pediatric preoperative anxiety. *Pediatric Anesthesia*, 16(10):1019–1027, 2006. doi: https://doi.org/10.1111/j.1460-9592.2006.01914.x.

[12] F. Patmon, T. L. Rylee, D. Holder, J. Woodworth, M. Anderson, and P. M. Gee. Nurse, parent, and nurse leader perspective on adoption of ipads for pediatric preoperative anxiety reduction. *Journal of PeriAnesthesia Nursing*, 37(3):393–397, 2022. doi: https://doi.org/10.1016/j.jopan.2021.09.005.

[13] A. Rokach. Psychological, emotional and physical experiences of hospitalized children. *Clinical Case Reports and Reviews*, 2(4), 2016. doi: 10.15761/ccrr.1000227. URL `https://doi.org/10.15761/ccrr.1000227`.

[14] R. M. Stanca. Tommi, il videogioco che aiuta i bambini malati di cancro, Jul 2017. URL `https://nuvola.corriere.it/2017/07/28/tommi-il-videogioco-che-aiuta-i-bambini-malati-di-cancro/`.

[15] J. Urlings, S. Sezer, M. ter Laan, R. Bartels, T. Maal, J. Boogaarts, and D. Henssen. The role and effectiveness of augmented reality in patient education: A systematic review of the literature. *Patient Education and Counseling*, 105(7):1917–1927, 2022. doi: https://doi.org/10.1016/j.pec.2022.03.005.

[16] J. Zhao, X. Zhang, X. Wu, F. Zhou, S. Yang, L. Wang, X. Wu, and F. Fei. Virtual reality technology enhances the cognitive and social communication of children with autism spectrum disorder. *Front Public Health*, 2022. doi: 10.3389/fpubh.2022.1029392.

Acknowledgements

Desidero esprimere la mia gratitudine alla Prof.ssa Garzotto per avermi ispirato lungo il mio percorso accademico e per avermi permesso di lavorare a questa tesi, grazie anche all'enorme supporto del Dott. Patti.

Ringrazio infinitamente mia madre Alessandra e i miei nonni Sergio e Rosetta per l'immenso sostegno e per avermi permesso di portare a termine gli studi universitari.

Un pensiero va anche alle mie persone del cuore, Christian, Lorenzo, Livia, Anna Giulia, Elisa, Chiara, Fabiola, Olivia, Lana e Francesco.

Un ringraziamento speciale va anche agli amici dell'Università e della residenza universitaria Giuseppe, Giacomo, Wuri, Maiva e Giorgio che mi hanno sempre dato una mano nello studio e mi sono stati vicini in questi ultimi anni.

Infine, vorrei ringraziare anche la Prof.ssa Carrera ed il Prof. Cortese, senza i quali non avrei avuto le basi per arrivare a questo grande traguardo.

Ad astra abyssosque!

List of Figures