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TECHNISCHE UNIVERSITÄT MÜNCHEN

Bachelor's Thesis in Informatics: Games Engineering

Examination of the role of Game Mechanics in Serious Games via analysis of an underwater archaeology simulation VR Serious Game.

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Untersuchung der Rolle von Spielmechaniken im Lernprozess bei Serious Games durch Analyse eines Unterwasserarchäologie Simulations VR-Serious Games.

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I confirm that this bachelor's thesis in informatics: games engineering is my own work and I have documented all sources and material used.

Munich, 15.11.2021 Guy Kost

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Abstract

In today's ever-evolving technological landscape, where the rate at which new technologies form and advance accelerates exponentially, the methodologies and technological instruments of most education systems in the world are extremely outdated. Advancements in the field of Serious Games could offer a potential way to supplement education systems, and help orient them into a more flexible, technologically-minded approach in the future.

Serious Games have a vast untapped potential to create a deep learning experience, leaving the learner curious, engaged on a fundamental level and compelled to play and learn more. This would stand in stark contrast to the general consensus among students nowadays that learning is a stressful and boring activity. This potential is all but squandered due to a trend in Serious Games that places the educational material above the gameplay in terms of emphasis given.

This thesis aims to examine the role Game Mechanics play in the learning process, and their importance both for games in general and in the facilitation of knowledge transmission in Serious Games in particular. To accomplish this an Underwater Archaeology Virtual Reality Serious Game demo developed for the express purposes of this thesis will be used as a case study, and examples of learning processes in both serious and non-serious games will be examined.

Contents

1. Introduction

The global onset of the COVID-19 pandemic caused drastic changes in the hitherto customary human way of life. Health regulations and safety concerns brought on by the disease have led to paradigm shifts in many fields. Of particular interest within the purview of this thesis are the changes caused to institutional education and individual recreational and cultural habits, specifically pertaining to the marked increase in the gaming industry compared to the relative decline of cultural and educational institutes (e.g. museums closing entirely, online education).

The practical nature of the difficulties faced by the traditional educational and cultural establishments poses an interesting query, as many of the aforementioned difficulties are either negated completely or lack any relevance with regards to games. Considering this, the field of Serious Games (SGs) could potentially "fill the gap" left in the absence of more traditional institutes. Online presence via the use of SGs could facilitate "virtual visits" to museums otherwise physically unavailable and could provide a fluent, active and immersive communication platform allowing for a potentially better method of remote-education over the audio-visual conference tools currently in use.

This potential becomes even more compelling when coupled with the rapidly advancing technology of Virtual Reality (VR), which would tremendously increase user immersion while partaking in said activities. This could also positively affect individual well being [1] as an interpersonal communication platform with a high degree of presence. An additional benefit of this enhanced presence lies in its ability to make available to the user experiences that would be all but impossible for them under normal circumstances.

Considering almost all aspects related to Underwater Cultural Heritage (UCH) in general and diving specifically as an example, the combined technology of a VR SG, especially one available to the general consumer in the comfort of their own home, could allow any individual otherwise barred from such experiences (be it due to physical difficulties, financial concerns, time and geographical constraints or all of the above) to enjoy them in a believable manner with little to no effort. To this effect - and as a general best-practice design principle - a high degree of fidelity and authenticity is required from such a UCH VR SG.

SGs are games targeted at delivering real-world knowledge to the player [2]. Examples of SGs are true-to-life simulators (e.g. flight simulators used to train pilots) or any other game with expressly educational content, which is also applicable outside the context of the game.

Game Mechanics (GMs) are "... the action invoked by an agent to interact with the game world, as constrained by the game rules"[3]. In other words the interactions between the player, different objects in the game and the game world itself, as well as the rules governing those interactions. This includes, but is not limited to, the control scheme (the way the player interacts with the game itself), the different actions a player can perform (the way the player interacts with objects within the game) and the consequences of the player's actions (the way objects in the game interact with the game itself).

Per definition, SGs need to contain educational material which uses the game as a transmission vector (see chapter 2). However, how this transmission occurs depends entirely on the design doctrine the developers choose to implement while developing the game. Throughout research of the subject of SGs, a dominant trend was observed both in published SGs as well as in research and academic articles regarding SGs.

The aforementioned trend is to place the accuracy and completeness of the educational material as the paramount requirement for the SGs, often above gameplay requirements - in effect by less carefully designing GMs. For ease of writing, that particular design doctrine will be referred to as *"Education forward"*. Alternatively, a design doctrine that emphasizes gameplay requirements (i.e. GMs design) and fun as well as the educational material in equal measures, which will be referred to as *"Game forward"*, could unlock the full potential of SGs as educational tools [4] and a self-contained game genre.

1.1. Contrasting the "Education forward" versus "Game forward" design doctrines through the lens of personal experience

In this section the "Education forward" and the "Game forward" design doctrines will be compared and contrasted by presenting and analyzing three examples:

- A non-serious game with educational value; presented in order to show the possibility and potential of knowledge transmission in non-serious games
- A SG with poor gameplay that hinders the objective of learning; presented in order to warn against over-heavy reliance on the "Education forward" doctrine
- An early SG that strikes a balance between gameplay and educational material; presented in order to demonstrate the merits of the "Game forward" doctrine

These examples are conveyed out of the writer's own past experiences with the games in question, both as an individual and as a learner, analyzed now through the experience of a games engineering student. Note that the "Game forward" doctrine is intended to emphasize a **balanced approach** to SG development, producing enjoyable games with meaningful educational content.

1.1.1. *"Medal of Honor: Allied Assault"* - a non-serious game with informative content

In the early morning of 6.6.1944, the allied forces launched a historic amphibious invasion of northern France, code-named operation Overlord. The invading forces landed on five stretches of coast code-named Juno, Sword, Gold, Utah and Omaha. A detailed recreation of that event, based on its depiction in the film *"Saving Private Ryan"*, is presented in the game *"Medal of Honor: Allied Assault"*[1] and allows the player to experience the events unfolding, rather than simply receiving the information by "traditional" means.

So profound was the experiential learning that even as a layman I have retained this information with little effort for well over 19 years, and it has sparked in me a life-long interest in military history. *"Medal of Honor: Allied Assault"* is not a SG, and yet through a combination of attention to accurate detail and a plausible, albeit somewhat fantastical, alteration of reality, that were targeted deliberately to induce enjoyment in the player, managed to create a meaningful and highly impactful learning experience, that went so far as to create a self-fueled, passionate curiosity in the learner.

It is worth noting that the details presented in the game vary from historically accurate (dates, some locations, weaponry and uniforms... etc.) to completely fictional (the missions, or levels, of the game themselves are mostly fictional). Despite not being completely and absolutely accurate in terms of historical details, the sheer enjoyment of the experience could galvanize the player to conduct their own research into the subject in order to determine actual facts. The question of precisely how much "creative freedom" could be taken with historical facts, while leaving the learning experience intact, will be touched upon further in this thesis, but warrants further research on its own.

1.1.2. *"Infinite SCUBA"* - A SG with little gameplay

As part of writing a seminar paper [6] that I have co-authored with my colleague Leonard Keil, we have examined several SGs pertaining to the theme complex of UCH. As a general observation the game presented little to no gameplay, which was subjectively unenjoyable. Extrapolating from the Steam reviews of *"Infinite SCUBA"*[2] it is not unreasonable to assume that the latter applies to most of the people who played it.

"Infinite SCUBA" gameplay involves the player exploring a model of a real-world diving site, taking pictures of local wildlife and cleaning the environment. The player is rewarded an in-game currency by performing these actions, which can be used to upgrade the player's diving equipment. Gameplay is sadly hindered by several issues, which include unpleasant controls and a lack of progress or challenge, as the different equipment offers no gameplay impact that I am aware of.

While the 3D model of the diving site and the flora, fauna and diving equipment are faithfully and accurately modelled, the lack of engagement lessens the learning experience.

[1] released in 2002, developed by 2015, inc. and published by Electronic Arts [5].

[2] released into Steam early access in 2017, developed and published by Cascade Game Foundry, remains in early access as of writing this document [7].

Considering Mihaly Csikszentmihalyi's flow model [8], the lack of challenge in *"Infinite SCUBA"* prevents players from entering a state of flow, thus squandering the primary benefit of SGs over traditional learning methods.

1.1.3. *"What About the Water in the Negev?"* - A good early example of balanced gameplay and educational material

During science class in 4th grade (circa 2000) I became acquainted with a SG called *"What About the Water in the Negev?"*[3] It was a point-and-click style management game in which the player is tasked with harnessing natural water for civilian and agricultural usage in the real town of Dekel in the Negev region of Israel.

The gameplay loop consisted of clicking on pixel art representations of different water sources and connecting them to different consumers. The player is then scored based on their decisions, such as leaving protected natural fountains untouched or using a fresh water source to provide drinking water to civilians. Throughout the game information about the source/consumer is available to the player in a side window by clicking upon the corresponding entity. When a decision is made the game scores the player and provides a short explanation for the score. Other than the short explanations the game provided the player with a glossary where the different entities are described in more detail (See Fig. 1.1).

"What About the Water in the Negev?" made superb use of the technology available at the time as well as its artistic direction and gameplay design decisions, and left a lasting impression some 21 years later. It also dealt with an important and ever-relevant subject in a manner that enriched players, and it is remembered fondly to this day.

Figure 1.1.: An image depicting the UI in the game *"What About the Water in the Negev?"* [9]

[3] released in 1991, developed by the Israeli center for educational technology (CET) as part of a series of SGs teaching various aspects of natural water and water infrastructure in different parts of Israel [9].

1.2. Initial hypotheses

The examples in section 1.1, while stemming from personal experiences, are meant to demonstrate a vision for SGs moving forward, as well as underline perceived failures in the current state-of-the-art of SG development. In the following, hypotheses regarding the process of developing SGs, specifically concerning the emphasis given to gameplay mechanics, will be stated and examined via a VR SG in the theme complex of UCH. The VR SG will be developed for the express purposes of this thesis.

Many researchers in the field of SGs exalt the merits of games as tools to transmit knowledge. Properties such as immersion, motivational benefits etc. are cited as important qualities of SGs that facilitate learning. However, key aspects of games - game mechanics, gameplay loop, enjoyment factor - that enable those important qualities to exist, receive little to no scientific attention. SGs developed under those conditions often negate the very qualities that make games such an enticing and useful tool for learning.

These observations, alongside the personal experiences which were described in section 1.1, have led to the formulation of the following hypotheses:

Hypothesis 1: A UCH VR SG developed specifically for this thesis could transmit accurate subject-specific information to the player.

Hypothesis 2: Such a VR SG would be immersive.

Nowadays games often involve handling of problems requiring soft and delicate skills, teaching real world concepts through implementation instead of rote memorization (e.g. first-person shooters requiring rapid reaction times and decision-making, puzzle games introducing a logical concept and then expanding on it etc.). Mastering these skills individually awards the player with an immense sense of accomplishment. That sense of accomplishment, being a driving force inducing fun in the player, can be achieved with a far less hands-on approach from the developers as shown by Mark Brown in "Half-Life 2's Invisible Tutorial" [10].

By delaying gratification and making the player exert themselves in order to achieve it, especially if the gratification is unexpected, SGs could produce self-sustaining interest in the subject learned [11]. Due to this, future SG design goals should avoid traditional structuring tropes such as heavy reliance on text-based information and rigidly linear level design. Alternatively, design goals should aim to allow the player to explore and learn at their own pace by accomplishing game tasks.

Some of the aforementioned design concepts will be attempted to be implemented in the accompanying SG developed for this thesis in order to test these hypotheses. Unfortunately, due to limitations posed by COVID-19, the size of the development team, the relatively short development time and the platform selected for development it may prove difficult, if not impossible, to produce a sufficient sample size for statistical analysis.

1.3. Overview

The following chapters will provide the reader with basic knowledge of the theme complex, present several relevant examples pertaining to different aspects of the thesis, detail both the implemented and theoretical design of the accompanying SG, propose a possible user-study design, deliver comparative analysis to other related work as well as previous work by the author and finally draw conclusions from the research presented and offer suggestions for future work.

Chapter 2 will expand upon the three component theme complexes that are relevant to this document and comprise the definition field of the accompanying game - SGs, VR and UCH - while supplying the reader with a base of knowledge regarding the information discussed further in this thesis.

Chapter 3 will introduce a comparative analysis of this thesis relative to other work in the field and the author's previous efforts. It will also deliver key evidence of the vitality of GMs, particularly in the context of SGs design, or as a bridge between non-serious games and SGs. This will be accomplished through means of an example incident in which an error in programming a single GM caused a non-serious game to enter a serious context which culminated in several academic papers and research in various fields. Additionally, this information will be reflected while considering a taxonomy which diminishes the pedagogical efficacy of non-serious games.

Chapter 4 will present a short history and related findings of the ancient city of Caesarea Maritima, which was selected as a model location for the design of the accompanying game providing it with its UCH relevance and material. The reasoning that led to that selection will also be recounted.

Chapter 5 will contain the envisioned general design guidelines for a theoretical future iteration of the accompanying game. These are meant to convey to the reader the sense of the planned complete game, but are not implemented in their entirety in this thesis. A select aspect of the detailed design plan will be implemented and described in the following chapter.

Chapter 6 will illustrate the implementation process of the accompanying demonstration game while stating the design goals that drove the design process. The design will focus on a single key aspect of the broader gameplay design planned for the "complete product" for pragmatic reasons as discussed in the previous chapter.

Chapter 7 will focus primarily on a suggested design plan for a possible future user-study (as such a user-study was prevented during the writing of this document due to COVID-19). The user-study will investigate player immersion as well as information transmission based on the game's serious context, basing the data-driven questions on well proven questionnaires while adding subject-specific (i.e. Caesarea Maritima) questions in order to test the efficacy of the game in transmitting knowledge.

Chapter 8 will conclude this thesis by briefly reviewing the information discussed and drawing deductions based on it. Finally, suggestions for future work based on theoretical information and unanswered questions raised by this thesis, as well as the design and implementation of the accompanying game will be made.

2. Serious Games, Virtual Reality and Underwater Cultural Heritage

In this chapter the subject complexes of SGs, VR and UCH will be introduced more thoroughly in order to provide the reader with a base of knowledge regarding the subjects discussed in this document. Notable examples of emergent technologies will be provided based on previous research conducted [6]. Please note that the subject complexes discussed in this chapter are vast, each encompassing copious amounts of research individually. It will therefore be unreasonable to cover anything more than a rudimentary introduction within the limits of this document and it is highly recommended that the reader conduct their own study into these subjects in order to establish deeper understanding.

2.1. Serious Games

SGs are games, either digital or physical in nature, that are developed with the express purpose of delivering real-world relevant knowledge that transcends the boundaries of the game itself to the player [2]. Such knowledge can be practical (e.g. accurate operation of an airplane in a flight simulator) or purely academic (e.g. an accurate 3D model representing a dive site in Belize in a UCH SG). The SGs industry grows with ever-increasing frequency and SGs are developed and applied in many academic and professional fields (e.g. healthcare, military, disaster control, personnel training, education and more [12, 13]).

2.1.1. Definition

A fairly recent definition dictates that SGs are "... any piece of software that merges a non-entertaining purpose (serious) with a video game structure (game)" [14]. While undoubtedly crucial for purposes of taxonomy construction, such a definition neglects the importance of combining both dimensions in **equal measures** in the process of designing a SG. More recently and in other words - "... for a serious game to be considered as such, it must maintain its game elements and it must be fun" [12].

2.1.2. The importance of fun and play in learning

The act of seeking entertainment and enjoyment is natural. It is a biological need that is evident, prevalent even, in many living species. "Fun" is a concept that is readily, intuitively and exactly understandable to any human. While in and of itself somewhat ambiguous and difficult to define [15], play - the act of seeking fun - remains an important aspect of human life. Moreover, the importance of play in child development is well documented [16]. It is therefore a reasonable assumption that play and fun hold a significant influence in matters regarding learning even from its most basic forms. SGs seek to capitalize on this influence and utilize it further with learning material of varied content and complexity.

Fun, and through association flow, require a measure of challenge from the participant [8, 17]. It is thus perplexing that many examples of SGs are devoid of any meaningful challenge. Two notable examples of this lack are *"Infinite SCUBA"* and *"Dive with Sylvia VR"* [6] (see chapter 3).

2.1.3. Taxonomy

Despite fair amounts of research in the field, a general consensus regarding a unified taxonomy for SGs has yet to be reached. Various ad-hock taxonomies were offered previously, with some even building upon one another for purposes of generalization. Unfortunately, several of the previously offered taxonomies are somewhat lacking, and are based on definitions for SGs that are incongruent with state-of-the-art standards and requirements. One such inadequate definition, which was shortly mentioned above, can be found in the paper written by Djaouti et al. [14].

The described taxonomy is based on said definition, which states that there are only two dimensions by which SGs should be categorized; the *"serious"* dimension, referring to the educational content of the SG, and the *"game"* dimension, referring to the actual game in which the former is delivered. Hence games that are not developed with the sole objective of delivering educational material should not be considered SGs.

The given definition of SGs is then immediately contradicted by examples of games developed for entertainment purposes that were "purpose-shifted" by professionals and educators in order to deal with real-world subjects. This of course proves that the *"serious"* dimension, per the definition, can be found in non-serious games, lending them credit as useful SGs and discrediting the rather simplistic taxonomy. This "purpose-shifted" category of SGs [14] should be thoroughly examined and researched in order to promote growth in the field.

In sharp contrast, the Comprehensive Serious Game (CSG) taxonomy [12] is far more detailed, up-to-date and as a direct result relevant. The granularity of the different categories of the taxonomy allow for far greater freedom of thought through its definitions. Additionally, as was mentioned above, the core definition of SGs upon which the taxonomy is based correctly places the importance of the enjoyment factor of SGs on the same level as that of the educational content, resulting in a more balance-oriented approach to the taxonomy in its entirety.

2.2. Virtual Reality

VR is a simulated experience, either recreating the real world or an entirely fictional setting, that typically involves a computer-generated 3D model of an environment that is viewed through a Head-Mounted Display (HMD). Other sensory inputs such as audio and haptic feedback may also be present in order to increase the user's sensation of being physically present in a different reality. Although predominantly used with a HMD, other modalities of viewing technology are available (e.g. CAVE systems [18]).

2.2.1. Different modalities

A demonstrative implementation example of a different modality through which VR can be achieved is a comprehensive simulation of vehicular dynamics. This can be seen e.g. in "The Warthog Project" [19], where an individual recreated a very close approximation of the cockpit of a *Fairchild Republic A-10C Thunderbolt II 'Warthog'* close air support aircraft, including relatively accurate controls and instrumentation while making use of a large multi-directional curved display. The debate regarding the merits and detriments of the different modalities of VR is increasingly relevant and important, particularly concerning the different levels of immersion achieved by each of them [20].

Specialized VR equipment is however not a necessity in order to create a believable alternate reality. Modern first-person perspective games for example continuously create such engrossing 3D realities without the use of anything other than a regular display. A complaint raised against this modality however is its relatively low immersion. To counteract this, a HMD with positional tracking and a built-in audio system can be used to improve user immersion. This is done by enabling more intuitive, less abstract head movement and through directional sound, both of which in turn allow the user a better sense of presence in the 3D environment.

2.2.2. VR-related terms

Augmented Reality (AR) is a technological subset of VR. In it, the user's real-world surroundings are layered with artificial, computer-generated imagery. This additional information is typically used to enhance the viewer's perception of their surroundings in some way, as can be seen e.g. in the Head-Up Display (HUD) interfaces of combat aircraft [19].

Mixed Reality (MR) is a mesh of real-world 3D environment and a virtual world that produces an interactive co-existence between physical reality and digital VR. A vivid example of this can be seen in the wildly successful game "Pokémon GO" [21].

Although not discussed further in this thesis, a deeper taxonomy of these terms as well as the VR-continuum theory are presented and elaborated upon by Milgram and Kishino (See Fig. 2.1) [22].

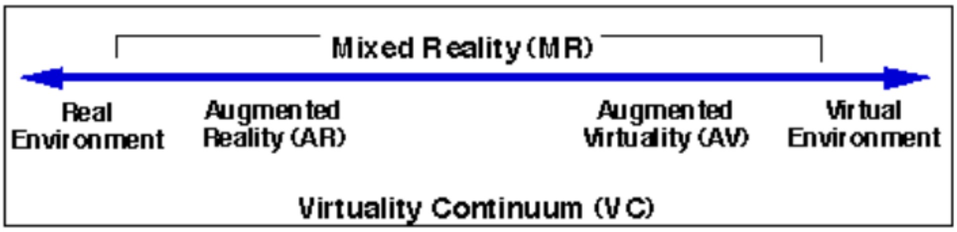

Figure 2.1.: The Milgram-Kishino Virtuality Continuum [22]

2.2.3. Recent history

While the terminology and concept of a "virtual reality" can be traced back as early as the 1800s, the field as it is more commonly known today did not formulate until the mid to late 20th century and did not reach the general consumer market until the 1990s. The opening years of the 21st century were marked by relative indifference towards VR technology. However, by 2016 VR related development skyrocketed and market leaders, such as Amazon, Apple, Facebook, Google and many more, employed dedicated AR and VR development teams.

Provided are notable examples of VR related developments that were released in that time-span:

Year	Product	Company	Notes
2010	*Oculus Rift*	Oculus (Facebook)	Prototype
2013	Low-persistence displays	Valve	Technological breakthrough
2014	*SteamSight*	Valve	Prototype
2014	*Playstation VR*	Sony	-
2015	*HTC Vive*	HTC and Valve	-
2015	*Cardboard*	Google	Stereoscopic viewing device

Table 2.1.: Examples of notable VR related products, prototypes and technology developed between 2010-2016

2016 saw the first commercial release of sensor-based tracking technology which allows users freedom of movement within a predefined space [23]. This technology is still in use in several HMD devices including the *HTC Vive SteamVR* from HTC and the *Valve Index* from Valve. In 2019 technological advancements such as standalone headsets (e.g. the *Oculus Quest* [24]) and individual finger tracking (developed for the open-hand controllers of the *Valve Index* [25]) were presented.

It is evident that the past decade ushered extremely rapid growth in the VR industry. The VR market is currently in a state of economic boom, with a predicted growth of over twenty percent to a total market value of 62.1 billion euros by the year 2027 [26].

Please note that this introductory explanation to VR is relatively compressed and rudimentary. A deep-dive into the vast world of VR, including related topics such as the importance of player immersion, is covered in Leonard Keil's thesis [27].

2.3. Underwater Cultural Heritage

Cultural heritage is a collection of markers and evidence of a specific culture or societal group's existence [28]. What constitutes a cultural heritage asset is subject to selection by modern society [29], and those assets are protected via legislation as well as enforcement by organizations such as the UN and UNESCO [30]. Human cultural heritage is therefore such a collection not limited to a specific group, but instead applicable to all humans. Underwater Cultural Heritage, or UCH for short, is a subset of all human cultural heritage assets that can be found underwater [31].

2.3.1. Taxonomy

Cultural heritage can be further subdivided into three main categories of interest. Those are tangible, intangible and natural heritage assets [32]. Tangible assets are physical objects, whether movable (e.g. coins or sculptures) or immovable (e.g. monuments, archaeological sites, historical buildings etc.). This category includes UCH assets like shipwrecks, sunken cities and any physical objects lost underwater like cannons, coins, statues and so on. This part of cultural heritage is well practiced and documented, as can be seen in the manifold disciplines of archival science, conservation and preservation. Intangible heritage assets are the things relevant to a specific culture that have no discreet physical form. Examples of these are customs, languages and dialects, folklore, rituals etc. This aspect of cultural heritage is relatively young both in practice and legislation, as shown in UN legislation [30]. Finally, natural heritage encompasses culturally relevant aspects of nature such as flora, fauna, topology, geological formations and many more.

Due to the practical nature of UCH, it is included in the tangible heritage category as all finds of cultural importance underwater are obviously physical in nature [33, 34]. However, UCH also deals with the natural heritage category in a direct manner. Aside from man-made artifacts and monuments, the flora, fauna, topology and any other aspect of nature underwater is also clearly part of human natural heritage. It is often the case that UCH sites of interest are integrated into their respective marine wildlife (for example coral reefs growing in and around shipwrecks).

2.3.2. Inherent difficulties

The delicate balance of biodiversity poses a serious problem for UCH research, as removal of any significant finds may upset said balance and cause a catastrophic deterioration in both the state of the object removed as well as the local biome. Additionally, while the process of removal itself may cause damages both to the cultural asset and the natural surroundings, further damage may come to the cultural asset due to the removal from favourable underwater conditions (e.g. salinity, levels of oxygenation) that often contribute greatly to preservation [35]. Finally, due to the relatively difficult conditions underwater, such as poor visibility and obfuscated orientation, UCH sites take on an extremely important charge as navigational marker points.

Another issue that increases the difficulty of learning and dealing with UCH is the specialty training that is required to enter the field. UCH sites are often difficult to reach, requiring at the very minimum a recreational diving license (e.g. the PADI open water diver license [36]). The process of obtaining such a license normally entails a week-long certification course that requires trainees to become acquainted with their gear, natural surroundings, possible dangers both from marine wildlife and improper diving, proper dive planning, and so on. Further skills relevant to UCH, such as proper search and recovery of sunken objects, the use of enriched air mixtures that allow for deeper diving or cave and ruin diving require even more specialized training and equipment which often entail a substantial investment of resources.

2.3.3. Potential benefits of a SG targeted at the field

Due to the difficulties listed above, the barrier to entry into the subject of UCH is rather steep. One of the merits of a potential SG portraying a reasonable simplification of these specialties and gear would lie in the opportunity to experience and experiment with the subject [13] in a safe, failure-tolerant and relatively low-cost environment prior to committing any valuable resources.

Such a game would also allow individuals to experience otherwise restricted or inaccessible environments [37, 38]. Persons incapable of diving due to disabilities or health related issues would benefit from such a game immensely, and it would enable such persons to experience the world of UCH vicariously. Additionally, the knowledge imparted in dive training is transmitted primarily through traditional study and revision. A SG implementing a high-fidelity facsimile of diving procedure could greatly aid learners as a revision tool. A promising pilot research [39] saw the use of VR as potential means of treating phobias. A VR SG dealing with UCH subjects could be adapted accordingly to assist with the treatment of thalassophobia.

A final point of harmony for a SG dealing with UCH subjects is that most if not all diving courses emphasize preservation of natural underwater surroundings, flora, fauna and any UCH assets found. Learning to respect and preserve the environment and its inhabitants, as well as any underwater historical monument or site, is part of every diver's basic training at the most rudimentary level. This knowledge can be instilled in the player, promoting the conservation efforts of UCH assets around the world [40, 41, 42].

2.4. Emergent technologies in the field

Several technological advances in the combined field of UCH VR SGs were made in recent times. Those tend to manifest in external hardware aimed at increasing the player's immersion through various means, meant to be used in tandem with traditional VR gear and software. In the following two notable examples of such hardware are presented.

LiquidReality

LiquidReality is "a wearable system that simulates wetness sensations directly on the user's face for immersive virtual reality applications." [43]. The hardware consists of a HMD which is integrated with a thermal unit that regulates the temperature at the contact point between the device and the user, as well as a vibrotactile module that is used to elicit haptic feedback that corresponds to the visuals shown via the HMD.

According to research [43] the sensation of wetness is experienced by humans primarily through a combination of a change in temperature and tactile perception. Said research guided the design process of *LiquidReality* and the first of two case-studies presented focus on ascertaining the type and level of feedback (exclusively thermal or a combination of thermal and vibrotactile) necessary to increase immersion in players. As shown, an exclusively thermal feedback - a change of three degrees centigrade per second - yielded the best outcome both in terms of perceived wetness and player comfort.

Based on the results of the preliminary study described above, a second study was conducted with the aim of measuring changes in player immersion while using the device. For that purpose the players were presented with two different visual scenarios associated with the different stimuli of the first study. The two categories of these scenarios were:

- Underwater scenarios - the user is fully immersed in water.
- Splash scenarios - water is being splashed on the user's face.

Results show that in every category an exclusively thermal stimulus is preferable to a combined thermal-vibrotactile one, with both outperforming the control group (no additional external stimulus). The conclusion can be drawn that a purely thermal variant of *LiquidReality* could positively impact player immersion when presenting water-based VR scenarios in a significant manner.

Amphibian

Amphibian is a diving simulator rig that focuses on physical elements of underwater experiences that are extremely difficult, if not entirely impossible, to emulate without the use of specialty equipment (or via the user's physical presence in water). Examples of these elements are the sensation of buoyancy, water-drag while swimming, breath motion (the changes that occur in a person's buoyancy based on lung volume during breathing), temperature changes and tactile feedback [44].

The *Amphibian* rig consists of a large frame connected to a suspended harness via elastic bands. On the ground in the center of the frame is a torso base with an inflatable cushion. A VR HMD device (specifically the *"Oculus Rift"*), noise-cancelling headphones, custom built gloves that act both as VR trackers and used for thermal simulation and finally a specialized mouthpiece are all worn by the user.

The torso base is used to create the sensation of buoyancy. The elastic bands recreate the sensation of drag while swimming (with the large frame and suspended harness allowing for a natural range of motion). The inflatable cushion in tandem with the mouthpiece measure the user's breath and apply changes to their "buoyancy" (i.e. inflating or deflating the cushion thus reducing or increasing the user's sense of weight) accordingly - thus providing breath movement as explained above. The VR HMD device, the headphones and the gloves work much like other VR equipment and provide the user with a sense of immersion (particularly enhanced via the changes in temperature afforded by the gloves).

A meticulous and exhaustive user-study conducted with twelve independent experienced divers concluded that the most realistically recreated part of the simulator was breathing motion. However, the users reported several issues regarding discomfort, the use of hand-based swimming gestures[1], the lack of full 6DOF enabled motion and lastly some issues with temperature simulation were reported.

Overall *Amphibian* shows deep intent in its design, thoroughly simulating every physical aspect of diving with the aim of greatly increasing immersion and presence in the user. It represents a significant step forward in diving simulation and a bright prospect for the future of the field. Combined with the technology of *LiquidReality* detailed above, the two devices working in unison could achieve levels of immersion vastly superior to current standards, as the two technologies complement each other's weaker points.

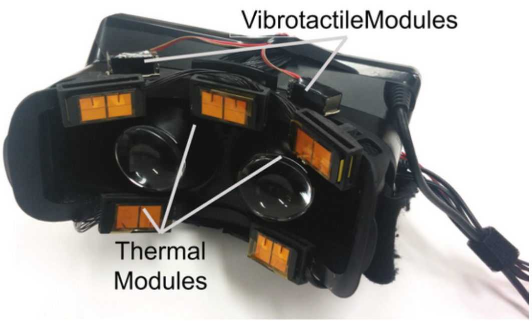

Figure 2.2.: An image of an initial prototype of the *LiquidReality* HMD [43]

Figure 2.3.: An Image of the *Amphibian* rig in use [44]

[1]Real-world diving is performed exclusively with the use of leg-based swimming while making use of fins.

3. Related work

This chapter will see the contents of this thesis and the accompanying game compared to several other sources. Among those sources is the author's previous effort in the field - a seminar paper which acted as a precursor for this thesis [6], provided in the interest of examining the progress and changes made compared to the earlier vision of the subject. Other sources will include several games, experiences and SGs, implemented both in VR and traditionally, all of which stand in relation to the tenor of this thesis. In addition, a detailed breakdown of a real-world incident in which a programming failure in a non-serious game created an emergent serious context that was the subject for research and academic study, which is still relevant to this day. This example is recounted in order to demonstrate the role and importance of GMs in all games (not just SGs), and show how they can influence and even create the serious context in which a game is considered.

3.1. Comparison to seminar paper

Several areas of the seminar paper were covered and expanded upon in this thesis. While the seminar paper constituted an initial exploration of the subject complex, this thesis is a far more comprehensive document - in particular on the subject of UCH as can be seen with the inclusion of chapter 4. The core subject of this thesis also more thoroughly examines a significant aspect that was only briefly discussed in the seminar paper: GMs and their importance (e.g. chapter 3).

The accompanying game, which embodies a direct result of the plan first established in the seminar paper, is a good example of both improvements and drawbacks of this thesis compared to the seminar paper. While the theoretical plans presented in the seminar paper were further bolstered and refined in this document and the theme complex was more deeply researched and applied, the accompanying game and its implementation also clearly defined the realistic limits of execution that were not fully considered in the seminar paper. The ambitious scope of the envisioned product described in the seminar paper is reduced to a realistic operational scale in this thesis, specifically in chapter 6.

Additionally, the technological advances in the field of VR that were briefly mentioned in the seminar paper are fully presented in chapter 2, alongside a more elaborate inspection of the theme complexes of SGs and UCH. Finally, while this thesis offers a potential user-study, due to the inability to execute it, the improvement from the seminar paper in this aspect is relatively marginal compared to the areas described above.

3.2. Comparison to external sources

During the writing process of the aforementioned seminar paper and through the research process conducted for this thesis many examples of different games, experiences and SGs, both as VR applications and standard non-VR applications, were examined. Some of those examples were commercial releases, some were attached to research documents and some were a combination of the two. Naturally, all the examples considered had to do with the theme complex of UCH VR SGs, or at the very least some subset of that theme complex. An examination of several concrete examples is in the following.

"Infinite SCUBA"* and *"Dive with Sylvia VR"

"Infinite SCUBA" is a third-person non-VR diving simulator developed by Cascade Game Foundry that was released into *Steam* early access in 2017 [7]. Gameplay in *"Infinite SCUBA"* sees the player taking control of a diver in order to "identify wildlife, find artifacts, collect branded SCUBA gear, and take photos to share with friends, while learning about dive science and the local culture, history, and environmental issues" [45].

Control of the diver is done primarily in third-person (with some rare occurrences of first-person control e.g. while taking photographs) in an exploration of 3D models of real-world diving sites in Belize and Micronesia. During the dive, the player can spot and photograph flora, fauna and artifacts in the environment using a camera to "identify" them and score "seashells" (the game's currency). The player can also score "seashells" by cleaning the environment. The currency can later be spent to acquire new gear (modeled after real-world diving gear).

In comparison *"Dive with Sylvia VR"* is a heavily simplified version of *"Infinite SCUBA"*. Also developed by Cascade Game Foundry, it was released in 2019 for the *Oculus Rift* and on *Steam* [46]. The "game" is a five minute long, on-rails tour of a real-life diving site in Belize. Guided by a virtual diver portraying National Geographic Explorer-in-Residence Dr. Sylvia Earle (said diver is also voiced by her), the player is led through the authentic aquatic wildlife and can listen to relevant information provided by Dr. Earle.

According to Cascade Game Foundry, the appearing wildlife in *"Dive with Sylvia VR"* is randomly generated anew with each playthrough in order to increase the immersion of the player and replayability, as well as realism. The player has two means of interaction with the world, a flashlight in their right hand to better illuminate the environment and a pressure-/air-gauge in their left hand to monitor depth and air supply [45]. However, depth and air-supply are seemingly static and have no apparent impact on gameplay in any meaningful form.

Both SGs lack the crucial component of challenge that is required to induce fun and flow in the player, and consequently squander one of the key benefits of SGs over other more traditional learning tools. *"Infinite SCUBA"* presents the player with no real challenge regarding the in-game tasks and offers very little replayability due to lack of variety. Even more critically, *"Dive with Sylvia VR"* not only lacks any sense of challenge but also any significant interactivity, with the definition of "Experience" applying far better while describing it. *"Dive with Sylvia VR"* can be defined as a SG only in the loosest of terms.

While the *"Infinite SCUBA"* SG does boast a high level of focus on UCH via the modeling of a real-world diving site and gameplay that is focused on the preservation of marine life and artifacts, it is extremely limited in terms of reliability and immersion and lacks any significant challenge. *"Dive with Sylvia VR"* on the other hand, while being implemented in VR and focusing on the subject of UCH, can scarcely be categorized as a game due to lacking any degree of interactivity - exhibiting only a short "on-rails" experience to the player. Compared to these two examples, the game accompanying this thesis - while lacking the same level of polish afforded by the different development conditions - is overall a more interactive, deeper exploration of the subject of UCH, while still displaying enough gameplay to be considered a SG implemented in VR.

As to the publications attached to the games, the somewhat self-congratulatory tone taken by McMillan et al. [47] diminishes the overall credibility and academic veracity of the information presented by them. Additionally, a case-study [48] of *"Infinite SCUBA"* seems to contain only an explanation of different GMs, as well as tangential information relevant to the topic of the game. While the analysis of some of the GMs in the game is welcome, it is by no means exhaustive. Comparatively, this thesis presents a thorough scrutiny of the different GMs on offer from their very inception to the method by which they were executed.

"Nefertari: Journey to Eternity"

An outstanding exemplar of an immersive VR experience in the field of cultural heritage, *"Nefertari: Journey to Eternity"* is a full-scale 3D recreation of QV66 - the tomb of Neferatri, wife of Ramses II, in the valley of the queens in Egypt [49]. The model and textures used in the recreation are of phenomenal quality, providing the visitor with significant immersion and a sense of presence in the now-restricted tomb. The experience is a truly commendable conservation effort, that not only enables the general public to experience the magnificence of the tomb "first hand", but also preserves a digital true-to-life copy of the original in perpetuity. An added benefit of VR and the immersion it offers lies in allowing any individual with access to a VR set to experience locations otherwise too remote or too expensive for them to visit, all from the comfort of their own home. This can vastly expand the cultural horizons of the user.

However, with that being said, *"Nefertari: Journey to Eternity"* cannot be categorized as a SG, as like in the case of *"Dive with Sylvia VR"*, since it is heavily lacking in terms of interactivity and completely devoid of challenge. "Gameplay" in *"Nefertari: Journey to Eternity"* is limited to movement between the different parts of the tomb with optional "interaction" with specific murals and wall-paintings playing a short audio clip containing an explanation about the images depicted. Sadly, during the author's "playthrough" of the experience the aforementioned audio clips did not function.

Compared to *"Nefertari: Journey to Eternity"*, the accompanying game contains at least a measure of gameplay and challenge, requiring an active effort from the player in order to receive the presented information. This can result in an overall better and more rewarding learning experience than the more simplified knowledge transfer e.g. in *"Nefertari: Journey to*

Eternity".

"Minecraft education edition"

Likely requiring no introduction at all as the world's best-selling game of all time, the phenomenon that is *"Minecraft"* was already used for educational purposes in its most basic form [50]. As a powerful creative tool that is potentially nigh-limitless and extremely popular to boot, it is highly encouraging to see adaptation of *"Minecraft"* as a serious-context educational tool in the classroom by educators.

Even more inspiring is the creation of a purpose-built educational platform in *"Minecraft"* - *"Minecraft education edition"*. This platform includes curricula from various fields ranging from science and math to climate change and sustainability, all presented within the world of *"Minecraft"* following the well established rules and GMs, that are already conveniently widely known by the target audience.

It is the author's strongly held belief, that bidirectional professional collaborative efforts such as these are the future of SGs. While not natively implemented in VR and not pertaining to the subject of UCH, *"Minecraft education edition"* is a beacon of the potential held by applying a serious context to enjoyable games. If the accompanying game successfully implements an experience on par with that on offer in *"Minecraft education edition"*, it should be regarded as a resounding success.

Figure 3.1.: An image depicting a *"Minecraft"* world designed for a curriculum about ancient Egypt [51]

3.3. The Corrupted Blood Incident

There is perhaps no clearer evidence of the importance of the ability to discern serious information and context even from non-serious games than the conduct, research, results and unforeseen repercussions of the incident that began on September the 13th, 2005, in the game *"World of Warcraft"* (commonly referred to simply as WoW) [52, 53].

The incident, known as the Corrupted Blood Incident due to the life-draining and highly contagious condition spell *"Corrupted Blood"* which was cast against players by *Hakkar the Soulflayer* - the final opponent in the then-newly-introduced *Zul'Gurub* raid, was a full-scale virtual pandemic which lasted for approximately one month before emergency actions finally managed to regain control of the disease.

The *"Corrupted Blood"* spell was designed to last only a few seconds and function exclusively within the raid area. Due to its primary target being high-level players, as the raid was designed to be undertaken by player near or at the game's level capacity at the time, *"Corrupted Blood"* caused relatively high amounts of damage. Additionally, the condition was designed to spread from player to player within a set distance while active. A programming oversight that allowed player-owned pets or familiars to contract the condition and transmit it back to the owner or to other players[1], but did not eliminate it as they left the confines of the raid, allowed the condition, which at that point could safely be classified as a rapid contagion, to break its containment within the raid and to propagate across the virtual world like wildfire.

Once free of containment, the contagion quickly spread through frequently used trade and travel routes. Non-Player Characters (NPCs), entities like merchants or quest-givers in the game world, could contract the contagion. Due to their extremely high hit-point pools the NPCs would not be killed by the disease, but could still spread it to players who come in contact with them. This effectively turned every single NPC into a potential asymptomatic carrier (as the *"Corrupted Blood"* condition had no visible external markers) and formed another transmission vector for the infection [55].

The ensuing pandemic, which was furthered by mistake, misguided altruism and malice, quickly killed lower-level characters and let to drastic changes in gameplay, as players attempted to avoid infection as best they could. Although actions were taken to mitigate the rate of infection, such as quarantines and abandonment of population centers that were both self-imposed and developer-ordered, the contagion persisted until the drastic measure of a combined server reset accompanied by several patches managed to stem the infection and finally end the plague on October 8, 2005. During the height of the epidemic, cities that formed population centers were littered with the remains of players dead and dying from the contagion, in a grim display reminiscent of the black plague (See Fig. 3.2).

Despite seemingly nonexistent stakes, as players could simply respawn or cease playing the game thus depriving the plague of any meaningful risk, player behaviour during the incident was remarkable in its resemblance to real-world human behaviour in such situations. These behaviours ranged from the altruistic - players with healing capabilities volunteering to

[1]Essentially forming a Zoonosis transmission vector according to World Health Organization (WHO) definition [54]

Figure 3.2.: Player remains littering the streets of a city in World of Warcraft (WoW) during the Corrupted Blood Incident. Image is © 2007-2019 ZME Science - Not exactly rocket science [56]

help combat the disease in varying degrees of organization and coordination[2]- through the neutral mass exoduses from population centers into the "countryside" inadvertently carrying the contagion into uninfected areas in the process [57], to the purposely malicious with players deliberately attempting to infect as many other players as they could or breaking quarantines [55].

These human behavioural reactions and the conditions that led to the genesis of this incident piqued the interest of epidemiologists as a possible simulation of actual human reactions to a real-world equivalent scenario. This interest was reignited very recently due to the eerie similarity between the Corrupted Blood Incident and the ongoing COVID-19 epidemic.

3.3.1. Research following the incident

In the wake of the incident research in several key fields relevant to the events that took place - namely epidemiology, behavioural science and terrorism research - was proposed, specifically aiming to examine the simulation data and human reactions as models for an epidemic.

Epidemiology research

According to Israeli epidemiologist physician Dr. Ran D. Balicer several similarities could be drawn between the Corrupted Blood Incident and Severe Acute Respiratory Syndrome (SARS) and avian influenza outbreaks. He also suggested that Role-Playing Games (RPGs)

[2]The less organized of these efforts, much like real life, had the adverse effect and caused the infection of many of the volunteers

such as WoW could server as a modeling platform for examining diseases and infection mechanisms [58].

During the Games For Health (GFH) conference which was held in Baltimore, Maryland, United States of America in 2008, the Corrupted Blood plague was compared to a real-world epidemic - the avian influenza. Both diseases originated in a remote region and were carried over travel routes to more populated areas, both were person-to-person transmittable as well as zoonotic (See Zoonosis), both were transmittable through close contact and finally both presented with asymptomatic carriers (NPCs as described above in the Corrupted Blood plague's case) [55].

An unforeseen aspect of the Corrupted Blood epidemic was curiosity, with players rushing into infected areas to witness the outcomes first hand. This behaviour can be compared to real-world behavior (e.g. journalists covering the effects and status of a disease and then leaving the infected areas) and was not considered previously in epidemiological models [55].

The epidemiological repercussions of the Corrupted Blood epidemic were the subject of an additional research paper [59]. One of the co-authors of said paper, Dr. Nina Fefferman, spoke at the 2008 GFH conference [55] mentioned above and the 2011 Game Developers Conference (GDC) [60] about the incident and the potential that large online communities possess to assist in solving problems inherent to the traditional epidemiological models. Fefferman suggested that designing new diseases to be introduced to the game could allow studying organically occurring phenomena such as rumour dissemination, individual risk management and public health notices management. Most significantly, Fefferman argued that a collaboration between researchers and developers could produce results that are **fun** and do not adversely impact gameplay [55]. Sadly, no further development was made on this issue.

More critically, subsequent to the incident *Blizzard Entertainment* - the company responsible for the development of WoW - was contacted by the Center for Disease Control and Prevention (CDC) with a request to provide information regarding the incident for epidemiological research purposes, but the company refused under the reasoning that the incident was only caused due to a malfunction, and that WoW was only a game and unintended to mirror any real life scenarios [52].

Similarity to COVID-19

Generally compared to the recent COVID-19 pandemic, research conducted on the Corrupted Blood Incident, particularly in the field of behavioural science, is being reused to better understand the spread of COVID-19 [61, 62, 63].

Dr. Eric Lofgren, who co-authored the aforementioned research paper alongside Dr. Nina Fefferman, is quoted in an interview with *"PC Gamer"* stating that "When people react to public health emergencies, how those reactions really shape the course of things. We often view epidemics as these things that sort of happen to people. There's a virus and it's doing things. But really it's a virus that's spreading between people, and how people interact and behave and comply with authority figures, or don't, those are all very important things. And also that these things are very chaotic. You can't really predict 'oh yeah, everyone will quarantine. It'll be fine.' No, they won't." [61].

Of the recorded player behaviour during the incident, a substantial subset of players partook in the practice colloquially referred to as "Griefing". Such players would intentionally spread *"Corrupted Blood"* to others, or break quarantine efforts maintained by other players and developers intentionally as previously mentioned in section 3.3. This counter-intuitive behaviour was criticized as lacking a real-world basis, lending little credibility to research dealing with it. However, human behaviour such as willfully ignoring health regulations (e.g. not wearing a mask on public transportation), or far worse - denying the credibility and efforts of the scientific community (e.g. the "Anti-Vax" movement) is easily equivalent to griefing.

Dr. Lofgren had the following to say to that effect: "one of the critiques we got from a lot of people, both gamers and scientists, was over this idea of griefing, ... How griefing isn't really analogous to anything that takes place in the real world. People aren't intentionally getting people sick. And they might not be intentionally getting people sick, but wilfully ignoring your potential to get people sick is pretty close to that. You start to see people like 'oh this isn't a big deal, I'm not going to change my behavior.' ... Epidemics are a social problem... Minimizing the seriousness of something is sort of real-world griefing." [61].

3.3.2. Reactions to the incident

Prior to any official statement released by *Blizzard Entertainment* regarding the outbreak, speculations were made whether it was an intentional event or the result of a programming bug [64]. Official game forums saw users positively reacting to the incident, regarding it a successful world event. However, not all reactions were positive in nature. Some players abandoned the game entirely pending a solution to the problem [65], and the manner in which the plague was terminated was also viewed with mixed reactions [55].

The reported reactions from *Blizzard Entertainment* employees were also varied in nature, with some claiming the incident inspired ideas for future (planned) events, while others stated that while no serious consequences followed, the plague was analogous to a computer virus, reminding users of the impact of computer code. Overall the event was unexpected for players and developers alike.

3.3.3. Discussion

The Corrupted Blood Incident, the events and the research that followed it - both during the incident and shortly after it terminated, as well as its more recent application to COVID-19 - lend extremely strong credence to the claim that non-serious games should not be disregarded as a valid source for serious information and contexts (as was previously shown in section 1.1). Had the incident and WoW been immediately classified by all participants as a serious context and SG respectively, the ensuing research could have progressed down very different paths - especially in terms of credibility and the level of seriousness at which that research was applied.

Lessons learned during the incident could have vastly altered world-wide response to COVID-19, perhaps even enabling complete prevention of the pandemic. Sadly that contingency is purely theoretical, and accepting definitions such as the one presented by Djaouti et al. [14] would ensure that these possibilities remain theoretical.

This example was brought in order to provide evidence to the following assertion: **All games have scientific value worth examining**. Disregarding information in games, be it present or emergent, simply because they were designed for the purposes of entertainment is tantamount to an Art History researcher dismissing massive bodies of work because "they don't like the style". This example also validates the theory that GMs are absolutely vitally important and worth close examination not only in non-serious games but also in SGs. This holds true since the genesis of the entire incident was firmly rooted in changes made to GMs - a single error in GMs programming turned a non-serious game into a high-quality serious context epidemic simulator that prompted multiple research papers that are relevant to this day.

4. Caesarea Maritima

This chapter will deal with the selection of Caesarea Maritima as a model location, including the reasoning for that choice, historical background information and some examples of cultural heritage finds (including UCH of course) of interest in the area.

4.1. History

Caesarea Maritima was an ancient port city in the Sharon Plain, Israel, on the coast of the Mediterranean. The once vibrant and flourishing city was destroyed several times and eventually abandoned completely. The ruins of Caesarea Maritima, which are located approximately two kilometers south of the modern Israeli city of Caesarea, were excavated in the mid-twentieth century and are part of the Caesarea National Park which is under the supervision of the Israel Nature and Parks Authority (INPA) [66, 67].

4.1.1. Early history

The predecessor city to Caesarea Maritima, "Straton's Tower", was established by Abdashtart I, or Straton I king of Sidon, likely as an agricultural storehouse [68] or as a Phoenician trading colony. Straton's Tower was captured by Jewish ruler Alexander Jannaeus in 90 Before Common Era (BCE) as part of his efforts to expand his kingdom and develop a shipbuilding industry, and remained in Jewish control until 63 BCE when the city was declared autonomous by the Romans who now controlled the area [69].

4.1.2. The golden age of Caesarea Maritima

In 30 BCE, Judea, which included the site of Straton's Tower, was gifted to Herod the Great by Rome. After receiving Judea, Herod began multiple construction projects, two notable examples of which were Caesarea Maritima - which included elaborate and advanced constructions such as a deep-sea harbour (detailed below) and temples to Augustus and Roma - and the reconstruction of the Jewish temple in Jerusalem [70]. Caesarea Maritima was built between 22-10/9 BCE approximately, near the site of Straton's Tower by order of Herod. The city was so named in honour of Caesar Augustus - the Roman emperor [68].

During the Roman conquest of Judea in 6 CE the civilian administration building and military headquarters were moved from Jerusalem to Caesarea, effectively making Caesarea the de facto provincial capital [71] before the region was renamed Syria Palaestina as a consequence of the Bar Kokhba revolt [72]. Roman Jewish historian Flavius Josephus described Caesarea Maritima and its artificial harbour in great detail: "Now upon his observation of a place near the sea, which was very proper for containing a city, and was before called Strato's Tower, he set about getting a plan for a magnificent city there, and erected many edifices with great diligence all over it, and this of white stone. He also adorned it with most sumptuous palaces and large edifices for containing the people; and what was the greatest and most laborious work of all, he adorned it with a haven, that was always free from the waves of the sea. Its largeness was not less than the Pyrmum [at Athens], and had towards the city a double station for the ships. It was of excellent workmanship; and this was the more remarkable for its being built in a place that of itself was not suitable to such noble structures, but was to be brought to perfection by materials from other places, and at very great expenses" [73].

Sebastos harbour

The harbour, so named in honour of emperor Augustus (Sebastos is the Greek name for Augustus) was ceremonially dedicated to the him in 10/9 BCE by Herod [74]. It consisted of two jetties made of a mixture of lime and pozzolana - a type of volcanic ash, over 24,000 cubic meters of which were imported from Italy for the project - that was set into a hydraulic concrete. The jetties were constructed between 22-15 BCE [75]. Despite its complexity, construction of the harbour progressed rapidly and at the height of its lifetime it was considered one of the most impressive and important commercial harbours of the period, even rivaling the harbour at Alexandria. By the time of its completion, Sebastos was the largest artificial harbour constructed in open sea [75, 76].

Due to the difficulties presented by underwater construction, creative technological solutions had to be devised in order to lay the concrete. One such creative technique was a method used in the construction of the northern breakwater. Carpenters constructed boxes with a watertight external wall consisting of two layers, with a small partially sealed gap between them. This cavity made the boxes buoyant enough to be floated into their appropriate place, where the cavity would be filled with pozzolana. This made the boxes sink into position where they were then fastened by divers with stakes. The rest of the box was then filled with the pozzolana-lime mixture until it rose above sea level [77].

However, due to issues present in the hydraulic concrete, a natural disaster and the fact that the harbour was constructed over a geological fault line, the harbour was ultimately rendered completely unusable, with the ruins of the two jetties now lying in a depth of more than five meters below sea level [74, 76, 78].

4.1.3. Later periods

During the Byzantine period, in the year 390, Caesarea became the capital of the new province of Palaestina Prima and remained the provincial capital throughout the 5th and 6th centuries until it fell to Sassanid Persia in the Byzantine–Sasanian War of 602–628, in 614, but later re-captured by Byzantium in the year 625. Byzantine control over the city was finally concluded with the Muslim capture of Caesarea in the year 640. Conflicting archaeological evidence suggest that during this capture the city was either razed, suffered an economic collapse or was merely reduced [79, 80, 81]. This conquest also signaled a shift in the region's definition from the Byzantine Palaestina Prima to the Muslim Jund Filastin (military district of Palestine) and a transfer of the provincial capital to other cities.

Nasir-i-Khusraw described Caesarea in his diary in 1047 as "a fine city, with running waters, and palm-gardens, and orange and citron trees. Its walls are strong, and it has an iron gate. There are fountains that gush out within the city; also a beautiful Friday Mosque, so situated that in its court you may sit and enjoy the view of all that is passing on the sea." [82] connoting the city was again developed, populated and even fortified. The writings of William of Tyre detailing the siege of 1101 support this description, as they describe the use of siege engines: "... And cometh by another cyte named cesaire ... whan our peple were comen to this brygge / thentre was wel denyed them, ffor grete plente of turkes were descended doun to the bariers / The other toures rested not to caste stones and shote so sore that it was a moche grete scarmuche and tiers..." [83].

Caesarea fell under crusader control (and subsequently destroyed a second time) following the first crusade between the years 1101 and 1187 and again between 1191 and 1265 [84]. In 1187 Saladin ended the first period of crusader control by capturing the city, which was again retaken from him in the third crusade (1191). The city was finally lost in 1265, when it fell to the Mamluks. Baibars, the Mamluk Sultan, ordered the complete destruction of the fortified city to prevent the crusaders from ever re-using it as a stronghold. This Mamluk "scorched earth" modus operandi was applied in other coastal cities as well [85]. The ancient city lay in ruins and saw little to no relevance under Mamluk and later Ottoman control.

In 1884 the small fishing village of Qisarya (the Arabic name for Caesarea) was built on the remains of ancient Caesarea by Bosnian immigrants [86], who moved to the area after the Ottoman-controlled Bosnia was conquered by Austria-Hungary in 1878. In February 1948 the village, vacated from its population following Lehi attacks, was conquered by a Palmach unit commanded by Yitzhak Rabin. In 1952, the Jewish town of Caesarea was established near the ruins of the old city, which were later incorporated into a newly-created National Park in 2011. As of the writing of this document the site and national park remain on the UNESCO "Tentative List of World Heritage Places" [87].

4.2. Cultural Heritage assets

Beginning in the 1950s and continuously progressing to this day, archaeological work in the area is conducted primarily by Israel and the United States. Cultural assets uncovered so far hail from the varied periods of the city (see section 4.1), with the majority originating from Roman, Byzantine and crusader periods. Examples of major Classical-era findings are:

- The Roman theatre
- A temple dedicated to the goddess Roma and Emperor Augustus
- A hippodrome
- The Tiberieum, where in 1961 a reused block of limestone (later named the Pilate Stone) bearing an inscribed dedication mentioning the Roman prefect Pontius Pilate [88]
- A double aqueduct that brought water from springs at the foot of Mount Carmel
- A boundary wall and a 60m wide moat protecting the harbour to the south and west, likely constructed on the orders of Louis IX in 1251 as part of fortification efforts of the city

The archaeological findings of L.I. Levine and E. Netzer (who sadly sustained severe injuries due to a fall that occurred while visiting a related site, the Herodium, with a group of archaeologists, resulting in his untimely death on the 28th of October 2010), collected over three seasons of excavations in the site between 1975-1979, were published in 1986 by the Israel Exploration Society [89].

A veritable treasure of roughly 2,000 gold coins was discovered in the area by marine archaeologists and diving club members from the Israel Antiquities Authority in early 2015. The coins, dated to be older than one thousand years, are theorized to be the cargo of a large merchant vessel trading in the area and intended to be the salary of a local military garrison [90]. In January of 2021 the treasure was re-examined and many more coins were recovered. The inscriptions on both sides of the coins are in Arabic, and the coins themselves are made of 95% pure 24 carat gold [91].

Figure 4.1.: The ancient gold coins discovered by divers in Caesarea Maritima in January of 2015. Image is © Israel Antiquities Authority [92]

4.3. Reasoning for selection

As detailed above the rich history of Caesarea Maritima is far-reaching, colourful and extremely varied. The site is an archaeological point of interest both for research and tourism (either on ground or underwater) to this day. Aside from the purely intellectual interest, the plethora of physical objects recovered in the area offers a more vivid example of a time long gone.

The recent findings of vast treasures of gold coins and jewelry spark the imagination and hearken to tales such as those penned by Robert Louis Stevenson or Jules Verne, or games such as *"Uncharted"* or *"Tomb Raider"*. Considering these facts, the selection of the site seemed almost trivial, given the breadth and qualities of the material available for processing into a SG. Of particular inspiration were the ruins of the jetties that now lay underwater, the sunken treasure discovered in 2015 and the vast quantity of imported volcanic ash used to form the hydraulic concrete used in the construction of the jetties.

Finally, the personal experience of the author with diving in general and diving in Caesarea Maritima in particular sealed the site as a trivial choice to be incorporated into this document.

Figure 4.2.: An image of the author during a dive

5. Planned story and gameplay loops

The SG developed for the purposes of this thesis was planned to be modular and usable in multiple contexts with minimal effort required by the consumer to switch between them (see chapter 6). In order to accomplish this the game was intended to enable multiple modi operandi (namely, multiple gameplay loops) via settings. This was intended to enable the game to function as a consumer product, as a museum exhibit and as a dive training supplement. In this chapter, the desired gameplay loops are described in detail, alongside a possible story progression to accompany gameplay in the consumer product context. All details listed here are to be regarded as a theoretical plan of implementation. These descriptions are merely meant to convey the vision of the game and are by no means an accurate description of the current state of the accompanying SG.

5.1. A note on the validity of diving information presented

The author is a PADI-certified Advanced Open Water Diver [93] and should be considered properly trained to discuss matters regarding recreational diving. This includes, but is not limited to, information regarding proper diving procedure, calculations involved in diving, risks inherent to diving as a sport, information regarding the experience of diving etc.

5.2. Planned gameplay loops

The following are potential gameplay loops for the three different application contexts described above. While the consumer product application context is described in far greater detail than the other two contexts, it should also function as the guideline in terms of design. It would be possible to repurpose elements from the consumer product design to function as parts of the other two contexts. Sadly due to multiple constraints (time and development team size chiefly among them) the accompanying SG will only be able to demonstrate a specifically selected representative part of the overall gameplay loop.

5.2.1. Consumer product gameplay loop

As a consumer product the game would be designed to focus heavily on a plausible yet fictional narrative which will be detailed in section 5.3. Gameplay will consist of two loops; a general game loop and a loop for individual dives (henceforth *per dive loop*). The external loop will be broken down into four distinct phases (one of which will be the per dive loop) which will be carried out sequentially. See Fig. 5.1 for an overview of these.

Phase one: Hub

In the first phase of the main gameplay loop the player will use a main hub (a research vessel, see section 5.3) as a base of operations in the game world. In this hub the player may perform various actions to determine the next phase of gameplay, select how to advance in the game's planned progression system (as explained below) or review both past achievements as well as accumulated learning material for purposes of revision and preparation for next dives.

Concrete examples of such actions include, but are not limited to:

- Set course for a different location on earth (essentially selecting the specifics of the next phase of gameplay).
- Upgrade personal diving gear, ship facilities, the ship itself etc.
- Review current and past missions.
- See artifacts and awards collected.
- Converse and build a relationship with the crew.

The first phase of gameplay will end once the player, having selected the specifics of the next phase, interacts with a specific part of the hub such as a dive room, a motorboat or similar objects used to signify the beginning of the diving phase. Between diving phases (second phase) the player may return to the hub in order to reexamine information collected in the dives and to conduct research (third phase). The end result will be a semi-bidirectional interaction between the first, second and third phases of gameplay.

Phase two: Dive

The second phase will begin almost seamlessly from the hub. After selecting the specifics of the dive, the player will plan and executes a day of diving (up to 3 dives per day, subject to upgrade in phase one). Planning will include performing depth and time calculations using real-life decompression tables, realistic safety procedures and stops, selection of gear, partner(s), depth and appropriate air mixtures (see chapter 2). During execution the player will leave the hub and perform a shorter per-dive gameplay loop. It is during phase two that the information and evidence necessary for the research occurring in phase three will be collected. Performing the calculation necessary to carry out dives correctly and the expedient and efficient collection of evidence for the research performed in phase three should be rewarded in an appropriate manner, or "punished" if performed incorrectly in the case of diving calculations - as mistakes involved in those can result in serious injuries and potentially death even in real life.

Per dive loop

During each dive the player would be required to dive down (this should normally happen as fast as possible in order to allow for maximal duration at depth), monitor and maintain buoyancy and air consumption and collect information, photographs and artefacts from specific points of interest on the bottom. During these dives, the player would also need to deal with unexpected events, hazards and opportunities. These could encompass encounters with local wildlife, cave-ins, unexpected discoveries, looters or pirates, and much more. At the end of each dive the safety procedure determined at the beginning of phase two would need to be followed in order to avoid diving related injuries such as decompression sickness. During this phase the player will get to experience a facsimile of UCH field-work by using tools such as underwater cameras, search grids, specialized vacuums used to clear sand and debris that might obstruct searches, mobile scale markers to provide photos of in-situ objects a reference point for size, special inflatable bladders used to surface heavy items from the ocean floor and many more. Please note that due to pragmatic reasons (e.g. time-frame, development team size as discussed previously) **only a part this aspect of the total gameplay loop was selected for implementation** as it represents the most important and interesting gameplay aspects of the game as a whole.

Phase three: Research

In the third phase, the player will return to the hub after one or several dives contributing to a specific research subject. During this time the player may inspect physical evidence and photographs collected during dives, suggest hypotheses, draw conclusions and compile coherent research to be published. The separation between phase one and phase three could be seen as purely semantic, but a key difference which necessitates this distinction is the presence of research material gathered in phase two. The performance of research should occur in a fashion that would require thought and understanding from the player, and prevents the ability to reach a solution via "brute force". There are several possible ways by which to overcome this [94]. Research will also enable another window into the work of UCH experts by presenting examples of work in the field such as identification of objects retrieved in phase two based on sources of knowledge such as books and catalogues, the careful cleaning of objects tarnished by the underwater environment rendering them unidentifiable, providing conjectures to the presence of certain items in certain locations based on historical theory and searching for evidence to corroborate or contradict the conjectures in future dives etc. In the words of Soren Johnson: "Given the opportunity, players will optimize the fun out of a game" [95]. In order to prevent exploitative optimization of gameplay (such as finding as single object and abandoning a dive in order to research it) design should strive to afford as little individual significance to single items, instead requiring multiple items to form meaningful and contextual theories.

Phase four: Reward

In the fourth and final phase the player's work is recognized via diegetic rewards both pragmatic and non-pragmatic. Examples could include academic publications, exhibitions in museums, monetary rewards or career advancement. Some of these rewards, e.g. the academic publications or museum exhibits, should be unexpected to the player [11] in order to create further interest in the subject. Game progression relevant rewards should however adhere to the game's planned progression system. The awards should also reflect player performance and be used to discourage exploitative gameplay further, e.g. by awarding the player better for fewer dives performed to completion rather than multiple shortened dives, or by providing better awards for research taking little in-game time. Although less desirable [95, 96], the reward phase could also be used in a negative connotation - a real-world dive that is executed incorrectly could result in very serious injuries such as decompression sickness, burst tympanic drums, burst lungs and even death. These perils are present from incorrect diving **alone**, not taking into account external dangers from the surroundings, flora or fauna. Players that dismiss or disregard these dangers could find their in-game avatar in the hospital, or worse.

Additional details

Due to narrative details gameplay will begin with a diegetic introductory stage prior to entering the main loop. This stage is intended to function as a hidden tutorial that will present the controls and key game mechanics to the player for both the general and "per dive" gameplay loops. Design goals for this tutorial would attempt to recreate a "developer hands off" learning experience in the spirit of "Half Life 2" [10, 97].

The progression system should see the player advance from receiving a single research mission and being able to perform only a few relatively shallow depth dives to being able to select from multiple research missions, with the ability to perform many dives of varying depths. This will enable further options in all phases of the gameplay loop and provide the player with a sense of accomplishment.

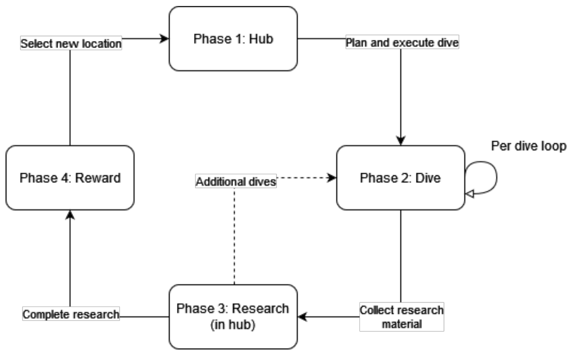

Figure 5.1.: Overview of planned consumer product gameplay loop

5.2.2. Museum exhibit gameplay loop

Depending heavily on the desired contents of the exhibit, several aspects of the consumer product gameplay loop can be redesigned to accommodate several areas of interest regarding UCH, the work of maritime researchers or a combination of the two. For example, a museum exhibit intended to showcase an underwater location could adapt a single dive (phase two in subsection 5.2.1) with little to no challenge in order to demonstrate the environment in a believable setting. In comparison, a museum exhibit designed to showcase the work of maritime researchers could adapt a single, linear progression through phases 1-4 with simplified gameplay.

Lacking a clearer design philosophy, a cost-effective option would be to design the areas of UCH interest shown in the game with a "built-in" virtual tour functionality, leaving the player free to explore a 3D model of a real-world culturally significant diving site with voice-over narration of points of interest. This would of course decrease interactivity significantly, however unfortunately this is likely an unavoidable trade between modularity of design versus the specificity of the desired museum exhibit.

5.2.3. Dive training gameplay loop

Repurposing the aforementioned gameplay into a dive training revision tool could prove relatively simple. All that would be required is a version of the diving phase (phase two, see subsection 5.2.1) that would enable accurate and realistic planning and execution of one or several dives. For additional entertainment or variety, encounters with wildlife and points of cultural significance could be left unchanged. Designing the game with accurate simulation of diving physics and behaviour would in-effect create such a tool implicitly.

Gameplay would then consist of a short pre-dive planning and calculation session for depth/time and additional dives, the dive itself including buoyancy and air control, safety procedures etc. and a post-dive review of performance. This should promote revision of different calculations relating to diving such as bottom time and Nitrogen debt.

5.3. Planned story

Provided here is a potential narrative progression for the game. At the beginning of the game the player steps into the shoes of a young marine researcher fresh out of college or university, being offered a coveted internship position aboard a prestigious globe-trotting marine research vessel. Upon accepting the position the player joins the vessel, gets acquainted with its crew and layout, and sets course for a short tryout/introduction dive in safe waters. After the tryout the vessel embarks for the middle east, to the coast of northern Israel, in order for the newest addition to the crew to learn proper marine archaeology procedure while examining some possible new discoveries in the region of Caesarea Maritima. After successfully conducting research on a newly discovered sunken ship, the player is officially inducted into the crew and offered their pick of personal diving equipment.

Following the player's induction into the crew, the vessel plans a voyage to several points of archaeological interest around the planet, where the dives become increasingly more complex and difficult. Progression in this part of the game would be in the player's diving skills and gear, allowing for the increases in depths and difficulty of multiple consecutive dives. For accumulating successes the player begins to receive sporadic academic recognition as well as additional responsibilities and ties to the crew. Upon completion of a gruelling five day investigation of a Spanish treasure galleon, during which some parts of the ship are surfaced by the player, they are rewarded with taking part in publishing their very first museum exhibit.

At this point the player is awarded even more responsibilities, such as the offer to select the next research projects and locales out of a small pool of options. This advancement will culminate in the player being offered a senior researcher position as commander of a new research vessel, which will allow the player to select any mission, equipment and crew they desire, as well as upgrade and customize the vessel itself. By this point the player will become a well published and respected academic with multiple museum exhibits and research credits.

6. Design goals and implementation

This chapter will provide a detailed overview of the design process of the accompanying UCH VR SG. The overview will begin with a recount of the core design principles guiding it, continuing through the technical specifics of the practical implementation of those principles, a short analysis of the game in terms of following the design principles and the general design plan detailed in chapter 5 and will conclude by presenting the CSG taxonomy [12] and analyzing the appropriate taxonomic assignment of the game based on it.

Please note that the technical aspects of the design presented in this chapter will involve implementation elements (e.g. models, scenes, GMs) dealing **exclusively** with the serious/educational UCH context of the game. For a deep technical breakdown of the diving mechanics and VR system please refer to Leonard Keil's thesis [27]. Additionally, as noted in chapter 5 section 5.2.1, the accompanying game and this chapter will only include a description of the implementation of the "per-dive" gameplay loop, as it is the best representative of the most interesting qualities of the planned game as a whole. This course of action was taken to ensure the best possible outcome, as it would have been impractical to attempt implementation of any other subset of the proposed design within the time-frame of the thesis.

6.1. Core principles

This section will cover the core principles by which all design of the accompanying game, past and future, should be conducted. These principles are set in place to ascertain that the planned nature of the game - an application usable in multiple contexts with minimal effort on the client side - is maintained. The three core pillars that should guide all design work made on the accompanying game are ***Modularity***, ***Extensibility*** and ***Authenticity***. A clarification and explanation of each will be provided in the following subsections.

6.1.1. *Modularity*

Generally referring to the ease with which different components of a system are grouped or separated, modularity *in design* is the general practice of combining closely related system components and reducing overall system complexity by creating abstractions for those combinations of components. A car, for example, could be considered an abstraction of the (incomplete) grouping *{motor, drive shaft, wheels, steering wheel}* - with the grouping itself containing the abstraction (*motor*).

A fundamental concept in Object-Oriented Programming (OOP), systems and programs designed with modularity as a guiding principle often enjoy benefits such as higher security and reduced system complexity due to obfuscation of inner workings via the abstraction, the latter of which proving useful when considering the task of extending the program (see below).

In view of the planned application contexts of the accompanying game described in chapter 5, modularity proves a crucial design principal. A system designed in a modular manner can enable minimal developmental investment - simply adding or removing different modular components to accommodate the different use contexts - to result in maximum output quality for the different clients, while also requiring minimal technical competence from them thanks to the abstraction afforded.

6.1.2. *Extensibility*

Extensibility is a measure of the ability and difficulty involved in extending a system from its current state. An extensible system is one that can readily, easily and with minimal effort on the extender's side be expanded upon with new content and components. Extensibility can be viewed as a close corollary of modularity (see above), as by definition a modular system can receive or remove new modules quickly and simply.

Albeit a sort of preexisting byproduct of modularity, extensibility is an important core concept worthy of special attention, not only in the design of this game but also in software engineering in general. The ability to extend and expand upon existing software provides it with a degree of future-proofing and elongates its life-cycle by allowing the developer to add content and make changes to the software as needed during the development and "shelf-life".

With one of the desired application contexts of the accompanying SG directing it as a consumer product, player retention through additional content in the form of Downloadable Content (DLC) becomes an important consideration. Extensibility would additionally be beneficial in the dive training and museum exhibit contexts, as it would require overall lower investment on the client's side. Any desired content the client (either dive instruction institute or museum) would wish to add to the game could easily be developed and added in an iterative fashion, tailoring the game to the specific institute by addition and/or subtraction of content. For example a museum could design a new exhibit and a diving course could request a model for higher diver certification requiring specialty equipment, both of which could easily be implemented and added to a system designed with extensibility as a core concept.

6.1.3. *Authenticity*

Specifically referring to nominal authenticity which is defined as "...the correct identification of the origins, authorship, or provenance of an object, ensuring ... that an object of aesthetic experience is properly named" [98]. Not to be mistaken with absolute realism, which, while acting as an important guideline in several areas of the design process, is a limiting and creatively stifling constraint that often results in lessened enjoyment unless handled in a very particular and consistent manner.

Thus, in order to maintain a **balance** (see chapter 1) between an enjoyable game and an accurate and informative SG, absolute realism - insofar as it pertains to the portrayal of UCH assets - was neglected in favour of authenticity. An authentically presented, detail-accurate but not absolutely realistic representation of information relevant to the subject of the SG could deliver said information to the player while maintaining the capacity to create an enjoyable experience. Moreover, the lowered requirement for absolute, unerring accuracy also simplifies and quickens the design process, which could result in more content of higher overall quality per development cycle.

A concrete example of authenticity rather than realism can be seen in the modelling of a ship carrying Pozzolana volcanic ash (see below). It is a known fact (see chapter 4) that Pozzolana was used to create the hydraulic concrete which was used to construct the artifical harbour at Caesarea Maritima, yet no shipwreck carrying Pozzolana was found in real life. By forsaking true-to-life realism while maintaining a high degree of **authenticity**, correct information can be transmitted to the player in an engaging and experiential manner rather than simply as a dry explanation. Another example of authenticity rather than realism can be seen in the selection of the 3D model of the coins present in the game. As was described in chapter 4, the coins recovered in 2015 were tentatively dated to the year 1191 and displayed writing in Arabic on both sides. As no model fitting that description was freely available during development, a model of a Roman coin portraying the emperor Augustus (which was indeed the Roman emperor during the golden age of Caesarea Maritima) was selected as a reasonably authentic replacement.

6.2. Practical implementation

This section will present the GMs present in the current version of the accompanying game and include a technical report of the implementation (code, modelling, etc.) of several elements - specifically those responsible for UCH-related GMs. Closing the section will be a short overview of the element-GM correlation in tabular form. As this thesis deals primarily with the role of GMs in SGs, the technical implementation of many elements is not covered in this document. The most notable examples of that are the VR system and specific implementation of diving mechanics. A detailed coverage of the aforementioned can be found in Leonard Keil's thesis [27]. The implemented gameplay loop followed the flow-path shown in Fig. 6.1 below. The different components shown are further explained in the following sections.

6.2.1. Game Mechanics

In order to produce a reasonable Minimum Viable Product (MVP) that is representative of the spirit of the planned design within the allotted time, a heavily reduced implementation of gameplay had to occur. This resulted in overall few GMs modelled, but those that were are absolutely vital (the "must have" mechanics, if considering the MoSCoW method described in the Dynamic System Development Method (DSDM) handbook [99]). With that in mind, detailed below are the GMs present in the current version of the accompanying game. For images depicting the different GMs during gameplay please refer to figures 6.2- 6.4.

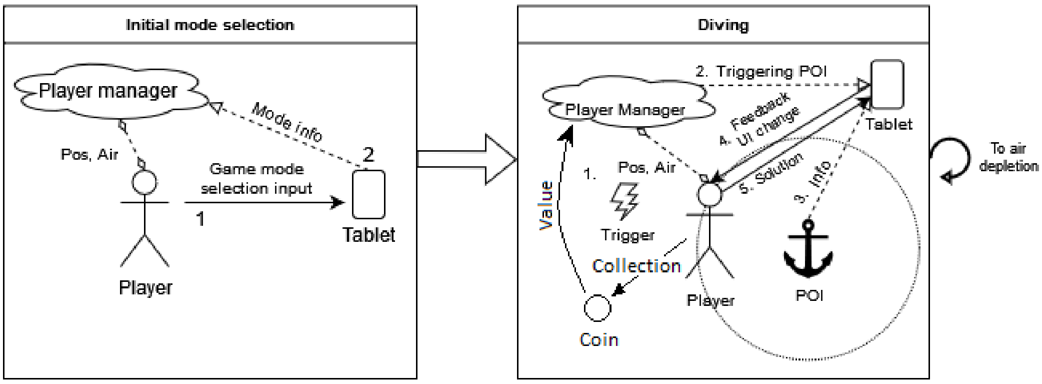

Figure 6.1.: A graphic demonstration of the flow of gameplay

Diving and air consumption - Primary Game Mechanic

An integral part of all UCH work and thus entirely indispensable as a GM is the experience of diving. An enjoyable and believable diving experience was the first GM to be considered "must have" as a result. However, the recreation of this experience touches upon several aspects of the game. The physics of underwater motion and buoyancy are a part of the VR control scheme the game implements, while the subject of air consumption is closer to a timer counting down in its definition. The former falls well within the limits of dive simulation in VR, as it is mostly control-based. Due to that, it was developed primarily by Leonard Keil, and is explained in detail as part of his thesis [27].

Equally relevant while considering the experience of diving, and closer to a pure GM rather than a control scheme, is the consumption of air while underwater. The depletion of air in a diver's tanks is a very strong impetus for the diver to terminate his current actions and surface as fast as possible. This impetus was translated into the game via air consumption calculations and termination of the current dive upon air depletion. Several degrees of complexity in this GM were implemented on the `PlayerManager` script, specifically in the complexity of the calculations being performed to determine the rate at which air is consumed.

The highest complexity level takes into account the diver's depth and the pressure that is exerted on them as a result, as well as "preliminary" data meant to represent the diver's calculated air consumption of a previous dive. The air consumption is then dynamically calculated based on all of the data mentioned above. This represents an authentic recreation of real-world air consumption. The least complex implementation on the other hand performs absolutely no air calculations and is intended to provide the user with a stress-free, tour-like visit to an underwater environment akin to a museum visit. The middle-ground is a simplified air calculation based on fixed values.

Research - Primary Game Mechanic

Another critical facet of UCH work, the research and examination of UCH assets and archaeological finds stands at the core of the desired experience for the accompanying game and therefore is another example of a "must have" GM. As was mentioned above the magnitude to which the work done by UCH researchers can be explored is astounding. In order to provide a sensible simplification for purposes of producing a MVP the process was stripped down to the scientific method behind it.

This begins with the player swimming closer to physical evidence of historical significance present in the scene (see POI below) and moving close enough so that the POI is visible. This is verified via a trigger-zone around the object that is set in accordance with the draw-distance setting of the water. Upon entering the trigger-zone the player is prompted by their tablet that new information is available.

Inspecting the tablet will reveal to the player an image of the POI alongside a short explanation of what is visible and two drop-down menus labeled as "theory" and "reasoning". The player may select a theory they deem acceptable based on the physical evidence present in the scene as to the nature of the POI presented and a corresponding reasoning for their theoretical assumption.

When the player is satisfied with their selection they may hit a button to submit their solution for evaluation. If they picked the correct theory and reasoning the player is presented with a more detailed explanation of the POI and awarded points. It is planned that due to combinatorial explosion discovering the solution via "brute force" will not be feasible. The score value of the research attempt will be decremented with each incorrect guess to further discourage this.

At the core of this GM is a basic simplification of the scientific method - the player observes their surroundings, postulates based on findings, examines evidence to confirm or deny the theory and reexamines the hypotheses if need be. The GM should provide a certain level of challenge, as the correct solution is based on the meta-data of the construction of the POI only. To this effect the small degree of prompting - the presence of the answer as an option in a drop-down menu providing the player with the correct answer before they can analyze the problem - present in the implementation of drop-down menus could be beneficial, acting as an organic hint that would still require active thinking from the player.

As this GM is so crucial to the entire experience of the game, it is the key GM implemented, with primary processing occurring on `TabletManager` with auxiliary support provided by `PlayerManager` and `PointOfInterest` as will be presented in the following. The other design elements presented further in this chapter are also pertinent to this GM in particular.

Item collection - Secondary Game Mechanic

Herein referred to as "coin collection", this secondary GM was implemented initially as a temporary test-case for interactions with the VR control system, but eventually gained permanence for several reasons. Chief among those reasons is the treasure of gold coins recovered in Caesarea Maritima as mentioned in chapter 4, a satisfactory representation of which was practically already implemented into the game with the coin collection GM.

Secondly and more importantly, while contemplating a believable manner by which to guide the player from POI to POI an emergent solution presented itself - making use of the coins as a "breadcrumb trail" would enable guiding the player to the different locations by means of motivational reward in a way that is not too unrealistic.

Later developmental iterations on the accompanying game saw the concept of refuse collection as well as coin collection as a means of incorporating the important subject of environmental preservation to the game. This would function in a similar manner to coin collection and would require even less attention to the model details to provide serious context.

The model selected for the coins to be collected proved to be a difficult hurdle to overcome. For purposes of authenticity, one of the core pillars of design for the accompanying game, it proved vital that a texture or a model with an appropriate serious context (i.e. relevant to Caesarea Maritima) be found and used. The coins were initially represented via a Unity primitive cylinder for testing and rapid development, thus at the very least an appropriate texture had to be applied.

A detailed texture of an era-appropriate Roman coin depicting emperor Augustus was found after intense scouring for a replacement model that would be relevant to the treasure found in 2015 (see chapter 4) did not yield adequate results. As was mentioned above, the Roman coin model was eventually accepted as the working model for presentation in order to maintain an acceptable level of authenticity while unfortunately foregoing pure realism.

Game Mechanic	Primary system	Serious context	Auxiliary systems
Diving and air consumption	VR controls [27]	Air calculation Diving experience	`PlayerManager`
Research	`TabletManager`	Scene Coins POIs	`PlayerManager` `PointOfInterest`
Item collection	`PlayerManager`	Coins	-

Table 6.1.: An overview of game mechanics, the primary system related to them, linked design elements providing serious context and auxiliary systems supporting them

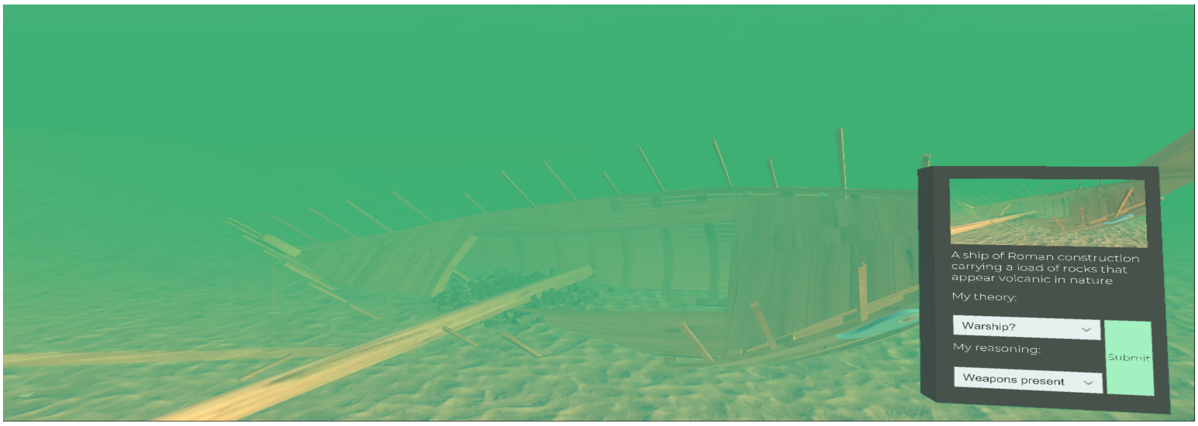

Figure 6.2.: Research during gameplay

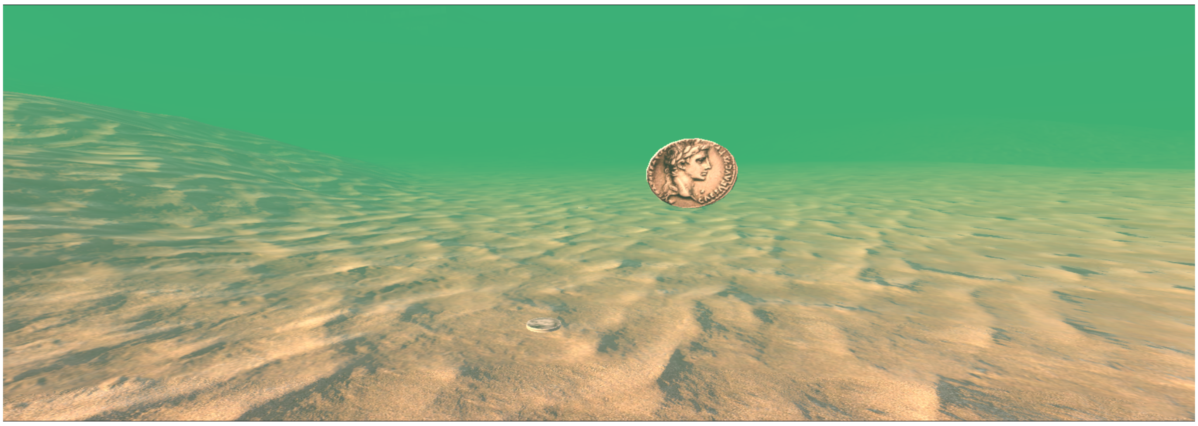

Figure 6.3.: Coin collection during gameplay

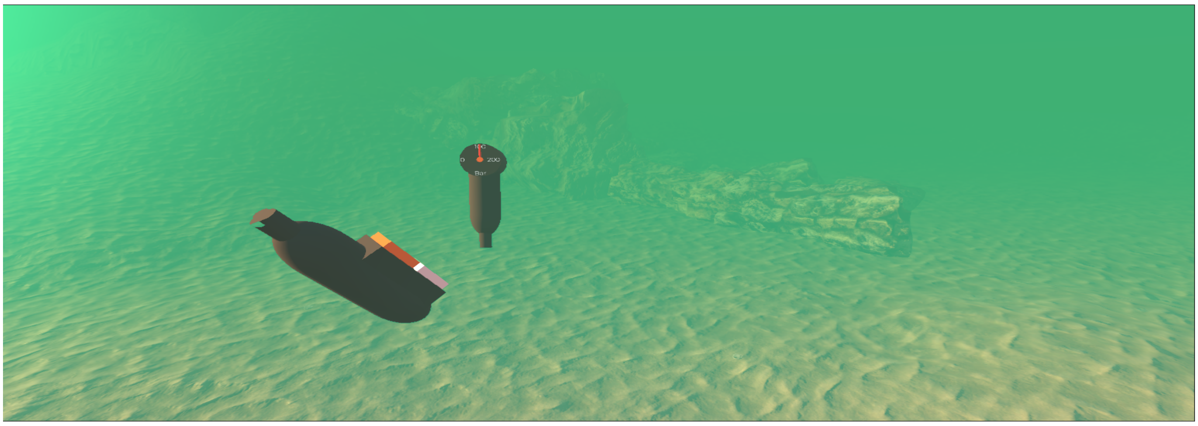

Figure 6.4.: Air consumption and diving during gameplay

6.2.2. Game logic

A total of three primary systems were designed to control gameplay in the accompanying game. Those systems are `PlayerManager`, `TabletManager` and `PointOfInterest`. Below is a detailed clarification of each of these systems as they were implemented - particularly while taking into account the manner in which they uphold the core design principles. For a general graphic overview of the primary system-system and player-system interactivity excluding coin collection, a diagram in the style of Unified Modelling Language (UML) (note - not actual UML) is provided (see Fig. 6.6).

PlayerManager

The `PlayerManager` script began as an ersatz game manager type script, meant to handle primarily player score and complex interactions between the player and external objects such as item collection. This approach, born out of necessity due to some technical difficulties cause by the VR platform, was serendipitous in that it allowed for a relatively simple in-place interaction control that could be attached to the player object (specifically in the "player controller" object in the hierarchy). That in turn allowed for interaction management based on the player's transform which was now readily accessible to the script.

Iterative development of the game saw an expansion of this script in order to handle item collection, air management - both static and dynamic, game mode adaptations and finally location-trigger based detection of Points Of Interest (POIs) (see below) in the player's vicinity. This script also handles certain aspects of player feedback, primarily in form of audio or voice-over. To this effect a certain degree of data exchange between `PlayerManager` and `TabletManager` was implemented (see Fig. 6.6). As POI detection is handled by `PlayerManager` based on the player's location within the POI trigger-zone, a reference of the relevant POI is passed to `TabletManager` to be processed further. The player's score is also passed to the tablet to be displayed.

The most interesting duty performed by `PlayerManager` is the dynamic calculation of the diver's (i.e. player) air consumption based on real-life equations taking into account physical conditions such as pressure as well as the diver's recorded statistics. This calculation also takes into account dynamic changes in said pressure based on the player's depth retrieved from the HMD's relative position. Provided are the equations used to perform dynamic air calculation:

$$sac = \frac{\frac{(TP_{Start} - TP_{End}) \cdot 10}{d_{median} \cdot 10}}{t_{tot}}$$

$$P = \frac{d_{cur}}{10} + 1$$

$$acrd = sac \cdot P$$

$$A = (-acrd) \cdot t$$

This calculation is only performed in the "full" game mode, with the decrease in the player's air being performed via a simplified static calculation in the aptly named "simplified" mode, or nor at all in the "tour" mode. Mode selection is done via player input on the tablet and is transmitted from the tablet to `PlayerManager`. The initial values for the player's "recorded statistics" are actual recorded values from a dive performed by the author. These physical calculations represent a degree of realism modelled in the game that can be expanded upon in the future.

In general terms, the concept of air consumption (especially dynamic air consumption) was modelled for two main reasons. Aside from the realism represented by this facsimile, it creates a time pressure for the player, increasing challenge and constituting a promising avenue for potential development and expansion. Air consumption while diving is also an inseparable part of the real-world experience and thus indispensable as a game mechanic.

`PlayerManager` in its current form is highly compliant with the core design principles - it is simple and "lightweight", and its placement on the player object affords it a great degree of modularity, as the player object will trivially be present in all future game builds. The relative simplicity also enables effortless expansion lending the system extensibility. For example, if any desired alterations to air calculations should be made (e.g. adding different air mixtures used for deeper and longer dives) those can be made entirely in-place on `PlayerManager` with attributes that are already included in the class. Finally, as the equations and data used in air calculations are the actual equations used in diving calculations and data recorded directly from a real dive respectively, the system is implemented as authentically as possible, while still maintaining the flexibility to allow for player-driven changes to gameplay via mode selection.

TabletManager

The formation of the `TabletManager` system was crystallized due to a pragmatic problem which led to a practical application conundrum: how to believably present information to- and allow input from the player in a diegetic manner. The inspiration for the solution was drawn from the real-world solution to this problem: the use of an erasable board and marker (see Fig. 6.5). This design concept, alongside the development of waterproof and pressure-proof electronic devices, led to the current design of an "underwater companion smart tablet" - the game object to which `TabletManager` is attached - which is capable of presenting relevant information to the player as it becomes available and record player input when necessary.

While conceptualized and programmed at a later stage in the development cycle relative to `PlayerManager`, `TabletManager` was designed closely alongside `PointOfInterest` with a primary goal of a reasonably high degree of interoperability between the three systems that was possible to achieve within the allotted time. To this extent, UI management and heavy game logic - both were originally intended to be implemented on `PlayerManager` - were instead shifted to the `TabletManager` system. This was done to offload some execution stress from `PlayerManager` and improve overall performance. Additionally, this improves modularity and extensibility, as the core GM regarding UCH - the finding and processing of cultural assets - is now represented in the game via an abstracted system that is exceedingly extensible (see `PointOfInterest` below).

The primary GM designed for this game - the "research" of UCH sites found in the game world - is primarily executed on, and with the help of `TabletManager`. This is accomplished via an interactive VR UI display attached to the tablet which changes dynamically during play based on context and player input. The most pronounced examples of these changes as currently implemented are at the beginning of play, where the tablet allows the player to pick its "mode of operation" (a diegetic abstraction for selection of game mode), and again when the player enters the trigger-zone of a POI (detailed below) - where the tablet changes to display certain information and an image of the POI, as well as allow player input in order to determine their theory and reasoning for the presented POI. As this is done almost exclusively via the use of dynamic UI changes, the bulk of attributes and methods in `TabletManager` involved UI management, with a degree of game logic performed based on the information provided from `PointOfInterest`.

While not entirely realistic and far from the simplicity of the real-world solution, the "underwater tablet" is a reasonable simplification that greatly assists in implementation of gameplay. It provides a convenient way to transmit and receive information to- and from the player in an intuitive manner that is not too detached from reality - considering the ever-progressing complexity of underwater-capable devices.

As detailed above, the core design principles were closely-held during the entire lifetime of `TabletManager` from ideation to execution. It represents an abstraction of the core game logic processes and is interoperable with `PlayerManager` and `PointOfInterest`, while requiring practically no context from the latter. This translates to a high degree of modularity, albeit with a slight dependence on `PlayerManager`, but considering the absolute necessity of `PlayerManager`'s existence it is a negligible concession at best. It is possible to easily extend `TabletManager`'s functionality relatively simply via UI design of additional assets and minimal code refactoring. The independence of `PointOfInterest` also contributes to the level of extensibility of `TabletManager`, as it produces additional content to be presented entirely autonomously of the implementation of the latter. The inaccuracy of the "underwater tablet" concept was discussed above. It represents, however, a simplification deemed necessary for purposes of enjoyment and an acknowledgement of the nigh-impossibility of faithfully recreating the complete breadth of underwater archaeological work in any reasonable time-scale.

PointOfInterest

The `PointOfInterest` script is the smallest and simplest of the three systems designed for gameplay. It consists exclusively of attributes and has no internal functionality. In essence it is merely an encapsulation of a data-set that would otherwise have to be manually integrated into each and every POI object added to the game. By allowing the attributes to be edited easily inside Unity through means of not initializing a predefined value on the attributes, the task of adding new POIs to the game is significantly shortened and simplified. This contributes majorly to extensibility and modularity.

The need to transmit a large set of different data types - such as images, text descriptions, drop-down menu items etc. - caused the development of `PointOfInterest` to occur simul-

Figure 6.5.: Drawing to scale, underwater; Image by Viv Hamilton [100]

taneously and in tandem with `TabletManager`. As the design of the latter improved and was further iterated upon, so was the former expanded and refined. The resulting script is tailored to the requirements of `TabletManager` in its attributes and can be added to any scene in three simple steps:

1. Create desired POI object (Blender, Maya, Unity...)
2. After placing the desired object in the scene, add to it an additional sphere collider marked as trigger and tagged as "POI" - this will act as the trigger-zone
3. Attach the `PointOfInterest` script to the trigger-zone and edit the attributes with the proper information in the Unity editor

The various attributes are also corresponding to the different game modes offered by `TabletManager` and `PlayerManager`. The "tour" game mode, for example, makes no use of drop-down menus, instead simply supplying the player with a more detailed text explanation of the POI.

As previously mentioned, a core GM of the accompanying game is the "research" to be conducted. The `PointOfInterest` script, despite its simplicity, is the lynchpin of that mechanic, as it contains all the UCH-relevant information to be presented to the player. The uncomplicated design of the script would also benefit any future design work done on the game thanks to its inherent clarity. Moreover, extrapolating this simplicity further to additional assets and perhaps the implementation of the game as a whole, whilst providing proper documentation and basic training could allow for "modding" - user-based creation of additional content for the game - which in turn would enable clients (be they individuals or organizations such as museums or diving courses) to rapidly create and disseminate tailor-made content. Such a possibility would greatly decrease production costs for content, particularly costs related to the employment of specialized experts to verify the validity of the serious information required for new UCH content, as the different institutions could produce their own desired content internally (provided the aforementioned documentation exists and training takes place).

In keeping with the core design principles, the `PointOfInterest` script is designed specifically to be as close to "plug-and-play" as was possible. Its simplicity and vagueness grant it immense modularity as was explained above. This nature is also inherently extensible since addition of new POIs can happen in-place and very quickly. Authenticity does not apply directly to the script, but rather to the information that is input into the different attributes. The obligation to verify the authenticity and accuracy of the information lies then with the person adding the POI object.

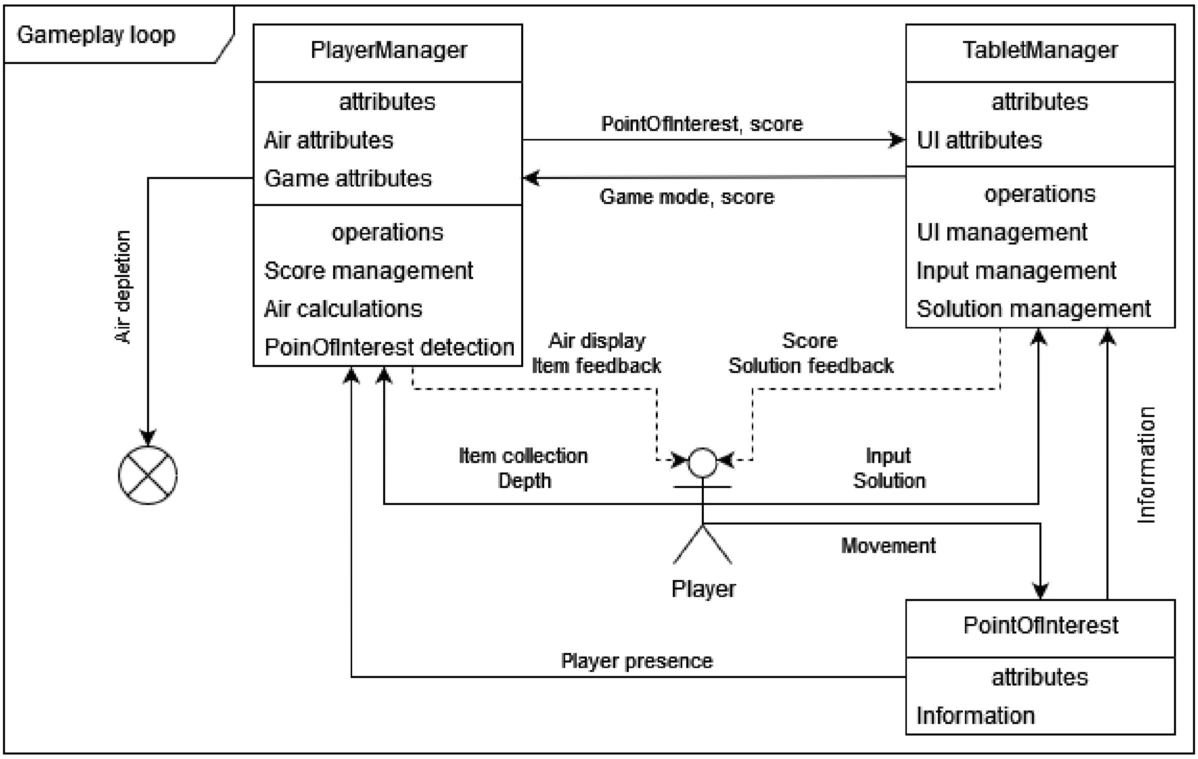

Figure 6.6.: A UML-style diagram of the player-systems interactions

6.2.3. Design elements

Brought here are the crucial elements of design present in the accompanying game that are not purely scripts. This includes the implementation of the coins for the coin collection GM, the 3D scene of Caesarea Maritima and the physical models for the different POIs.

Coins

As was explained above, coin collection was initially intended as a placeholder GM for testing VR interaction and the implementation of `PlayerManager` and the general player controller assembly (as detailed in Leonard Keil's work [27]). However, during development the decision was made to keep the coin collection interaction in order to create a viable way of directing the player towards POIs in a believable manner without resorting to the use of immersion-breaking methods such as UI directions or hints.

The execution of coin collection is performed entirely on `PlayerManager` in a single method. The structure of the player controller object determines a specific "pocket" (a designated VR snap-zone that allows objects to be attached to the player) which is reserved for coin collection. Upon dropping items into said "pocket" during play, `PlayerManager` verifies if the dropped object is tagged as a coin. If that is true, the object is then destroyed to simulate it being entered into a pouch on the diver's person and a sound is played for player feedback. The player's score is then incremented to promote collection of additional coins.

In terms of the core design principles the coin collection GM is substantially compliant with modularity and extensibility, but requires further refinement and attention to details to be fully authentic. This, however, does not exclude all authenticity from the function of coin collection - as can be seen in chapter 4, gold coins were indeed found and collected in real life. The coin collection mechanic can be fully extended to allow for further collection and storing of other items, e.g. collection of refuse that may be found underwater as suggested in Leonard Keil's thesis [27]. The secondary nature of the GM also grants the system that governs it both extensibility and modularity, as it can either be expanded as desired or removed completely without significant impact to the core gameplay loop.

Scene

A 3D model scene intended to recreate the coastline of the Caesarea Maritima area was created in the "Gaia" *Unity* plug-in. This model was based on aerial photographs and maps of the area (as can be seen in the images to follow). This was done in order to heighten the sense of immersion and presence in the player, as well as provide additional authenticity regarding the UCH subject of the game as per the core design principles. For a more detailed review of the technical specifics of terrain generation and water simulation please refer to Leonard Keil's thesis [27]. The technical specifics of the use of "Gaia" fall outside the scope of this document and thus will **not** be further elaborated here. Images depicting the finished scene, as well as the references used are provided herein.

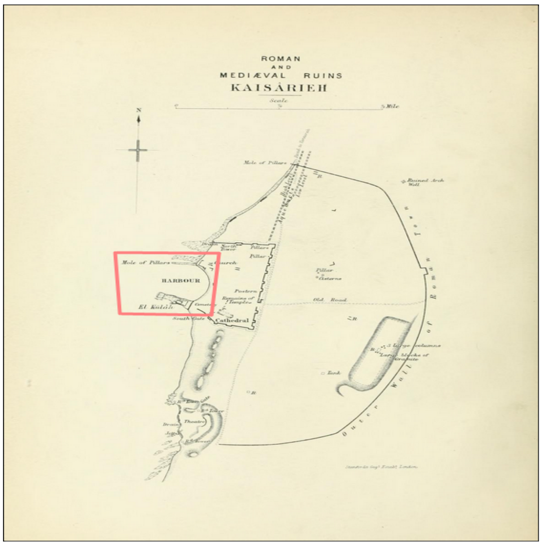

Figure 6.7.: A map of the Caesarea Maritima area [101] used as reference

Figure 6.8.: An equivalent aerial photo of Caesarea Maritima [102]

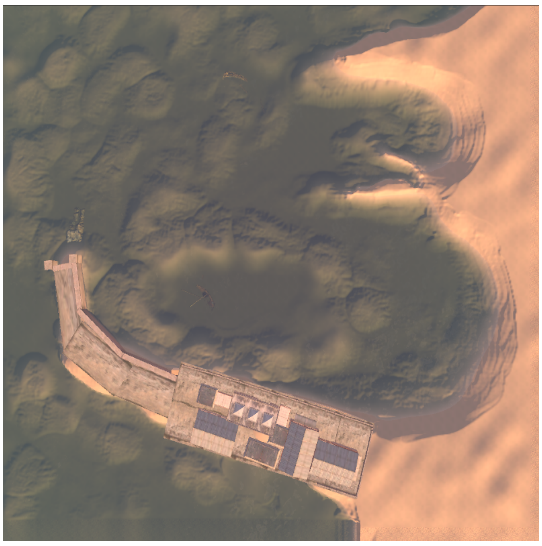

Figure 6.9.: The scene of Caesarea Maritima modelled for the game

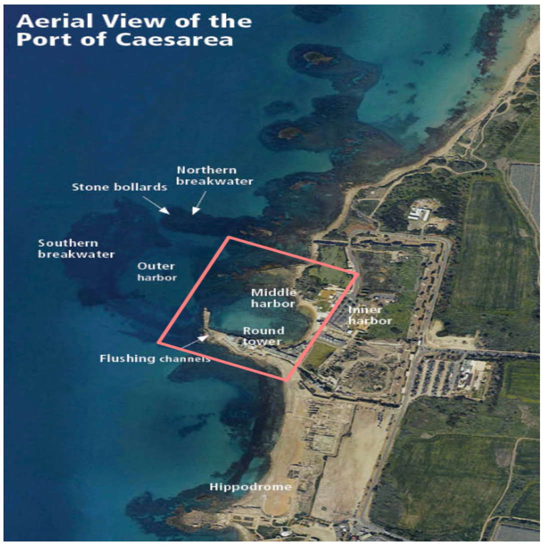

Figure 6.10.: The reference aerial photo of the harbour [103]

Points of interest

In order to test the functionality of the different systems described above and for self-evident gameplay purposes, three distinct POIs objects were considered and implemented. These represent three historical details of import from the annals of Caesarea Maritima as described in chapter 4. A detailing of each of the objects and the reasoning for their selection is presented below. A gradient (hence "realism gradient", see table 6.2) of accuracy in historical detail was implemented in the three assets. Of the three POIs one represent real-world objects that can be found in Caesarea Maritima and the second represents a slight alteration based on scientific theory. The third, however, is a completely fabricated object that is created based on verified factual information and dominant theory but has no real-world equivalent. This gradient was created in order to examine if a certain degree of "artistic freedom" can be taken in the development of SGs while still maintaining factual relevance and accuracy, thus granting some creative leeway in future SG design work.

Ruins of one of the jetties A representation of the physical debris of one of the two jetties that formed the artificial Sebastos harbour at Caesarea Maritima was recreated as faithfully as possible based on reference images and diagrams. This POI was constructed with little to no artistic liberty. These jetties were selected for implementation as they were part of a then-highly-advanced artificial harbour and therefore represent an important and intellectually engaging example of state-of-the-art technology at the time due to their composition of a hydraulic concrete made in part from imported volcanic ash and the manner in which they were constructed. This POI is the "most realistic" extreme of the aforementioned "realism gradient".

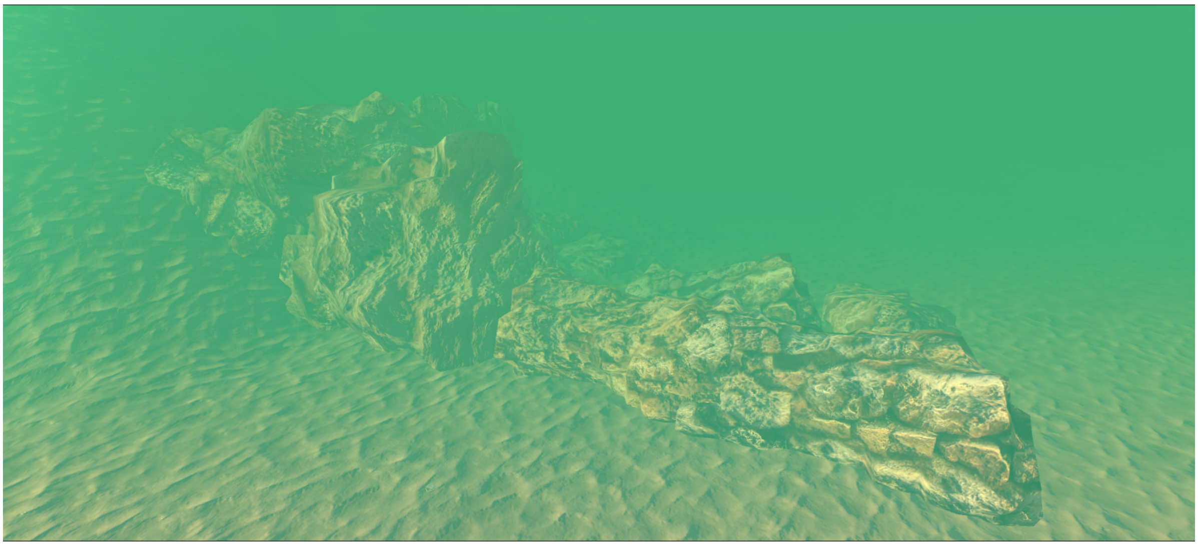

Figure 6.11.: The ruins of one of the jetties recreated in the game

Merchant ship As was covered in chapter 4, in 2015 a sunken treasure of about 2,000 gold coins was recovered in Caesarea Maritima. This treasure was theorized to be carried by a merchant ship that was trading in the Mediterranean at the time and was intended as the salary of a military garrison stationed at Caesarea Maritima. This historical detail was elected for recreation due to purely emotional factors, as it sparks the imagination in ways akin to some exemplars of high-adventure games in the vein of *"Tomb Raider"* and *"Uncharted"*. In order to represent this archaeological find, a large ship model with a considerable amount of coins (see above) was selected as a representative. While the actual merchant ship was never found and the coins (albeit era-appropriate) are incongruent with the actual historical find, simply delivering information regarding the coins upon collection to the player left something to be desired while play-testing internally. To combat this, the model of the merchant ship - admittedly fictional, but based on solid theoretical assumptions - was added for additional visual flare. This POI is the "middle-ground" of the "realism gradient".

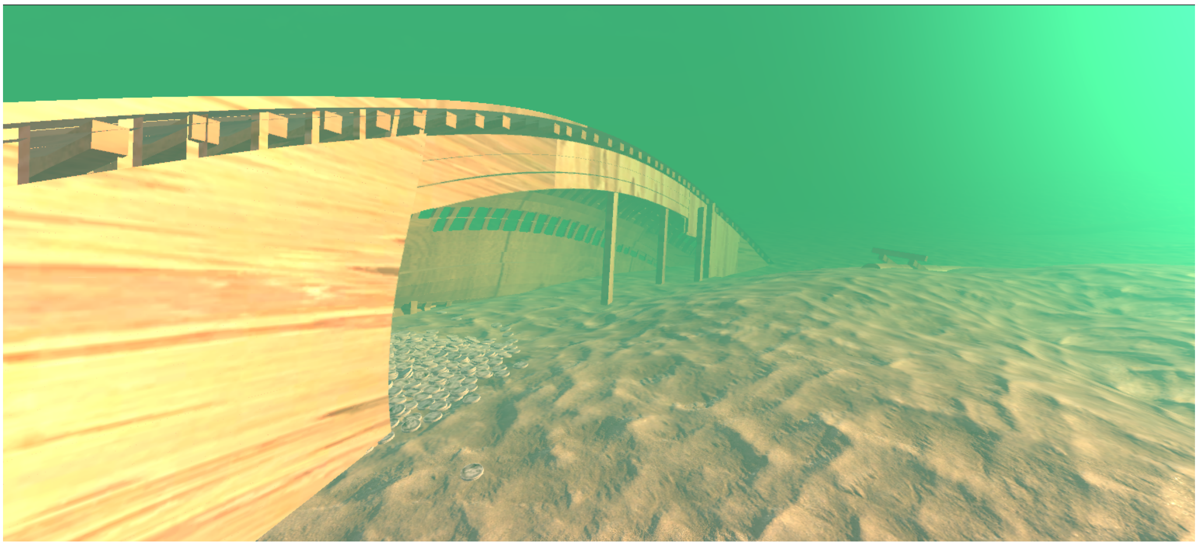

Figure 6.12.: A sunken merchant ship with a bounty of coins

Pozzolana ship Pozzolana is a volcanic ash that was imported to Caesarea Maritima in order to create the hydraulic concrete that was used in the construction of the artificial harbour. It was most likely imported as cargo aboard ships, with some estimates stating that at least 44 full 400 ton cargo ships were necessary in order to import the amount present in Caesarea. There is however no visual evidence of this interesting fact present in the real-world site other than the debris of the jetties - which do not provide much visual stimulation, and show only the hydraulic concrete and not the Pozzolana that was used to create it. In order to circumvent this shortcoming, a model of a ship carrying Pozzolana was fabricated completely in order to provide the player with a "visual anchor point" for the information. This POI is the "least realistic" extreme of the "realism gradient".

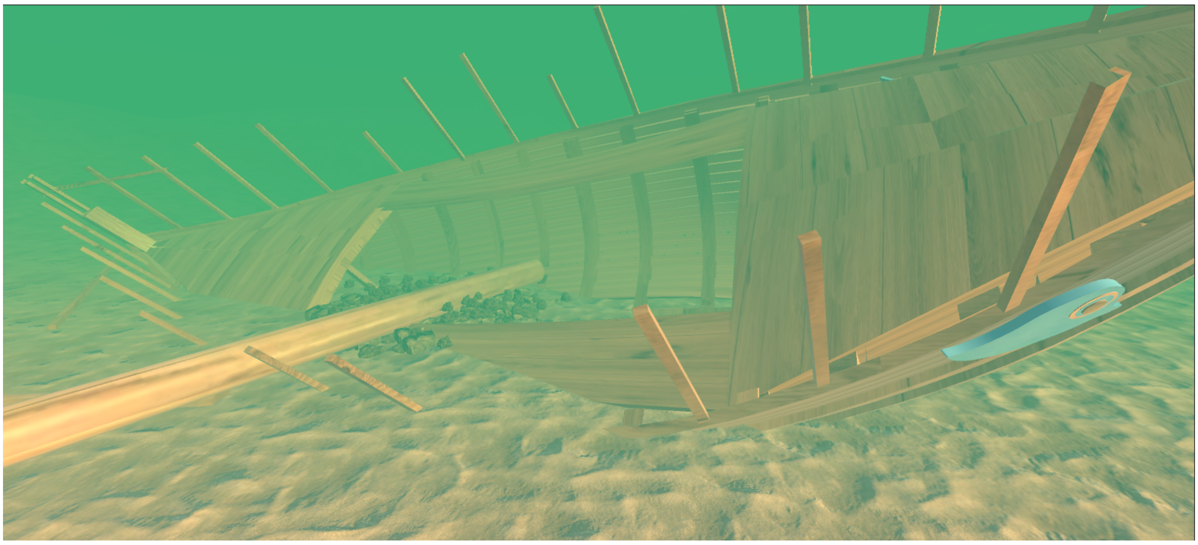

Figure 6.13.: A sunken cargo ship carrying pozzolana

The aforementioned "realism gradient" is presented here again in tabular form to provide the reader with an overview of the level of accuracy of each of the POIs.

POI	Level of realism	Reason
Ruins of the jetties	Most realistic	Factual
Merchant ship	Middle-ground	Strong theoretical basis
Pozzolana ship	Least realistic	Fictional but based on theory

Table 6.2.: A tabular overview of the level of realism associated with each POI

6.3. Analysis of implementation vs. planned design

In this section the practical implementation formerly presented will be compared to the design principles listed in this chapter and the general design plan presented in the previous chapter.

A detailed breakdown of the compliance of the different systems and design elements was provided individually as can be read above. For brevity's sake the following table presents a synopsis of the different components implemented and their degree of adherence to the three principles:

Component	***Modularity***	***Extensibility***	***Authenticity***
`PlayerManager`	High	High	High
`TabletManager`	High	High	Medium-High[1]
`PointOfInterest`	High	High	Indeterminate[2]
Coins	High	High	Medium-High[3]
Scene[4]	Low	Low	High
Ruins of jetty[5]	Low	Low	High
Merchant ship[6]	Low	Low	Medium-High[7]
Pozzolana ship[8]	Low	Low	Medium-Low[9]

Table 6.3.: A synopsis of implementation components compliance with design principles

Per the design plan described in the previous chapter, the current implementation of the game allows for multiple modi operandi, which allow for the game to be used in the consumer product and museum exhibit contexts. The "full" and "simplified" game modes described above are respective to the consumer product context, while the "tour" game mode allows for a relaxed exploration and learning experience that can serve as a museum exhibit. Sadly, the diver tool context was unfeasible, as it requires more involved calculations and dedicate comprehensive design (e.g. Nitrogen debt, different perils and conditions faced by divers etc.). Regardless, every measure to ensure the proximity of the experience to realistic diving available in the given time was taken.

As was previously discussed, the implemented gameplay represents a fraction of the general design plan due to pragmatic limitations. Nevertheless, the current state of implementation contains a vital portion of the general gameplay loop. It represents a solid basis for the "per-dive" gameplay loop, which is meant to be the most interactive, challenging and interesting

[1] Tablet is fictional but could theoretically exist in the near future
[2] Depends entirely on the information provided at creation
[3] Requires careful attention to texture provided for the coins
[4] Referring to the specific scene and not the process of scene creation
[5] Referring to the specific object and not the process of object creation
[6] Referring to the specific object and not the process of object creation
[7] The ship itself is fictional, the treasure factual
[8] Referring to the object scene and not the process of object creation
[9] entire POI fabricated, based on historical facts but no actual physical evidence

aspect of the game. The game in its current state also includes a good initial design for the third phase of the overall gameplay loop - research. This addition was not originally planned for implementation, as it was believed to require a time investment exceeding the time allotted for the writing of this document.

Despite the rudimentary nature of the implementation of the research phase in the current game, it is in keeping with the spirit of the design plan and can easily be expanded upon and shifted to its own stage of the gameplay loop. This is due to the heavy focus given to modularity and extensibility during development. One weakness inherent to the current design of research is prompting, which decreases the overall difficulty but could in fact be beneficiary as mentioned above. To combat the potential decrease in difficulty, no hints were programmed into the game. This requires the player to observe the find and analyze it prior to submitting an answer - relegating the difficulty to the meta-data provided by the design of the different POIs.

The overarching narrative, the less mechanically oriented gameplay phases, buddy-diving and dive preparation and procedures, which were described in chapter 5, are not present in the current stage of development. This omission was a conscious choice, and was done in order to afford more development time on more crucial aspects of the game such as authenticity and enjoyment. This is in keeping with the MVP concept. The concession of these GMs allowed for the development of core systems and elements relevant to the themes and subjects of both this and Leonard Keil's theses [27].

6.4. CSG taxonomy assignment

As its name suggests, the Comprehensive Serious Game (CSG) taxonomy presented by Rafael Prieto De Lope and Nuria Medina-Medina [12] is deeply thorough, encompassing multiple definition categories for game details, which allows for extremely granular - and as a direct result accurate - taxonomy assignments. The taxonomy was developed based on various previous partial definitions or taxonomies, and was the subject of a case-study where the taxonomy was applied to 22 games [12].

The taxonomy criteria are ordered as follows:

Game development	**Game platform**	**Game design**	**Game use**	**Game users**	**Business model**
Authorship	Hardware architecture	Genre	Assessment	Target audience	License
Development methodology	Deployment	Narrative	Gameplay	Player interaction	
		Interactivity	Adaptation	Dedication	
		Context of use			
		Application area			

Table 6.4.: CSG taxonomy criteria as presented by De Lope and Medina-Medina [12]

In all categories, with the single exception of genre, the definitions offered by De Lope and Medina-Medina [12] as based on their work were used. The genre category was assigned according to *Steam* tag conventions, as that definition is more descriptive of the accompanying game.

Gameplay (see table 6.5) involves direct satisfaction measurement, with the percentage of unresolved challenges as a measure of challenge, interview based motivation measurement and based on sensory stimulation.

Game development	**Game platform**	**Game design**	**Game use**	**Game users**	**Business model**
Leonard Keil & Guy Kost	PC VR	VR simulation puzzle	Manual pre+post assessment with a questionnaire	Target age range 12+ (IARC)[10]	Commercial license (theoretical)
Iterative R&D	Local Unity build	Full/Complex	See **Gameplay** above	Single-player	
		Active interactivity	Adaptation to operational context	Core gamer[11]	
		Research only UCH/diving simulation			

Table 6.5.: CSG taxonomy criteria as applied to accompanying game

[10] According to target age at which entry into the sport of recreational diving can be made
[11] The barrier to entry associated with owning a VR device prevents this from including casual gamers

7. Execution analysis

In this chapter the desired specifics of an experiment to determine the validity of the initial hypotheses described in chapter 1 will be proposed as part of a theoretical user-study design. Statistical data collection would be performed via three separate questionnaires - a preliminary pre-play-session questionnaire, a post-session questionnaire testing knowledge delivered in the game and finally an Immersive Experience Questionnaire (IEQ) [104]. The latter is based on previously verified work for the purpose of measuring player immersion, while the former are tailor-made questionnaires intended to determine demographic & previous experience and the quality of knowledge transmission in the game respectively.

7.1. COVID-19 disclaimer

As previously mentioned in various parts of this document under differing contexts, the limitations posed by COVID-19 have mounted difficulties in almost every aspect of the formation of this thesis. The VR nature of the accompanying game was a further limiting factor, as it hindered the potential to demonstrate the game even further by restricting usable hardware and space constraints. As those facts stand, it proved unattainable to gather a sufficient sample size of players in order to produce statistically significant results. This relegates the contents of this chapter to theoretical proposition and potential future work only.

7.2. Proposed user-study design

The user-study will take the form of a fifteen-minute-long play session in the accompanying game, during which no user questions should be answered by the personnel conducting the study to prevent tampering. The play session will be preceded by a five-minute-long preliminary questionnaire and followed by a 10-15 minute period used to fill out a post-session questionnaire and an IEQ (see appendices A.1, A.2 and A.3). This will result in roughly a 30 minute total time investment per user in the study.

The time investment required by the personnel performing the study can be mitigated by allowing multiple users to "queue" for the study and fill out the preliminary questionnaire simultaneously while waiting for their play session, as the limiting factor for concurrency will be the availability of VR hardware. Additionally after the play session, the collection of the questionnaires from the players can be handled passively, shortening the time required for the study even further.

With that in mind, it is of course preferable to gather as much data as possible in order to improve the statistical significance of the results, thus the user-study should have a broad user-base from which to pull participants. Such a user-base can be easily found in general university functions open to the public, such as "demo-day", or in a more targeted fashion via a designated user-study offered to students.

After collection and digitization of user data from the questionnaires, statistical analysis can be performed and conclusions drawn based on it. When considering the results, weighted averages should be applied based on user demographics. The answers to the knowledge questions of a user who has former experience with the learning material presented in the game, for example, should hold less statistical significance than those of a user completely unfamiliar with the subject when regarding the quality of knowledge transmission. For that reason, and for the reasons mentioned previously, it would be prudent to collect not only a large user-base, but also one that is varied in its demographic composition.

Questionnaires

A preliminary questionnaire was written in order to establish demographics and previous experience of the users (see appendix A.1). It contains general questions to determine general demographic details, such as age and gender (optional), and binary questions regarding the user's previous experience with the different subjects relevant to the accompanying game. Additional space is left after each binary answer for the user to recount the specifics of their experience if they have any. The cumulative results of all preliminary questionnaires would form the demographic division and would enable to determine the weighted averages necessary to compensate for previous experiences in each of the fields.

The postliminary questionnaire regarding the learning experience (see appendix A.2) was written to include questions targeting the transmission of knowledge in the game, as well as general questions meant to record the overall user learning experience. This is done in order to provide analytical data points relevant to hypothesis 1 (see chapter 1 section 1.2). The questionnaire will provide a grade of zero to six points of actual knowledge transmission based on the first five questions that can have either a right or wrong answer. Each question is targeted at a specific point of knowledge transmission in order for trends to emerge and determine if a specific failure in any particular methodology occurred. The following seven questions will provide a grade range of seven to thirty-five points, generally conveying the user's attitude towards different aspects of the learning experience in the game. These are general questions that are meant to explore the concept of using serious games as educational tools, as well as the subjective reception of the accompanying game. A pure statistical average can determine both of these attributes from the gathered results. The last two questions allow users to provide input and feedback regarding the game and/or the user-study. This can prove a valuable source of feedback and inspiration.

A proven IEQ [104] (see appendix A.3) will be used to measure player immersion in the game and provide statistical data to verify or disprove hypothesis 2 (see chapter 1 section 1.2). The selected questionnaire is an improved version of an earlier questionnaire used in two previous experiments. The questionnaire contains the following items: "... basic attention

(4 questions), temporal dissociation (6 questions), transportation (6 questions), challenge (6 questions), emotional involvement (5 questions) and enjoyment (4 questions). Participants are asked to rate from a scale of 1 to 5 how they felt at the end of the game (where 1 = not at all and 5 = very much so)" [104]. Immersion score is then calculated per user by summing the values assigned to all questions. The questionnaire was validated by presenting it to a large sample audience - 260 participants, 94.3% male and 5.7% female - and performing a factor analysis on the results. This survey was performed online with user responses made by typing in demographic information or by selecting the most appropriate response from a drop-down list of Likert scale [105] options next to each of the presented questions. The subsequent factor analysis was performed citing Foster et al. [106] and yielded good results, with the questionnaire determined to be measuring cognitive involvement, real world dissociation, emotional involvement (person factors), challenge and control (game factors).

8. Conclusion and future work

This chapter will conclude this thesis. It will be comprised of a short summary of the topics covered, the findings of the research performed and the conclusions that can be drawn from those findings. Finally, suggestions for future work and potential avenues of additional research will be suggested.

8.1. Summary

As this thesis is intended to be readable by any interested individual regardless of their level of knowledge in the field, the first four chapters are used in an introductory capacity. The first chapter provides a broad introduction to the themes presented in this document and it conveys the spirit of the author's ideology in writing it via the use of personal examples. The first chapter also states the hypotheses at the base of all further research presented.

Following the general introduction to the theme and ideology of the paper, the reader is provided with a knowledge base befitting the depth and complexity of later chapters in chapter 2. This includes a deepening of the reader's familiarity with SGs and the subjects of UCH and VR. To strengthen that familiarity, concrete examples of emergent VR technology are presented at the closing of the chapter in order to cement the knowledge acquired.

Armed with the knowledge required to understand the importance of SGs, chapter 3 presents the reader with examples of related work relevant both to the thesis and the accompanying game. These examples encompass previous work by the author and external work from various sources. Additionally, critical evidence of a real-world incident that transposed the context of a non-serious game into a SG context (and thus, in effect, is to be considered as related work) that was not utilized to its full capacity - resulting in harsh ramifications with magnified relevance in the present-day world facing COVID-19. This introduction is brought to the reader in order to stress the importance of viewing **all** games, and not just SGs as a source of valid, important and real-world-relevant information.

chapter 4 introduces to the reader the cultural heritage muse that acted as the inspirational basis in the creation of the game accompanying the thesis - Caesarea Maritima, a national park, famous archaeological site and breathtaking diving site on the shores of the Mediterranean in northern Israel. The chapter recounts the history and unique features of the site, covers interesting heritage assets that were found in the area and lastly demonstrates the reasoning for the selection of this specific site as a model for the purposes of writing this document and designing the accompanying game based on the implementation presented so far.

With the due diligence of overture concluded, the next chapter signifies an entry into the practical segment of this thesis covering the plan and implementation of the accompanying game and a proposed user-study utilizing it. This segment is embodied by chapters 5-7. At the outset, chapter 5 presents the theoretical design plan for the accompanying game, particularly in terms of a possible narrative and the different gameplay loops which were envisioned for the differing contexts in which the game was intended to be applied.

Logically following presentation of the plan, chapter 6 covers the implementation. Beginning with the design principles that guided the process, the chapter dives into the practical application of said principles in multiple components of the game, while striving to maintain a balanced approach to gameplay and serious content. The chapter is concluded by introducing a taxonomy used for SGs and applying that taxonomy to the accompanying game.

Now considering the implemented accompanying game as a viable subject for research, chapter 7 focuses on both the design and potential execution of a user-study utilizing the game to provide analytical evidence to confirm or deny the initial hypotheses presented in the introduction, as well as the questionnaires that will be used to conduct it.

8.2. Findings and conclusions

Over the course of research and writing of this document a few general conclusions were reached. Firstly, a shift toward more accurate games, that incorporate expert advisory staff as part of the design team would signify a major step forward for the games industry. Much like the film industry before it, which is relying ever more heavily on accuracy of depiction via external advisors, such a step would manifest a natural evolution, leading to overall better products. Such a progression, while initially appearing impossible or uneconomical, is in all likelihood the correct step to be taken, as was demonstrated by the film industry. A beneficial side-effect of such an evolution would be the facilitation in creation of detailed, accurate and enjoyable SGs due to the availability and establishment of work relations with the experts required to ensure the quality of teachable content in an advisory capacity.

As shown in this document, production of an accurate SG that upholds all the desired criteria mentioned throughout involves multiple academic areas, each requiring their own research and expertise such as psychology, pedagogy, history, archaeology, game engineering, diving etc. No single individual or even a small team could reasonably be expected to be proficient in all aforementioned subjects to a degree that allows for sufficient accuracy of the material in independent development. This relegates the task of developing fitting SGs to a concerted effort carried out by a combined team of experts from the various fields. This poses a massive difficulty in development, as such a team would be extremely expensive to assemble when examining the issue under the current standards of work in the games industry. That difficulty must be overcome in order for the industry to evolve and march forward as discussed previously.

Secondly, as was shown in chapter 3, the dismissive approach with which non-serious games were so-far regarded is irresponsible. While a movement of change in this approach is growing - as was shown in the research conducted on the Corrupted Blood Incident - it is still very much in its neonatal stages. The root of this attitude can probably be traced to the moral panic [107] that has plagued the gaming industry [108] since its establishment in the 1970s to this day. The stinging admonition of the wasted research potential of the Corrupted Blood Incident, echoed by COVID-19 should serve as a stark reminder to the scientific community that, much like other research fields, **all** games are valuable data points worthy of serious consideration and examination.

As the user-study proposed in this thesis was not carried out, no experimental findings regarding the veracity of the initial hypotheses exist. However, taking into consideration the generally positive reception of VR SGs and particularly the examples relevant to the field combined with UCH which were brought here, the assumption that the accompanying game would fulfil its intended role in a satisfactory manner wouldn't be an unreasonable conjecture. The immersive nature of VR often allows users to "forget themselves" and lose track of anything other than the game. As the accompanying game was indeed implemented in VR, it is likely that that immersion would be present in it as well - providing strong backing to the second hypothesis.

Such certainty is however not guaranteed in trying to validate the first hypothesis. While the design of the accompanying game was inspired and based on best practices present in other games of similar ilk, the development team is not specifically trained in pedagogy. This may have resulted in sub-par methodology with regards to transmission of the learning material. This hypothesis would require further testing and could incur a need to alter the accompanying game for future reexamination of the subject. Despite this uncertainty, the author is confident that even in its current state the accompanying game would result in favourable outcomes for the user-study and in proving the hypotheses.

8.3. Suggested future work

The potential for further research in the field of SGs is vast. Even in the relatively specialized field of UCH VR SGs there are multiple available directions to explore and in which to advance the state-of-the-art.

The first and foremost possibility for future work would be in performing the user-study suggested in this thesis. Based on the results of that preliminary user-study, further improvements could be made in the accompanying game or a reexamination of the methodology by which knowledge is transferred could be carried out. Considering the outcomes from the user-study, the development team could be expanded via the addition of a pedagogical expert for further iteration on the accompanying game if the manner in which knowledge is transferred is found lacking.

Secondly, a full implementation of all of the planned content would make it possible to examine in more detail the implications of a SG designed with entertainment as part of its primary objective. The implementation of all of the different methodologies used in UCH work described in chapter 5 could offer valuable insight into the challenges and benefits inherent to them. This would include an expansion of the existing implementation scope to the museum exhibit and dive training tool contexts, which could possibly entail additional personnel requirements to accommodate the complex knowledge required with the highest degree of authenticity possible.

The emergent technologies shown in 2 could be integrated into a future implementation, particularly regarding the dive training context. This would require a redesign of the diving controls present in the current version of the game into an even more realistic recreation of diving. The use of *"Vive"* trackers could theoretically enable the use of the user's legs to control swimming - presenting a much closer experience to real-world diving. This would also improve overall immersion in the player and open a path to implementation of a breath-controlled diving and air consumption GM, instead of the current motion-only-movement and time-based air consumption implementation.

A future implementation containing the museum and dive training contexts could function as an examination of the viability of implementing a single application for all three desired contexts. A copy of the game could be explored in concert with a representative museum [42] and dive training institute, opening a potential testing ground for a more complete version of the accompanying game. If such an application would be relevant in the aforementioned contexts, the accompanying game could be tested for its compliance with the desired standards and ultimately iterated upon further if the need arises. Such a collaboration could enable the detailed design of some of the missing game mechanics, particularly pertaining to research - as access to museum caliber sources would highly enrich the possibility to model faithful research sources in the game itself.

A commercial release of the planned product, if produced in a caring and high-quality manner, would be a source of generated interest in the combined field. To this effect sponsorship and involvement of relevant organizations - particularly to verify the standard of the work and to secure resources that would afford higher levels of design, implementation, polish and accuracy - could be mutually beneficial for both the developer and the aforementioned organizations. This would manifest in monetary gains for all parties involved, an increase in interest in the subject and thus public relations for the organizations supporting the project and a continued partnership with the developers to ensure future quality and satisfaction. An additional benefit could be a financial "back wind" for further research in the subject in order to promote the game further - resulting in a positive feedback loop of research and development.

The accompanying game in its current state was developed by two undergraduates on a part time basis over the course of four months intermittently alongside other duties. A fully dedicated development team whose goal and occupation are entirely focused on the quality and accuracy of the game, allotted a more significant development period, dedicated to keeping to the design principles described here and maintaining an approach that does not dismiss the importance of enjoyment in the product could produce stellar results. A deeper involvement of external experts in the development process could improve these results even further, potentially manufacturing a one-of-its-kind UCH VR SG.

A. General Addenda

Presented here are the the questionnaires discussed in chapter 7.

A.1. Preliminary Questionnaire

This questionnaire will precede the play session and is intended to determine demographic details and previous experience.

Personal details and previous experiences

Please answer the following questions by by circling the relevant answer or writing in the designated blank areas.

- Age: ________________________

- Gender: ________________________ (please leave blank if you would rather not say)

- Do you have previous experience with diving?

  YES | NO

- If yes please describe shortly:

  ____

  ____

  ____

  ____

  ____

- Do you have previous knowledge or experience with the cultural heritage site of Caesarea Maritima?

  YES | NO

- If yes please describe shortly:

- Do you have previous experience with Virtual Reality?

  YES | NO

- If yes please describe shortly:

A.2. Post-session Questionnaire

This questionnaire will be presented to players after they finish their play session and is intended to test the quality of knowledge transmission in the game.

What you learned in the game

Please answer the following questions by circling the relevant answer or number, or by writing in the designated blank areas. In particular, remember that these questions are asking you about what you learned while playing the game and how you felt about the learning experience.

- Where in the world is Caesarea Maritima?

  ____

- Who built Caesarea Maritima?

  ____

- Was the harbour at Caesarea Maritima natural?

  YES | NO

- What were the two ships that were in the game carrying?

  1.____

  2.____

- According to the previous answer, was **the material** local in its origins?

  YES | NO

- Would you say that it is possible to learn real-world relevant information from things displayed in a VR game?

  Strongly disagree || 1 | 2 | 3 | 4 | 5 || Strongly agree

- Did you feel like you learned useful information in the game?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very much

- Did you enjoy the learning experience in the game?

  Boring | | 1 | 2 | 3 | 4 | 5 | | Enjoyable

- Was the information presented in an interesting manner?
  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very interesting

- Would you consider games such as this one as a useful tool to deliver information?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very much

- Would you be interested in learning more about Caesarea Maritima after playing the game?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very much

- Did you think the way the game presented the information was believable?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very much

- Do you have any suggestions or wishes for the game?

  ____

  ____

  ____

  ____

  ____

  ____

- Do you have any additional feedback?

A.3. Immersive Experience Questionnaire (IEQ)

This questionnaire will be presented to players after they finish their play session and is intended to asses the immersive quality of the game. This questionnaire was not changed from its original form [104].

Your experience of the game

Please answer the following questions by circling the relevant number. In particular, remember that these questions are asking you about how you felt at the end of the game.

- To what extent did the game hold your attention?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | A lot

- To what extent did you feel you were focused on the game?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | A lot

- How much effort did you put into playing the game?

  Very little | | 1 | 2 | 3 | 4 | 5 | | A lot

- Did you feel that you were trying you best?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very much so

- To what extent did you lose track of time?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | A lot

- To what extent did you feel consciously aware of being in the real world whilst playing?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very much so

- To what extent did you forget about your everyday concerns?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | A lot

- To what extent were you aware of yourself in your surroundings?

  Not at all || 1 | 2 | 3 | 4 | 5 || Very aware

- To what extent did you notice events taking place around you?

  Not at all || 1 | 2 | 3 | 4 | 5 || A lot

- Did you feel the urge at any point to stop playing and see what was happening around you?

  Not at all || 1 | 2 | 3 | 4 | 5 || Very much so

- To what extent did you feel that you were interacting with the game environment?

  Not at all || 1 | 2 | 3 | 4 | 5 || Very much so

- To what extent did you feel as though you were separated from your real-world environment?

  Not at all || 1 | 2 | 3 | 4 | 5 || Very much so

- To what extent did you feel that the game was something you were experiencing, rather than something you were just doing?

  Not at all || 1 | 2 | 3 | 4 | 5 || Very much so

- To what extent was your sense of being in the game environment stronger than your sense of being in the real world?

  Not at all || 1 | 2 | 3 | 4 | 5 || Very much so

- At any point did you find yourself become so involved that you were unaware you were even using controls?

  Not at all || 1 | 2 | 3 | 4 | 5 || Very much so

- To what extent did you feel as though you were moving through the game according to you own will?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very much so

- To what extent did you find the game challenging?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very difficult

- Were there any times during the game in which you just wanted to give up?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | A lot

- To what extent did you feel motivated while playing?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | A lot

- To what extent did you find the game easy?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very much so

- To what extent did you feel like you were making progress towards the end of the game?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | A lot

- How well do you think you performed in the game?

  Very poor | | 1 | 2 | 3 | 4 | 5 | | Very well

- To what extent did you feel emotionally attached to the game?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very much so

- To what extent were you interested in seeing how the game's events would progress?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | A lot

- How much did you want to “win” the game?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very much so

- Were you in suspense about whether or not you would win or lose the game?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very much so

- At any point did you find yourself become so involved that you wanted to speak to the game directly?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very much so

- To what extent did you enjoy the graphics and the imagery?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | A lot

- How much would you say you enjoyed playing the game?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | A lot

- When interrupted, were you disappointed that the game was over?

  Not at all | | 1 | 2 | 3 | 4 | 5 | | Very much so

- Would you like to play the game again?

  Definitely not | | 1 | 2 | 3 | 4 | 5 | | Definitely yes

A.4. Asset Credits

This addendum provides credits to all external assets used in the demo that require it. All items have been lightly modified to work in the *Unity* engine.

- "Denario de plata (CAESAR AVGUSTVS)" (https://skfb.ly/oqv7s) by arqueomon is licensed under Creative Commons Attribution (http://creativecommons.org/licenses/by/4.0/).
- "Scuba equipment" (https://skfb.ly/6s7SH) by Steren is licensed under Creative Commons Attribution (http://creativecommons.org/licenses/by/4.0/).
- "Diving Tank" (https://skfb.ly/6WQZt) by pixelated_stars is licensed under Creative Commons Attribution (http://creativecommons.org/licenses/by/4.0/).
- "Scuba Mask" (https://skfb.ly/6WUBw) by pixelated_stars is licensed under Creative Commons Attribution (http://creativecommons.org/licenses/by/4.0/).
- "Flippers" (https://skfb.ly/6XDY9) by pixelated_stars is licensed under Creative Commons Attribution (http://creativecommons.org/licenses/by/4.0/).
- "Dirty Bouy" (https://skfb.ly/6YTUp) by pixelated_stars is licensed under Creative Commons Attribution (http://creativecommons.org/licenses/by/4.0/).
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Glossary

A Available gas in tank in Bar. 43

acrd Air consumption rate at depth. 43

Augmented Reality A technological variant of VR in which additional computer-generated information is layered on top of the real-world view of the user. 10, 78

d Depth, median refers to median depth of test dive, cur refers to current diver depth in meters. 43

decompression sickness Also known as the bends, divers' disease, Aerobullosis or caisson disease, decompression sickness is a serious medical condition caused by gasses dissolved in a person's bloodstream (e.g. due to high pressure, such as that experienced during diving) returning to gaseous form as bubbles in body tissues during decompression. Since the bubbles can form in- or migrate to any part of the body, decompression sickness can produce many symptoms and its effects may vary from joint pain and rashes to paralysis and death. 33

Degrees Of Freedom The number of independent physical displacements available to an object or body. In a 3D environment there are six degrees of freedom; a positive and a negative movements along the three axes delineating the three cardinal directions that generate the vector space. 78

Game Mechanic A system governing interactions between the actors involved in a game such as the player, non-player entities or the game world. 78

griefing A colloquial description of a player's behaviour during a game, stemming from the word "grief". Describes behaviour of constant harassment and irritation of other players, often disregarding agreed-upon gameplay norms and rules in order to elicit a strong emotional response from the target. 23

Mixed Reality A technological variant of VR in which 3D computer-generated objects or imagery and real-world 3D environment are mixed. 10, 78

P Pressure in atmospheres. 43

Professional Association of Diving Instructors An organisation that offers licensed membership to recreational divers, as well as organizes diver training on various levels of specialty and difficulty. 79

raid A raid in the context of this thesis is a type of mission in a game where a group of players attempts to defeat a powerful enemy in a sever instance that is separate to the main game. 20

sac surface air consumption of diver based on data collected in a test dive, measured in Bar/min. 43

Serious Game A game with educational material pertaining to real-world areas or subjects. 79

t Time, tot refers to total dive-time of test dive, no subscript refers to current elapsed dive time in minutes. 43

TP Tank pressure in Bar at different points of test dive denoted via subscript. 43

TUM A university in Germany, Bavaria, in the city of Munich. 81

Underwater Cultural Heritage A collection of all physical evidence and markers of human culture's existence that can be found underwater. This includes any artificial or man-made artefacts as well as flora, fauna, topology and any other natural element found underwater. 1, 12, 79

Virtual Reality A simulated experience that is used primarily for purposes of entertainment and education. Typically involves a computer-generated 3D environment viewed via a HMD. 1, 79

Zoonosis A disease (pathogen, virus, contagion, bacteria, etc.) transmittable from animals to humans. 20, 22

Acronyms

3D Three Dimensional. 10, 18, 38, 48, 76, 77

6DOF Six Degrees Of Freedom. 15

AR Augmented Reality. 10, 11

BCE Before Common Era. 25, 26

CDC Center for Disease Control and Prevention. 22

CE Common Era. 25

CSG Comprehensive Serious Game. 9, 55

DLC Downloadable Content. 37

DSDM Dynamic System Development Method. 38

GDC Game Developers Conference. 22

GFH Games For Health. 22

GM Game Mechanic. 1, 2, 6, 16, 18, 19, 24, 36, 38–41, 44–46, 48, 54, 63

HMD Head-Mounted Display. 10, 11, 14, 15, 43, 74, 77

HUD Head-Up Display. 10

IARC International Age Rating Coalition. 56

IEQ Immersive Experience Questionnaire. 57, 58

INPA Israel Nature and Parks Authority. 25

MR Mixed Reality. 10

MVP Minimum Viable Product. 38, 40, 54

NPC Non-player character. 20, 22

OOP Object-Oriented Programming. 36

PADI Professional Association of Diving Instructors. 13, 30

PC Personal Computer. 56

POI Point Of Interest. 40, 41, 43, 45–48, 50–54

RPG Role-Playing Game. 21

SARS Severe Acute Respiratory Syndrome. 21

SCUBA Self-Contained Underwater Breathing Apparatus. 9, 17

SG Serious Game. 1–6, 8, 9, 13, 16–19, 24, 29, 30, 36–38, 50, 60–63

TUM Technical University of Munich. 77, 81

UCH Underwater Cultural Heritage. 1, 3, 5, 6, 8, 12, 13, 16–19, 25, 32, 34, 36–40, 44–48, 56, 60, 62, 63

UI User Interface. 44, 45, 48

UML Unified Modelling Language. 43

UN United Nations. 12

UNESCO United Nations Educational, Scientific and Cultural Organization. 12, 27

VR Virtual Reality. 1, 5, 6, 8, 10, 11, 13–19, 36, 38, 39, 41, 45, 48, 56, 57, 60, 62, 63, 76

WHO World Health Organization. 20

WoW World of Warcraft. 20–22, 24, 74

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