DM

Interactive Geodesic Structures for Attracting Wider Audience to Marine Concerns

MASTER DISSERTATION

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INTERNATIONAL MASTER OF INTERACTIVE MEDIA DESIGN

UNIVERSIDADE da MADEIRA
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Mestrado em Design de Media Interactivos

Interactive Geodesic Structures for Attracting Wider Audience to Marine Concerns

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supervisionado por

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10 de fevereiro de 2023

Abstract

Recent surveys indicate that there is a greater emotional disconnect between the European population and Europe's aquatic environments [1]. Although a wider audience recognizes anthropogenic issues (i.e. litter pollution, overfishing, noise pollution, etc) where most people can feel connected to nature, however, they do not exhibit pro-environmental behaviors towards them. Interactive environments, which depict marine concerns, remain passive and informative, i.e. not being able to engage with the audience, failing to provide a long-term positive effect. This thesis explores the usage of geodesic structures in depicting marine concerns, exploring possible interactive environments among them in effort to increase the awareness of marine concerns. Dissertation performs five geodesic dome iterations and validations. In first, it studies the role of the open and porous geodesic structure, resembled as four marine species (seabird, sea turtle, dolphin and whale). In second, it enhances the first with the covers, studying more immersive experiences. Third setup contributed to the scaling-down of the geodesic dome marine species. Fourth setup showcased its deployment in wider public spaces. Fifth setup streamlined further the structures, so they can be used at diverse public spots. Two additional Augmented Reality modalites were used, with the former with interaction with the sea turtle and the latter, interacting with the whale.

Keywords: Geodesic structures · Interaction Design · Rapid prototyping · Marine Issues

Resumo

Pesquisas recentes indicam que há uma maior desconexão emocional entre a população europeia e os ambientes aquáticos da Europa. Embora um público mais amplo reconheça questões antropogênicas (ou seja, poluição maritima, pesca predatória, poluição sonora, etc.), onde a maioria das pessoas pode se sentir conectada à natureza, no entanto, eles não exibem comportamentos pró-ambientais em relação a eles. Os ambientes interativos, que retratam preocupações marinhas, permanecem passivos e informativos, ou seja, não conseguem envolver o público, deixando de proporcionar um efeito positivo a longo prazo. Esta tese explora o uso de estruturas geodésicas na representação de preocupações marinhas, explorando possíveis ambientes interativos entre elas em um esforço para aumentar a conscientização sobre preocupações marinhas. A dissertação realiza cinco iterações e validações de Domes geodésicas. Na primeira, é estudado o papel da estrutura geodésica aberta e porosa, semelhante às quatro espécies marinhas (ave marinha, tartaruga marinha, golfinho e baleia). Na segunda, potencializa a primeira com as coberturas, estudando experiências mais imersivas. A terceira configuração contribuiu para a redução de espécies marinhas na cúpula geodésica. Na quarta configuração foi implantada em espaços públicos mais amplos. A quinta configuração simplificou ainda mais as estruturas para que possam ser usadas em vários locais públicos. Foram utilizadas duas modalidades adicionais de Realidade Aumentada, a primeira com interação com a tartaruga marinha e a segunda com interação com a baleia.

Keywords: Extruturas Geodésicas · Design de Interacção · Prototipagem Rápida · Preocupações Marinhas

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Life is a cluster of moments. We filled them with people, episodes, and stories that helped us identify as individuals. Values create the individual, and the individual sets goals. This moment reflects the set of all seconds I collected over these years. Sometimes high, low, and others are important to be here and outline the next steps.

My first acknowledgment goes to my family, thanks.

My tremendous thanks to Marko Radeta as a teacher, advisor, and above all, as a person. When I embraced this project, I did it because I believed and continue to believe in its value and importance. It is an exciting challenge that can positively contribute.

I was not alone. The fantastic Workshop team, always available to support us in all projects, deserves special thanks. To Victor Azevedo, who interrupts his tasks to provide support. To Louis Michael, Ruben Freitas, Jorge Lopes, Hugo Aguiar, and André Freitas for their promptness and friendship. Jocelyne Pestana, Francisco Silva and Andres Millan did a fantastic job developing the

[1] `https://wave-labs.org`

application. They were willing to help construct the structures, the user tests, and the presentation of the projects. Many thanks to João Pestana, a great colleague and friend with a great organizational capacity.

Thanks to everyone who has kindly helped, supported, and made life easier. More enormous thanks to those who did not believe in my capabilities and difficult my days. I would never choose this path without you.

With dignity I savor this moment.

To all my thanks.

Pedro Abreu

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1 Introduction

Recent surveys indicate a more significant emotional disconnect between the European population and Europe's aquatic environments. Approximately 63% of the European population has no idea how harmful our actions are to the species. We and our technologies enhance the marine and megafauna concerns. According to the European Council, the global shipping sector emits greenhouse gases contributing to climate change. International shipping accounts for around 2-3% of total global greenhouse gas emissions, which is more than the emissions of any EU state [1]. Marine transportation generates negative impacts on marine megafauna, including CO2 polution, garbage, underwater noise pollution, ship-strikes on marine megafauna, among other constraints [2].

In Madeira island, its inhabitants have always taken advantage of natural resources. The island's orography forced the population to build terraces to increase the arable area. Moreover, it increased the cultivation area and took advantage of the richness of the soil to develop plantations.

The sea surrounds Madeira, and the sea is a world of opportunities. The vastness and the abundant marine life support the island's inhabitants. Those who live on the coast depend on the waters for their livelihood and family's well-being. Sea is an extension of their homes and is a space they care for preservation.

However, the species inhabiting it no longer have the relevance one would expect. The litter starts to slip from the hand with some ease and frequency. There are fishing nets, plastics, and all marine debris that directly or indirectly end up in the oceans and endanger the environment and marine species [3].

According to a report of the Direcção Regional da Estatistica da Madeira (DREM)[2], in 2019, Agriculture and Fisheries are the business sector that employs more persons on Madeira Island.

Tourism is Madeira's main development engine, all because of the island's natural wealth. In Madeira, according to ACIF data - www.acif-ccim.pt, in 2019, there were 87 maritime tour operators registered in Madeira. Based on

[2]published on March 29, 2021, `https://estatistica.madeira.gov.pt/download-now/economica/empresas-pt/empresas1-pt/empresas1-emfoco-pt/send/253-empresas-em-foco/13323-empresas-2019.html`

the example of a vessel belonging to one of the Maritime-touristic operators, Catamaran Leopard 51 Powercat consumes an average of 420 liters of fuel per trip, and each of these pleasure boats makes about three (3) trips per day (420*3= 1260 L/day). Each liter of fuel consumed produces 2.7 kg of CO2, greenhouse gas drivers. If we multiply the 1260 liters of fuel consumed daily by 2.7 kilograms of CO2 produced, we get a value of 3.4 tons of CO2 per day per boat [4]. Suppose we multiply this fuel consumption by a single vessel from each operator. In that case, we will have an enormous amount of CO2 expelled daily, not counting the transatlantic vessels that dock in our port.

Pollution remains a pertained issue for species [5], for the environment [6] and consequently for the economy [7]. It is important to create mechanisms to minimize them. Several studies show the vulnerability of the Macaronesian archipelagos to marine plastic pollution [8], and the phenomenon of Plastic waste present in the rocks of the south coast of Madeira island is called Plasticrusts [9]. Recently, the scientific community concluded that the Mediterranean is the most polluted sea in Europe [10]. In addition to plastic waste, fishing nets remain a considerable problem for the aquatic environment. Not only because of the pollution but also the consequences they produce (i.e. when throwing fishing nets for swordfish, they drag the turtles to the bottom of the ocean), and as such, species are prone to instant mortality [11].

1.0.1 Environmental Impact

The tourism sector is based on exploiting natural, cultural, and human resources and can significantly change places where it develops. It is our region's most significant source of income and employment, but it can threaten the local natural heritage. These potentialities and vulnerabilities create new ways of dealing with the tourist sector. New experiences favor people's contact with the marine megafauna, allowing them to establish effective ties with it and leading to an environmental awareness capable of determining postures and attitudes. According to an article published in JM (Jornal da Madeira) on 07/12/2022[3], according to the representative of the maritime-tourism activities sector of ACIF - Associação Comercio e Industria does Funchal[4], by the end of 2022, the expectation is that 250 thousand people will be able to enjoy the

[3] https://www.jm-madeira.pt/regiao/ver/178510/Milhares$_t em_p rocurado_a tividades_m aritimo-turisticas_n a_M adeira_c om_v ideo$

[4] https://www.acif-ccim.pt

offer made available by the 87 registered operators across the island. He also alerts us that the ability to see cetaceans is at its limit and requires more supervision. "At this time of summer, unfortunately, we have 10 to 12 boats on top of the same group of animals.

The Tripadvisor website displays the ranking of the best maritime-tourist experiences in Madeira[5]. We are going to review the top-rated company, VipDolphins Luxury Whale Watching[6]. The company reports that Funchal's waters are home to whales and dolphins - and this luxury catamaran tour offers the best way to spot them. On the trip, travelers will enjoy champagne, cocktails, soft drinks, and snacks such as local bread and cheese. If people wish, take a break to swim and snorkel at Cabo Girao before returning to shore. Each trip lasts three (3) hours and is limited to a maximum of seventeen (17) travelers aged between two (2) and one hundred (100) years. Prices start at €59.00. The boat is not accessible to wheelchair users.

VipDolphins Luxury Whale Watching offers different Marine experiences: Dolphin and Whale Watching - 3 hours experience. Morning from 10h to 13h and Afternoon from 14h30 to 17h30; Luxury Sunset Cruise - 3 hours experience, from $18H30to21H30$; Private Whale Watching - 3 hours experience, three times a day: 10h-13h, 14h30-17h30, and $18h30 - 21h30$. Privat Charter Full Day - 3 hours experience whale watching, eight full hours day private charter or 24 hours Sleepover private charter for €2900,00.

They use the boat Leopard 51 Powercat Catamaran, produced since October 2013. We highlight the most relevant characteristics: Length: 15.54 m; Beam: 7.64m; Engines: 2 x 370 hp; Fuel Capacity: 1,500 L and estimated consumption of 140 liters per hour / Light Ship[7].

Each trip consumes around 420 liters of fuel. Each day, this vessel transforms 1260 liters of fuel into carbon dioxide. If we multiply the fuel burned by the 87 tour operators that sail in Madeira, accounting for just one Ship, the carbon dioxide produced is frightening.

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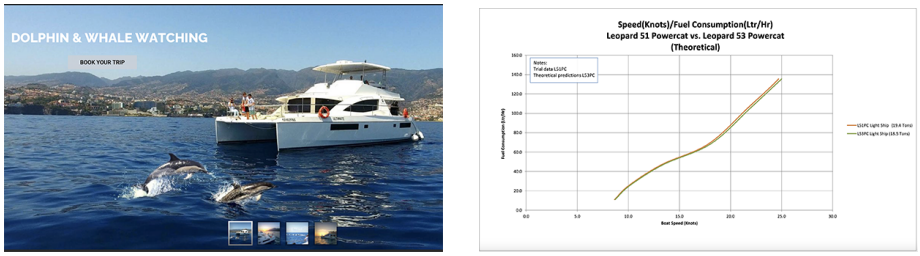
[5]https://www.tripadvisor.pt/Attractions-g189167-Activities-c55-Funchal$_{M}adeira_{M}adeira_{I}slands.html$

[6]https://vipdolphins.com

[7]https://www.leopardcatamarans.com/news-and-events/press-releases/leopard-51-pc-press-release



(a) (b)

Fig. 1: (a) Catamaran Leopard 51 Powercat. (b) Boat consumption.

According to the Council of Europe, the global shipping sector emits significant greenhouse gases contributing to climate change. They estimate that greenhouse gas emissions from international maritime transport amount to around $2-3\%$ of the global total, which is more than the emissions of any EU State. If the shipping industry were a country, it would rank sixth on the world's most emitters list. At the EU level, CO2 emissions from maritime transport increased by 48% between 1990 and 2008, and in 2015, this sector was responsible for 13% of total emissions[8].

Human behavior affects the climate and makes the species vulnerable to these changes [12]. The vitality of the environment and ecosystems reflects the surrounding community. Environmental constraints directly impact society's health, economy, and well-being. The impact of our actions lasts in time and space and extends into the future. It is essential to make society aware of the importance of a healthy environment and ecosystem, with a reduction in the ecological footprint. The suggestion is to appeal to the emotional side of the individual as a way to overcome the anthropogenic impact on ecosystems.

The dissertation hypothesizes that it is possible to educate wider audiences about marine concerns, using interactive structures to inspire their curiosity. Several geodesic systems aligned with an interactive augmented reality mobile application can increase ecological awareness.

[8] https://www.consilium.europa.eu/pt/press/press-releases/2019/10/25/co2-emissions-from-ships-council-agrees-its-position-on-a-revision-of-eu-rules/

1.1 Are Current Means Enough to Protect Biodiversity?

Biodiversity is the name we give to a variety of life on earth, and "biological diversity" is the diversity of species in an ecosystem. All living things exist in their habitats and interact with each other. Biodiversity is the life support system [13], and the balance between species contributes to the general well-being of the planet [14]. A synergy of human threats, including over-fishing, global warming, biological introductions, and pollution, has caused a rapid decline in global marine biodiversity, measured by species extinctions, population depletion, and community homogenization. Global biodiversity loss will continue and will likely accelerate in the future, with potentially more frequent ecological breakdowns, community-wide changes [15], and increased potential extinction risk of species [16].

Indeed, biodiversity plays a fundamental role as ecosystem services in maintaining natural ecological processes that benefit people who receive from natural ecosystem functions. For instance, biodiversity contributes to air quality maintenance, regional climate, water quality, nutrient cycling, reproductive habitats of commercial fish, and others. With such benefits, they contribute to the economic values of products that nature can provide: wood, food, fibers to make paper, resins, chemical, and organic products, genes as well as knowledge for biotechnology, including medicine and cosmetic sub-product [17]. Still, human activity is causing high rates of biodiversity loss. Economic inequality has been shown to affect public health and is a link to environmental problems in general [18].

For instance, North Atlantic right whales (NARW) face many threats. Entanglement in fishing gear, vessel strikes, climate change—which may alter their migratory patterns and feeding areas—and the impacts of ocean noise on their ability to communicate, find food and navigate. The North Atlantic Right Whale (NARW) is one of the most endangered whale species in the world; the latest preliminary estimate suggests fewer than 350 remain. Whaling is no longer a threat. In the early 1890s, commercial whalers had hunted NARW to the brink of extinction. NOAA Fisheries and partners estimate that over 85 percent of right whales have been entangled in fishing gear at least once[9].

[9]Published by NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION | U.S. DEPARTMENT OF COMMERCE, `https://www.fisheries.noaa.gov/species/north-atlantic-right-whale`

There are ways to protect biodiversity. Whale and Dolphin Conservation (WDC) is the leading charity that saves whales and dolphins. WDC operates at international meetings and works across many seas and oceans, as well as through its offices in the UK, North America, Germany, and Australia. They work globally through campaigns, lobbying, advising governments, conservation projects, field research, rescue, and educational activities. Promote a non-intrusive - viewing method for watching whales and dolphins from land and offer the chance for the public to get involved in citizen science, such as the Shorewatch program in Scotland. A question arises, why is it essential that whale watching is carried out responsibly? Recently, concerns have been raised about the industry's impact on whales and dolphins, whether at the individual, group, or population level. For WDC, in many cases, whale watching involves targeting specific whale and dolphin communities for prolonged, often close-up, encounters. As the demand for more frequent encounters increases, it is the responsibility of us all to ensure that we are not unintentionally harming whales and dolphins in the process[10].

Since protecting biodiversity is causing even more pollution, one may suggest that there is a possibility to resort back to formal and informal education and understand how we can provide responsible biodiversity growth and protection.

1.2 Potential for Responsible Biodiversity on Madeira Island

We live on a small island in the middle of the Atlantic Ocean. Small pebbles full of beauty and natural wealth attract numerous visitors. The natural beauty of the territory is vast. About 20% of the island's environment is a protected area and has existed since the arrival of Portuguese navigators. It is called the Laurissilva Forest. The indigenous forest of Madeira is considered a Tertiary relic[11]. The immensity of the sea that surrounds us is rich. It features warm waters and a mild climate throughout the year. The Madeira archipelago is a beach destination with a wide range of maritime leisure activities. It is natural that the amount of activities and tourism substantially increases pollution and interferes with the ecosystem.

[10] Published by Whale and Dolphin Conservation, `https://uk.whales.org/whales-dolphins/whale-watching/`

[11] https://ifcn.madeira.gov.pt/areas-protegidas/parque-natural-da-madeira/laurissilva-da-madeira.html

Madeira Island is one of the four islands that make up the Autonomous Region of Madeira and is located in the Atlantic Ocean, close to the northwest coast of Africa. Have a subtropical climate and warm temperatures throughout the year. It is a green volcanic island with $801Km2$ [12], inserted in a marine inland waters area with $825km2$ [13]. According to official data from the Direcção Regional de Estatistica da Madeira (DREM), the 2021 Census indicates that the resident population in the Region was $250,769$ inhabitants [19] and the total number of overnight stays in the summer months (July, August, and September) totaled 3.1 million [20]. The basis of the RAM economy is the tertiary sector, tourism. It is one of Europe's favorite destinations. Madeira offers several tourist attractions throughout the year, emphasizing the Christmas and New Year Festivities, the Flower Festival, the Wine Festival, the Atlantic Festival, and Carnival. In the agricultural sector, banana production is aimed primarily at regional and national consumption. Madeira flowers and wine contribute positively to the regional economy[14]. According to TimeOut magazine, Madeira is the right destination for any time of the year, whether you love diving or hiking. The offer of nautical activities in Madeira is extensive and covers all tastes, wallets, and stomachs. It ranges from watching Cetaceans to water sports: surfing, stand-up paddle, diving, boat trips, and sport and leisure fishing, among others[15].

This dissertation leverages the existing local marine biodiversity in effort to increase the knowledge of the existing marine concerns to both locals and visitors. Dissertation proposes the construction of geodetic structures of megafauna species, depicting local biodiversity, inspiring curiosity, making the first connection to such species from shore, exploring augmented reality interactions to engage the audience with marine concerns, and studying means how to suggesting the monitoring of such continuously.

1.3 Validation Protocol and Objectives

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[12] https://www.visitmadeira.com/pt-pt/a-madeira

[13] https://www.dgrm.mm.gov.pt/am-ec-zonas-maritimas-sob-jurisdicao-ou-soberania-nacional

[14] https://madeira.best/guia/factos-madeira/economia-da-ilha-da-madeira

[15] `https://www.timeout.com/pt/madeira/coisas-para-fazer/as-melhores-actividades-nauticas-na-madeira?itm_source=parsely-api`

We developed the project over time and according to the evaluation of the users. Our initial objective was to build five geodesic structures of marine animals. We assemble the Domes of four animals, a seabird, turtle, dolphin, and whale. After the first user test at the University's atrium, we received feedback on the coverage of the structure. From this point on, we directed the entire experience according to user feedback because we intended to increase the public's interaction with the experience.

This dissertation describes the iteration and evolution of geodesic structures based on user studies input between September 2021 and October 2022. In September 2021, during the Macaronight activity, We did user tests with forty (40) individuals. Tests focused on the emotional state analysis of users when comparing the existing mobile application[16] when used with and without the geodesic structure. During an internal meeting with marine ecology experts from research unit MARE[17], the dissertation further performed another user test with 23 scientists, studying the structure preference, whether covered vs. uncovered. Based on their feedback and iterations of structures, we did additional 3 studies with 20 passersby users, external 52 users, and 23 students from the Azores visiting Arditi's facilities. The study aimed to identify the audience's perception of the megafauna species portrayed in the structure. An additional reference user test was during the Ciencia Viva activity in Praça do Povo in Funchal in July 2022, from dissertation-validated 81 tests when we performed the structure in the public setting. In September, of 2022, we did an additional 18 user test with a new design. The last validated user test was at Macaronight 2022 with 23 subjects. All user tests contributed to the validation of the structure, the other interactive experience and mobile application based on augmented reality, and the combination of the two in creating an appealing narrative for a wider audience.

Although there are appropriate scales to measure user interaction, we opted for a mix of questions from the most varied usability scales among the ones described below. I am aware that it was not the most appropriate measure. However, the interactive conditions of the activities did not allow us to have extensive user tests with dozens of questions. The places of experience were public and susceptible to the most various interferences. While plethora of

[16] https://play.google.com/store/apps/details?id=com.tigerwhale.ardome&hl=en&gl=US&pli=1

[17] https://mare-madeira.pt/

existing scientifically validated scales measure users' emotional states, has the Intrinsic Motivation Inventory (IMI) [21], the system usability scale (SUS) [22], Natural Environmental Paradigm (NEP) [23], and NASA Cognitive Load Index (TLX) [24], such surveys remain very limited to specific services or are outdated. Thus, the dissertation proposes the creation of new questions, combining some inputs of the aforementioned ones, targeting the questions pointed towards the role of the structure itself.

1.4 Research Questions

The dissertation explores the importance of geodesic structures in attracting a broader audience to marine concerns. We use a questionnaire that is essential to confirm that the geodesic structures benefit the interaction and the experience and have a long-term influence on users' awareness.

RQ1 - The structure arouses interest from the participants/general audience that interacts with it? Such addresses the question if the structure arouses interest in the audience. Does the structure erected in a public space spread interest and attract passers-by, instilling a desire to participate in the proposed interactive activity?

RQ2 -Does the structure adds value to the experience or does the structure add value to the exploration of the geodesic structure? Such questions further explores whether the structure adds any specific value to the experience. What if we change its configuration - would such cause a change the user's emotional state?

RQ3 - Is the overall experience within the structures engaging? Further analysis is based on understanding how engaging is the experience. What kind of activities would users be willing to do in such?

RQ4 - Does the experience contribute to a stronger connection to environmental awareness? Most importantly, dissertation outlines if such experiences within the structures are significant. Do we positively and effectively reflect the message we are trying to convey? How such will have a positive long-term effect?

1.5 Conducted Experiments

Five experiments were conducted which will be further elaborated throughout the dissertation:

1. **Exp 1 - Open Geodesic Marine Species.** Tests include the deployment of 4 geodesic structures in field, and tests with the interactive mobile application with turtles.
2. **Exp 2 - Closed Geodesic Marine Species.** Several tests challenge the covered geodesic structure, analyzing further the weight constraints.
3. **Exp 3 - Smaller Closed Geodesic Marine Species.** Streamlined marine species as geodesic structures, with user studies depicting the the visual appearance of the structures to the users.
4. **Exp 4 - Smaller Closed Geodesic Marine Species in Wider Public.** Experiment which depict the the deployment at the public square, and tests with with interactive mobile application with whales.
5. **Exp 5 - Smaller Geodesic Structure.** Tests encompassing the streamlined version of the structures, capable for versatile deployments.

1.6 Glossary of Used Acronyms

In below, the dissertation depicts some of the commonly used acronyms throughout the document, facilitating the reference to the reader.

2V Two vertices

3D Three dimensions

ABAE Associação Bandeira Azul da Europa

ACIF Associação Comercio e Industria do Funchal

AL Local Accommodation

AR Augmented Reality

ARDITI Agência Regional para o Desenvolvimento da Investigação, Tecnologia e Inovação

ARDome Augmented Reality Dome Application

App Mobile applications

DREM Direcção Regional da Estatistica da Madeira

FCT Fundação para a Ciencia e Tecnologia

HCBI Human Computer Biodiversity Interaction

HCI Human Computer Interaction

Hexa Hexagonal

IGS Interactive geodesic structures

IMI Intrinsict Motivation Inventory

INTERTAGUA Interfaces Aquáticas Interativas para Deteção e Visualização da Megafauna Marinha Atlântica

IOS Mobile operating system from Apple Inc.

JM Jornal da Madeira

MARE Centro de Ciências do Mar e do Ambiente

MDF Medium-density fiberboard

MR Mixed Reality

NARW North Atlantic Right Whale

NEP Natural Environmental Paradigm

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

PETG Polyethylene terephthalate glycol-modified

PIDDAC Portuguese National Funds

PLA Thermoplastic polymer

Penta Pentagonal

QRCode Bar code

RAM Região Autonoma da Madeira

SAM Self-Assesment MAnikin

SUS system usability scale

TLX NASA Cognitive Load Index

VR Virtual Reality

WDC Whale and Dolphin Conservation

1.7 Structure of the Document

Next, the structure of the document follows. The related work shows an overview of the current usage of geodesic structures, with its context through history. The dissertation describes the use of domes in scientific and educational environments and characterizes the lack of maritime and environmental education and its impact on the ecosystem. In addition, HCBI studies and projects as a tool to emotionally connect individuals with species. The methodology section describes designing, modeling 3D design, and the construction process of the structures—the collecting and preparing of the wood, connectors printing process, and semblance in public spaces. The dissertation describes the experiences and development processes of the different geodesic structures of marine megafauna animals: birds, turtles, dolphins, and whales. It further describes the constraints caused by the weather and insecurity that resulted in their collapse. We present structures' re-design, their construction in public spaces, and the design process of the posters used in the ARDome App. In another chapter, the dissertation offers some educational and institutional activities of the ARDome project. It next talks about the ARDome Turtle activity, encompassing user studies carried out with the correspondent Dome and the visual image of the ARDome Whale App implemented in Praça do Povo, Funchal, during the Ciencia Viva activities in July 2022. The dissertation further depicts the obtained results of the studies in the different stages of the project's development, showing graphs, forms, tables, and images that contribute to the discussion and corroborate the results. In the discussion, we elaborate on using the structures in public spaces of RAM. We demonstrate the possible economic and environmental impact, as well as the effects of tourism on the ecosystem and marine species. The findings chapter describes what the dissertation gained in the different stages of the project based on the iterative design and user studies. The dissertation describes the contributions to the research questions, outlining the following challenges. The dissertation also showcases guidelines, suggesting how to approach the emotional side of the individual as a means of changing effective behaviors in the long term. Future work summarizes potential further work on geodesic structures, including the possibility of using such facilities combined

with digital technologies to offer more immersive experiences. The conclusion finalizes the dissertation findings based on the multidisciplinarity involved, lessons learned, and room for improvement.

2 Related Work

The literature review encompasses existing work applying geodesic structures and artistic installations used for educative purposes. Existing efforts for engaging the audience with marine concerns are depicted, outlining the overall gap with the lack of public maritime education.

2.1 Prior Efforts with Geodesic Structures

For centuries, geodesic structures have been present in people's lives [25]. They served as shelters, tents for parties and concerts, gardens, interactive installations, and are used for a variety of purposes [26]. Domes were popularized by R. Buckminster Fuller in the $20th$ century, who used them to improve human shelters [27]. Geodesic structures served researchers in the most diverse disciplines to develop novel ideas [28]. Indeed, the influence of geodesic structures transcends the fields of engineering and expands to the most varied areas of science and design. Recent works in the literature also explored such usage for educative purposes. The proposed dissertation, based on the previous work in the literature [29], deals with the interactive scenarios, narratives, and geodesic structures that bridge the emotional gaps between the wider audience and the sea protagonists. Instead of the work with essentially theoretical characteristics of the interaction with mobile applications with the geodesic structures, this dissertation will have a more practical feature in developing the domes themselves. In addition, several projects inspire this dissertation further, such as: In Pinch-the-Sky Dome [30], a sizeable immersive installation where several users can interact simultaneously with Omni-directional data inside of a tilted geodesic dome. Instead of using a projector or camera in the center of the Dome as a way to foster interaction with the user, in our project, the user makes use of his cell phone to, through the existing ARDome App [18], interact with the marine environment.

Another work explored the usage of geodesic domes depicting pollution - Pollution Pods. Pollution Pods are part of the Climart project. This broader research program looks into novel ways art can change people's perception of climate change [31] and hopes to disrupt our embodied experience of pollution. Indeed, the domes work as an appealing and enriching physical element [32] that offers an environmental connection. They further invite users to approach

[18] `https://play.google.com/store/apps/details?id=com.tigerwhale.ardome`

and connect them to the mobile application [33] to enrich the experience. Domes can be used for educative purposes, but not much work measures their effect on the rising marine issues. Therefore, this dissertation uses geodesic structures to engage users in an immersive interactive experience to increase the emotional connection with marine species and increase environmental concerns.

2.2 Existing Education Installations

Playing encourages learning and contributes to development [34]. During joking, children encounter challenges that force them to observe, reflect, understand, anticipate decisions, and act. They develop fundamental skills and strategies for their development. Usually, children are interested, adventurous, curious, creative, fun, imaginative, explorers, emotional, reactive, inventive, and like learning. Adults generally are visual and have an intrinsic need to touch and feel things. These geodesic structures are the trigger we use to offer users an interactive experience. We use artificial realities to create virtual environments [35]. Geodesic structures are an attraction themselves. We will use them to offer new interactive, immersive, technological experiences and provide information through a narrative. Is the interactive experience limited to the interior space of the Dome? The answer is no. The Dome serves as a trigger. The interactive experience starts outside and continues when entering the structure itself. What interactive experiences can we offer? In the first phase, an interactive game engages with a storytelling [36], ARDome, that provides an immersive environment about marine species and ecological concerns.

2.3 Existing Outreach Activities

The Blue Flag program is the most relevant project that aims at environmental protection at an institutional level. Its principle is the promotion of sustainability in coastal environments, beaches, marinas, and recreational and tourist boats. Eco-Escolas is an international program developed in Portugal in 1996 by the "Foundation for Environmental Education" designed by Associação Bandeira Azul da Europa (ABAE), dedicated to Education for Sustainable Development, the management, and recognition of sound environmental practices for schools and students.

2.4 The scarcity of appropriate education reflects the anthropogenic problems of marine ecosystems

The increase of anthropogenic pollution by marine litter and floating marine macro-litter have consequences for megafauna [6]. There is a nefarious impact on marine biodiversity, and such remains an issue for human health, environment, and economy [5]. Almost half of the global waste is attributed to packaging, which is commonly used daily. Nearly one credit card of microplastics is typically eaten each week by people [11]. Every minute, one garbage truck of plastic is tossed into the oceans [37]. More responsible actions are needed, and higher education about marine ecosystems.

2.5 HCBI is a tool to connect individuals emotionally with remote species.

The rapid development of technology enhances the creation of new interactive metaphors [36]. In recent studies on HCI showcases, Kobayashi proposes the concept of HCBI to connect audiences in public spaces with remote biodiversity [38]. With the extension of HCI to human-computer-biosphere interaction (HCBI), Kobayashi collected sound marks in a forest and showed that it could contribute to the public's connection with nature [39]. HCBI's objective is to contribute to the benefit of belonging to nature without causing environmental destruction. In 2016, audio samples collected from Fukushima, Japan, were broadcast continuously as a live stream of sound data [40], where audiences in public spaces can reflect on the current biosphere that populates dangerous zones. However, we must do more work to apply the HCBI concept to marine concerns. It shows the potential for new insights into aspiring to an emotional connection with the seas, increasing marine literacy and pro-environmental actions.

2.6 The usage of IGS in public spaces as an interface to inspire pro-environmental actions.

We use geodesic structures as interactive installations [33]to instill pro-environmental actions where the general public becomes more sensitive to ongoing marine concerns. Geodesic structures have helped researchers in the most diverse disciplines. The influence of geodesic structures transcends the fields of engineering and expands to the most varied areas of science and

design. They are used to develop new ideas and influence several fields of science: biology, chemistry, physics, mathematics, and golf ball design [28]. Recent work in the literature has also explored its use for environmental awareness, and educational purposes [35]. Domes in public spaces represented the scents of various cities, allowing the public to understand the levels of carbon dioxide contamination [31]. Furthermore, Radeta et al. 2020 showed how the IGS could be used to portray the constraints of marine megafauna, proposing interactive narratives and scenarios. IGS bridges the emotional gaps between the public and marine species. However, the proposed work remains at the concept level. We need to be aware of the effect of IGS on the daily routine of a wider audience and how it can create emotional connectivity with the ocean [29]. With the development of geodesic structures inspired by marine species and augmented immersive experiences, we aim to instill pro-environmental actions where the general public becomes more sensitive to ongoing maritime concerns.

3 Methodology

Next, the dissertation describes the process for the design of geodesic structures, encompassing modeling, sample wood gathering, 3D printing, and covering the Dome with MDF. We also describe the experiments we enrolled in during the development process of the ARDome.

Inspiration. In line with the work previously developed in INTERAQUATICA [29], the geodesic structures are of the 2V type given their simplicity as it has only two dimensions (e.g., Fig. 2a). We raise the height by increasing the lower part to accommodate people inside. The domes were 4m in length and $3m$ high. To increase the strength of the structures, we designed smaller domes with $3.5m$ in diameter by $2.75m$ in height and removed a horizontal batten to make it possible to enter and exit visitors. The Domes design started as 3D models in Fusion360, and the render was in Blender after being exported. The structure remains a key and fundamental element of the entire user experience. The ARDome mobile application is just one more app among millions of others on the Play Store and the App Store. Without Dome, substantial financial investments in advertising and Marketing would be necessary to reach the public and achieve the intended purposes. The purpose of the Dome is to expand the interactive experience and serve as an interpersonal link with the five marine species we want to focus on, the Turle (e.g., Fig. 2b), Dolphin (e.g., Fig. 2c), Sea bird (e.g., Fig. 2d), Whale (e.g., Fig. 2e) and the Seal (e.g., Fig. 2f).

3.1 Design of Geodesic Structures

For the construction of geodesic structures, we chose wood. Wood is an organic, natural, biodegradable, resistant, easy-to-handle, lightweight, and affordable material. For its characteristics and availability, wood has been used directly or as a raw material since the beginning of humanity for construction, protection, as a weapon, food, and energy source, among others. Although wood usage is in decline and the demand for composite materials is increasing, we still use it in construction. In Madeira Island, due to a large number of buildings, it is relatively easy to find this material, especially on pallets. The pallets initially used as a base to store heavy and construction materials, primarily due to their strength and durability, are given new uses and transformed into furniture, decorative objects, and, in our case, Domes. We

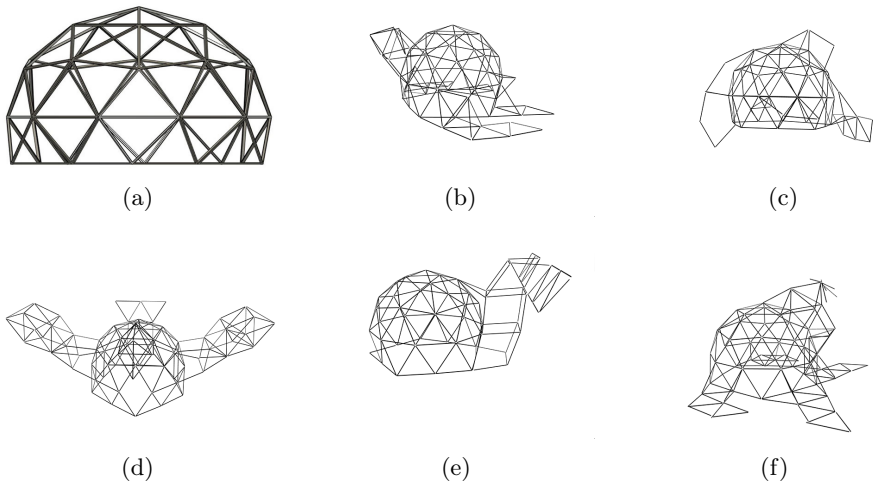


Fig. 2: (a) 3D Render Dome. (b) 3D Render Dome - Turtle. (c) D3D Render Dome - Dolphin. (d) D Render Dome - Seabird. (e) 3D Render Dome - Whale. (f) 3D Render Dome - Seal.

built the geodesic structures from wooden slats taken from pallets collected from construction companies. We are recycling and reusing existing wood; otherwise would pollute the environment. For dismantling the pallets, we use fare hammers, pliers, iron bars, drills, and chisels, among others (e.g. Fig. 3a). We disassemble pallets without compromising the quality and robustness of the slats. Slats are cut, milled to smooth the edges (e.g. Fig. 3b), drilled a hole at each end (e.g. Fig. 3c), and fixed a pin using a long screw.

3.2 Assembling the Geodesic Structures

Until August 2022, we provided three domes of different dimensions. The first model was more significant than the following. The woods had two dimensions. The largest slat measured $110cm$, and the smaller $97cm$. The Dome had approximately $3,6m$ in diameter and $2.5m$ in height due to the addition to the main structure. In the second Dome, we used the smallest slats of the previous design, the $97cm$ wood, as the largest and made a new $85cm$ cut for the smaller slats. The second Dome had an approximate diameter of $3,15m$ by $2,2m$ in height due to the increase in the structure's base. Due to safety constraints, we made the Dome more robust, reducing the dimensions of the wood and increasing its thickness. We cut the wood with the dimensions of $85cm$ and $76cm$, respectively, and the thickness increased to $4cm$, against the previous

(a) (b) (c)

Fig. 3: (a) Used tools. (b) Wood cut process. (c) Slats drill.

$2,5cm$. The Dome's diameter became $2,90m$, and the height decreased to approximately $1,80m$. Its basic construction requires wood, connectors, and screws. The timber used is taken from pallets. The connectors are 3D printed on PLA. The screws and nuts are metallic and are purchased. To assemble a basic Dome requires 30 short, 66 long slats, 6 Penta connectors, 30 Hexa, 36 connector covers, 36 Philips short $M6$ screws, 36 washers, wing nuts to attach the connectors to the caps, 190 pins, and 190 long screws to secure the pins to the slats. For the finalization of the Dome, the artistic part that identifies the species, we have an approximate number of pieces as it depends on the physical space where it will assemble well as the creative component of interaction. It can vary well double the amount of material used in the main structure.

The site - https://www.ziptiedomes.com gives us the possibility to calculate the dimensions of the different types of Dome(e.g. Fig. 4a) and choose the number of vertices (e.g. Fig. 4b) (other sites provide the same kind of tools). The Dome construction process begins with the 3-dimensional design of the structure. We used Autodesk's Fusion 360 program to design the 2V geodesic structure (e.g. Fig. 4c) of the marine megafauna species, the connectors, the caps, and the pins. We increase the Dome height to enable interactive activity. Adding a set of long slats horizontally to the base of the Dome, we have increased the size of the structure by about 80cm.

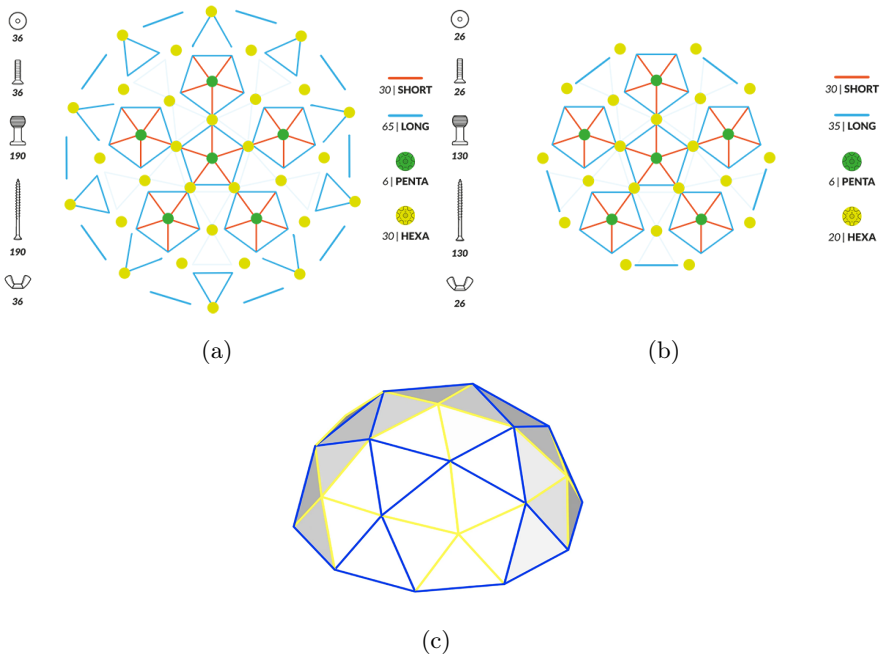


Fig. 4: (a) Large Dome instructions. (b) Small Dome instructions. (c) 3D Dome.

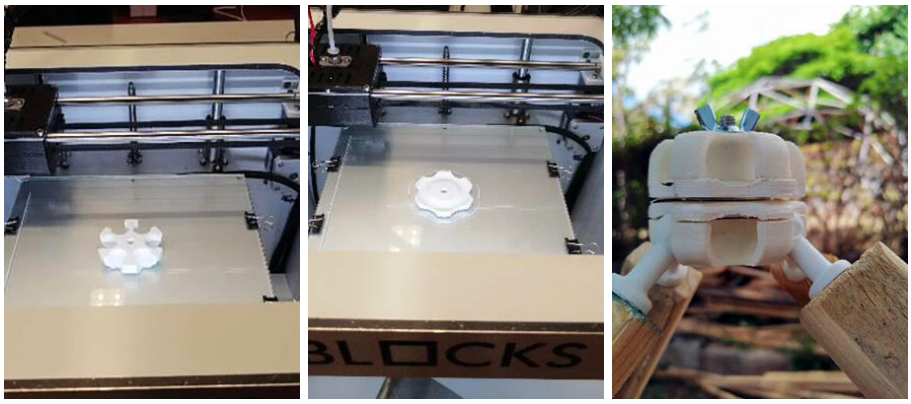
The below-mentioned Hubs [19] allows the user to purchase the integral kit (build yourself) of a 2V geodesic structure strong enough for uses as fruit cages, garden rooms, chicken runs, etc. These constructions are recommended exclusively for private and supervised spaces. It is not a toy. Climbing and lifting heavy objects is not recommended. Hubs also provide the simplified CAD version of the models of hexagonal (e.g. Fig. 6c), pentagonal connectors (e.g. Fig. 6d), and the pins (e.g. Fig. 6e)for download, allowing their 3D printing. Victor Willson, an assistant engineer on the INTERAQUATICA project, designed the covers to seal the connectors (e.g. Fig. 5b).

We use manual tools for wood preparation, such as hammers, crowbars, pliers, and electric instruments, such as electric saw, drill, and milling cutter (e.g. Fig. 3a).

The design of the virtual elements was made and rendered in Blender, and Unity was the program used to build the ARDome App. We used Adobe

[19] https://buildwithhubs.co.uk

Illustrator to design the posters, pictograms, QRCode, interactive elements, and MDF triangles. The mobile phone is an indispensable technology, the link between the user, Augmented Reality marine species, and the Dome (the aesthetic element that attracts this activity).



(a) (b) (c)

Fig. 5: (a) Hexagonal connector PLA 3D printing. (b) Cover connector PLA 3D printing. (c) Connector sandwich.

3.3 3D printing of joints, covers, and pins

Connectors (e.g. Fig. 5a)and pins were 3D printed on Ultimater Original and Blocks MKII, using polyethylene terephthalate glycol-modified (PETG) filament, water-resistant, smooth surface, economical, much more ecological, and easy to print [41]. Each hexagonal and pentagonal connector has $5,5cm$ in diameter and $1,5cm$ height, and a hole in the center with a diameter of $0,5cm$ takes appx. $45min$ to print. Pins are $3cm$ long, $1cm$ in diameter, with a hole in the center with a diameter of $0,5cm$, and printed on approx $13min$. Covers (e.g. Fig. 5b) have $5,5cm$ in diameter, and $0,5cm$ height, with a hole in the center with a diameter of $0,5cm$ printed in $25min$, and used to block the pins in the connectors using screws, washers, and nuts (e.g. Fig. 5c).

3.4 3D Modelling

Following previous work [29], 3D modeling of the megafauna previews developed and giving domes a new purpose, adapting it to this study focus on

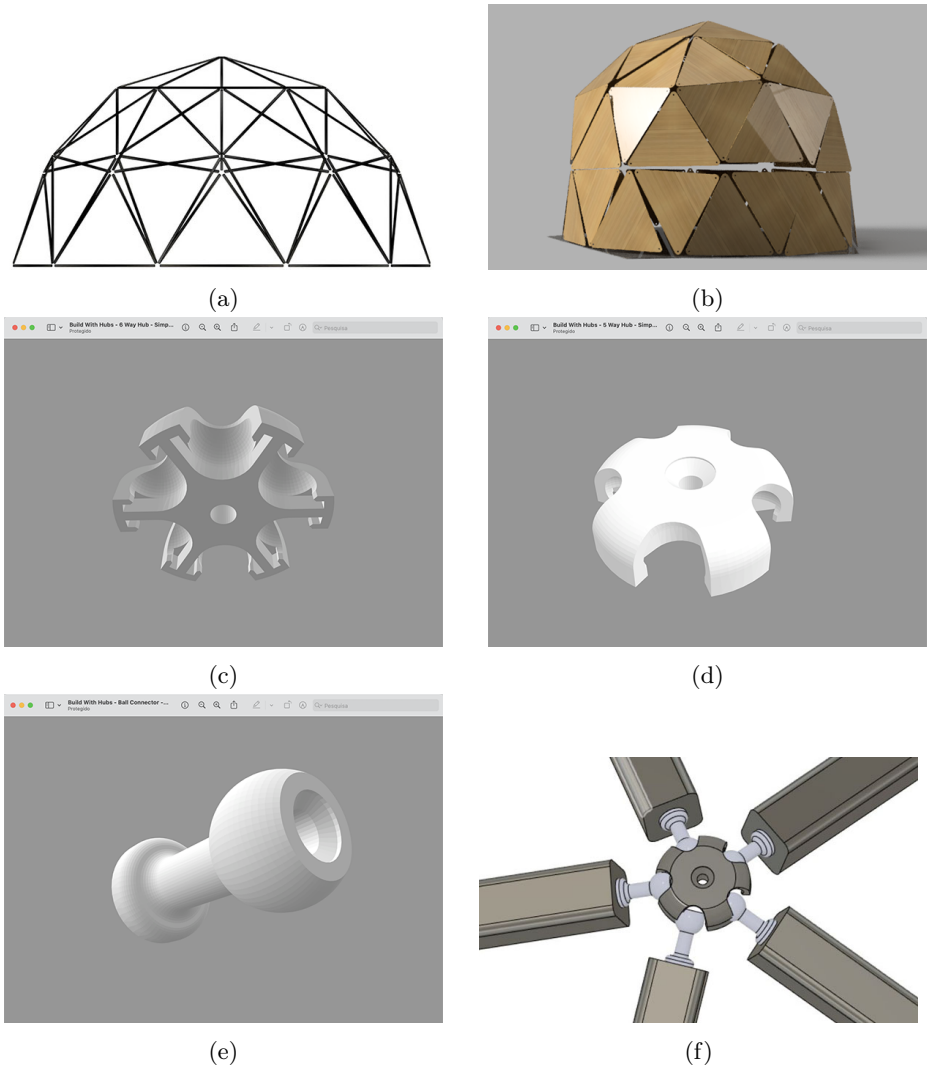


Fig. 6: (a) 3D 2V Dome. (b) 3D Render Dome. (c) 3D Hexagonal Connector. (d) 3D Pentagonal Connector. (e) 3D Pin Connector. (f) Connector with wood slats.

building the Dome structures in land for direct interaction with general users. In the project's first stage, the goal is to implement the envisioned 5 (five) geodesic structures in the shape of megafauna species in their habitat. The Autodesk Fusion 360 program is deprecated for component and dome modeling.

The geodesic structure was modeled virtually, initially in its original dome form, and then appendices were added that transformed it into the intended marine species. The wood of two lengths is drawn and then gradually arranged to form the Dome. We made two 3D versions of the structure (e.g. Fig. 6a), one with the wood and another with the timber and pins connected to the connectors (e.g. Fig. 6b). We were not able to make all the connections with the corresponding connectors. The modeling of the connectors followed the geometric shapes necessary for the construction of the Dome. We need two types of connectors, Hexagonal (e.g. Fig. 6c) and Pentagonal (e.g. Fig. 6d). Pentagonal connectors are used on the top of the structure and the sides and connect the smaller slats. We use Hexagonal connectors at the ends of shorter woods, and after connecting with more extensive woods, they form the pentagonal figure (e.g. Fig. 6f). The pentagonal and hexagonal covers aim to attach the slats to the connectors using the pins (e.g. Fig. 6e), also modeled in 3D.

3.5 Geodesic Structure Covering

The MDF boards we use are purchased and measure 120x60x0, $3cm$. From each, we cut two (2) triangles (e.g. Fig. 8a). The machine we use to make the cuts is the Universal laser System, and without engraving, it costs approximately $3min$. The Cut and graving take approx $45min$. Each MDF triangle has the particularity of having engraved, on one side, ARDome QRCode (e.g. Fig. 8b), icons, and symbols (e.g. Fig. 8c) that call attention to the preservation of species and the environment. It is placed in an MDF circle with an engraved QR Code ARDome application at the entry of the dome. After downloading the app, users can interact virtually with the structure. Each vertice of the triangles has a 1cm diameter hole and ties a natural and biodegradable string of natural fibers to the closest connector of the dome. The application of triangles was started upwards from the lower sections and circumvented the structure to cover it. We use 68 MDF triangles that weigh $650gr$ each, a ladder to reach the higher spaces, natural fiber thread for the moorings, and scissors. For safety and comfort reasons, two individuals performed the task. Once completely covered, the dome offers protection from sunlight and shade that favor the interaction activity.

(a) (b)

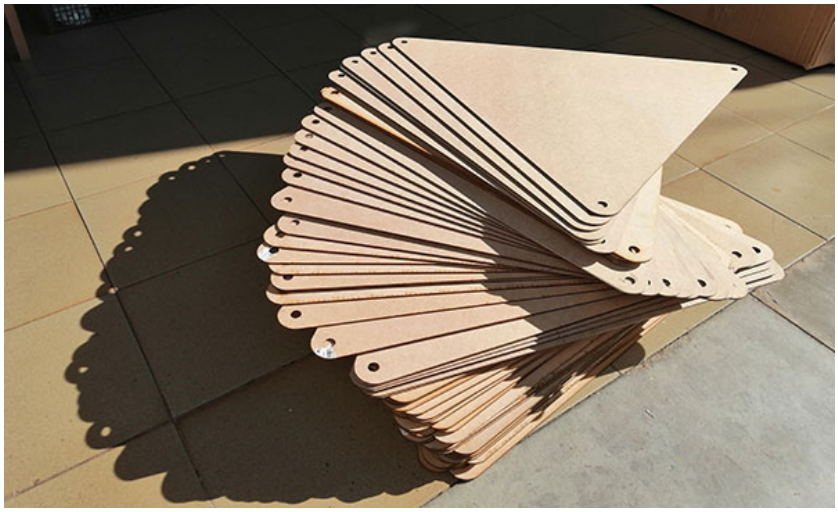
(c) (d)

(e) (f)

Fig. 7: (a) Dome building. (b) Appendices construction. (c) Turtle Dome. (d) Dolphin Dome. (e) Whale Dome. (f) Smaller geodesic Dome.

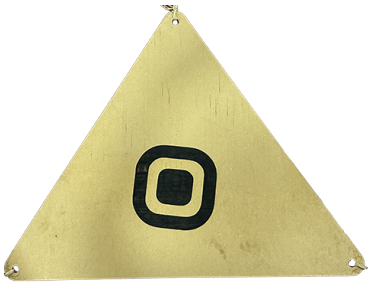
3.6 Geodesic Structure Experiments

During the entire development process of the Geodesic structure, we conducted user studies to analyze its effectiveness and measure audience interaction. The collected information allowed us to understand and evolve the project. The



(a)

(b)



(c)

Fig. 8: (a) MDF triangles cut. (b) ARDome QRCode. (c) MDF interaction Info-graph.

form underwent modifications, and we redesigned and reinforced the wood and connectors. We added interactive elements to the structure itself, giving it a new purpose in the interactive experience.

3.7 Exp 1 - Open Geodesic Marine Species

In the initial phase, we conduct the tests in the open domes. The structure was open to the elements, only with the slats. The Dome had considerable dimensions that allowed the free movement of users inside it during the experience of the ARDome Turtle App.

3.7.1 Seabird

The first construction we did was the seabird (e.g. Fig. 7a), the seagull. It showed us the difference between a two-dimensional 3D scheme and manual work. While in 3D design, everything is very linear, the success of the physical construction of the structure depends on several factors, physical (available spaces, materials, and individuals), emotional, and creativity. We have the constraints of wood, there are two different lengths, and if they can break, the connectors differ between hexagonal and pentagonal, the pins can be difficult to fit into the supports and consequently break, and the difficulty in erecting the structure itself. We followed a clear plan to build the dome, but the transformation into an animal species depended exclusively on creativity and tirelessly repeating the construction. Making the structure look like the intended animal is the most challenging part and reflects the success of the process. We erect appendices on the sides of the dome, which are wings. The size and weight unbalance the structure and threaten to collapse, which happens days later due to rain and wind, and encourages us to review the design and safety (e.g. Fig. 7b).

3.7.2 Sea Turtle

We chose the University of Madeira atrium to build the turtle geodesic structures. The available space and the number of pedestrians are an asset and an excellent opportunity to measure user interaction and project success. The building of the Dome starts with the placement of the pentagonal connectors and the fixation of 5 simple strips of short wood. This first Penta is the center of the Dome. Hexagonal connectors are fixed and connected with long wooden slats on the other sides of the strips. A simple Dome is composed of 5 Pentagons that intertwine to form an oval shape. To heighten the Dome is added a set of long woods to the base of the structure, allowing the free movement of users inside. The Dome is the shell, and the creative part of the transformation into the marine species starts with the addition of wooden slats. The turtle's head is appended in front of the Dome. The tail and fins are the last parts to be fixed to the structure. By analyzing the first study and following user feedback, we felt the need to make the structure and experience more interactive, engaging, and personal, so we added the MDF triangles (e.g. Fig. 7c).

3.7.3 Dolphin

The dolphin was the next step in constructing the 5 (five) domes of marine megafauna. The construction of the main structure is identical for all Domes. It all starts with assembling the top pentagon, interconnecting 5 (five) other pentagons with each other, forming the Dome. We added wood slats, and the muzzle formed in front of the structure—raised tail from the posterior end base of the Dome and finalized with the side and back fins. Once we finish the structure's skeleton, we remove a horizontal wooden slat from the front, forming a diamond to allow the entry of users during the interactive experience (e.g. Fig. 7d).

3.7.4 Whale

Following the construction of the Domes, the whale(e.g. Fig. 7e) was the third construction. We erect the polyhedron composed of six pentagons, five of which are vertical and one of which is top. The customization of this 2V structure (two vertices) will transform it into a whale. The customization of the whale tail begins with the sandwich placement of the central and lower rear connectors. This new way of connecting the connectors is due to the improved maneuverability of the woods, added security, and ease it provides. Between the connectors, we placed the caps, and a long screw holds them in a sandwich shape using washers and wing nuts. We started using this new connector placement system on all structure extensions with multiple connections, tails, fins, and appendages.

The worst weather conditions of December 2021 caused the collapse of the previously erected dome, so we stopped the construction.

3.7.5 ARDome AR App - Turtle Mode

The user downloads ARDome from App Store (only available for Android devices). We engrave The QR Code on the poster (e.g. Fig. 18c) and in the MDF circles duly placed on the floor in front of the Dome. We place the QRCode in front of the square traced on the floor, on AR experience, which delimits the activity space. Once installed, the home screen presents four buttons: Play, Did you know, About, and Instructions (e.g. Fig. 18d). The "Play" button gives access to the game/activity. "Did you know" control offers information about the species, its importance, and its contribution to the

ecosystem? "About" explains the ARDome project and the interactive experience based on geodesic structures to raise awareness of marine conservation and how they affect the ecosystem. Finally, the "Instructions" explain how to use the App. The experience ends with releasing the turtle, initially trapped in fishing nets at the entrance to the cave. The turtle goes swimming after collecting ten (10) pieces of garbage inside the cave (e.g. Fig. 9e).

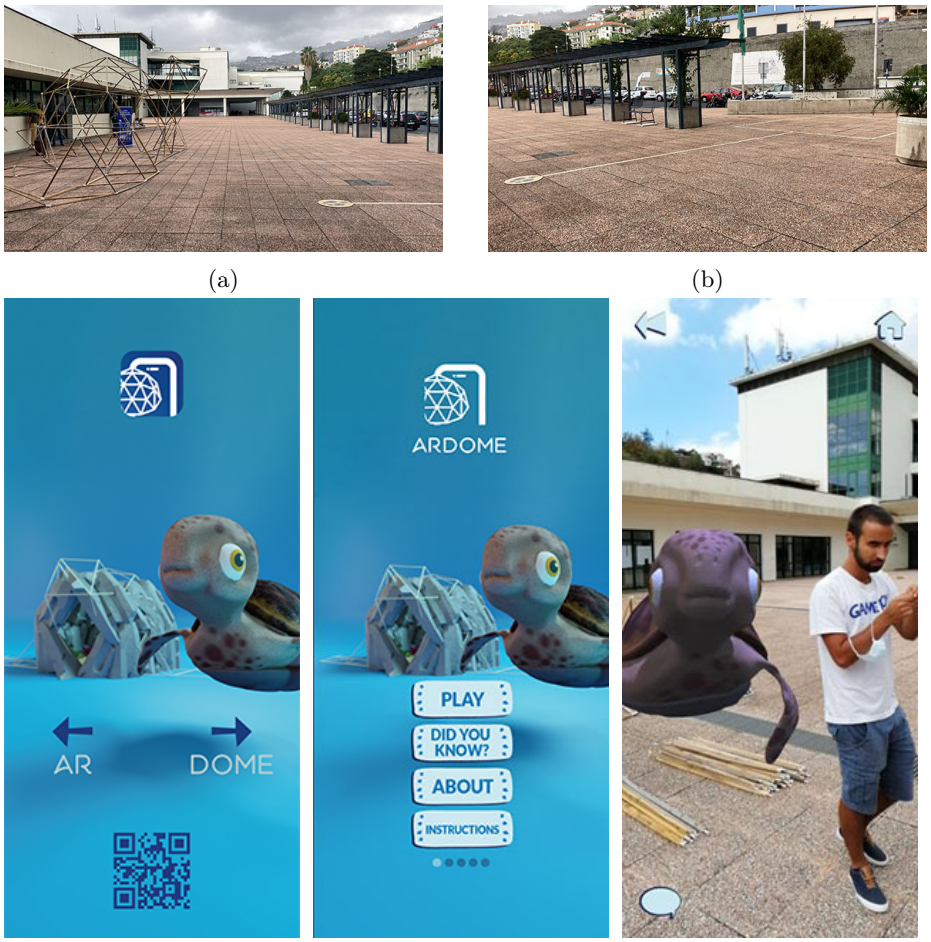


Fig. 9: (a) Turtle experience with Dome. (b) Turtle Experience without Dome. (c) App ARDome Turtle. (d) App ARDome Turtle initial screen. (e) Augmented Reality Turtle experience.

3.8 Exp 2 - Closed Geodesic Marine Species

(a)

(b)

(c)

Fig. 10: (a) Turtle Dome covering process. (b) Covered Dome Interior. (c) Smaller Dome covered with interaction elements.

As part of the 2021 Macaronight activity, we presented the ARDome project. It uses a geodesic structure of a marine megafauna species, the Turtle (e.g.

Fig. 10a), in conjunction with a mobile application / didactic and informative AR game and aims to free a sea turtle trapped in a fishing net. In this activity, the most registered feedback from users is related to the uncovering Dome, without privacy, open to the elements, and that the clarity and brightness limited the experience.

Following the users suggestions, we idealized the use of MDF to cover the structure (e.g. Fig. 10b). The choice of this material is exclusively due to its durability and ease of handling. The design made using Fusion 360 allows us to envision the model and appearance of the Dome virtually.

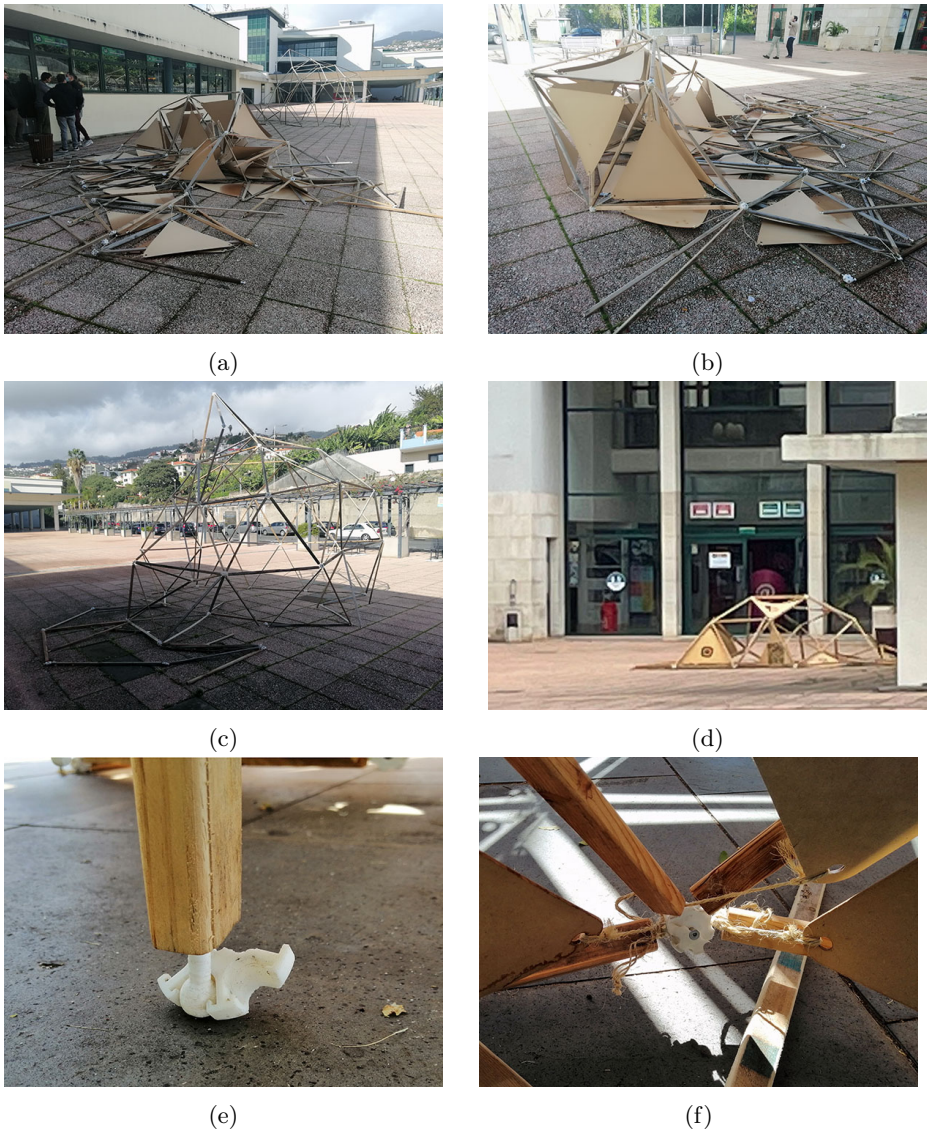
We purchased MDF boards with dimensions of 120x60cm, which allowed us to cut 2 (two) triangles. At each end of the triangles, we drill a 1 cm hole in diameter, allowing us to pass a wire. A biodegradable wire measuring approximately 30 cm attaches the MDF triangles to the Dome connectors.

We filled open spaces with MDF triangles, and the Dome was covered entirely. The roofing process starts from the base of the structure to the top (e.g. Fig. 10c). Once covered, the Turtle Dome underwent a new user test.

3.8.1 Collapse

December was a month with bad weather. Strong winds and heavy rains caused the collapse of the structure (e.g. Fig. 11a). The previously covered turtle, dolphin, and whale dome are in the final stage of construction. This event made us stop and review the level of security they offered. Domes are interactive objects we intend to make available to the general public to raise awareness of marine and species constraints and issues, so safety is a requirement (e.g. Fig. 11b).

When removing the collapsed structure, we had to untie the wires that held the MDF triangles to the connectors. Water and win cracked some connectors and pins. Broken wood, mainly in weak spots, and ends with broken screws or completely torn off. The MDF triangles had an excessive weight due to the accumulated rainwater. It is noticeable the weather conditions and rain were the reason for the collapse of the Dome, along with the force of the wind, which, being so vital, turned the MDF triangles into sails and helped to break the structure. The weight was relevant for the collapse of the structure. Evident compared to the other Dome erected a few meters away. Dolphin was



(a) (b) (c) (d) (e) (f)

Fig. 11: (a) Whale Dome collapse. (b) Whale Dome collapse. (c) Dolphin Dome collapse. (d) Smaller Dome collapse. (e) Broken connector. (f) Broken connectors.

built only with wooden slats and had only a few broken planks of wood, which are not vital for the collapse of the structure (e.g. Fig. 11c).

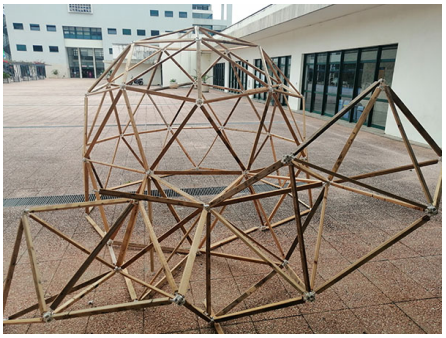
Decreasing the size of the wood and the subsequent decrease in the size of the structure, maintaining the thickness of the wood, we thought the weight was not relevant for safety, and we lifted the Dome again. It collapsed, despite not being completely covered (e.g. Fig. 11d). It was easy to find weaknesses: a broken connector (e.g. Fig. 11e) and a wooden batten broken into a knot. Two weak points made the entire structure break (e.g. Fig. 11f).

3.9 Exp 3 - Smaller Closed Geodesic Marine Species

Based on previous experiences, we focus on the dimensions of the structure. We deduce the constraints and insecurity owing to the wood length and lower quality of the slats. Some woods broke at weak points, such as knots, ends, connectors, pins, and screws. We returned to the computer and reduced the wood's size in this new version of the Dome. We used the $97cm$ slats for as long as possible and decreased the size of other shorter slats to $85cm$. We deduced that the reduction of the structure would increase the safety and took the new construction in progress in the patio between the building of the University of Madeira and the building of Madeira Tecnopolo (e.g. Fig. 7f).

We built the whale dome using redefined wooden slats. Visibly reduced in dimensions, compared to previous structures, but much more robust. Making the tail was a challenge. It collapsed a couple of times, and we had difficulty getting a satisfactory identity result. We aim to make the tail come out from the base of the structure and extend beyond the dome's height in the same way that the bottom emerges from the ocean. We were unsuccessful a couple of times. Adding wooden slats increased the structure's weight, and in the case of the tail, as all its weight where concentrated in three dome connectors, we needed more solid and precise support. The connectors could not support the weight of the extension and repeatedly broke. So we had to redefine and redesign the tail and downsize and, as such, compromised its appearance. The whale's tail frequently confused the structure with a snail, in the opinion of passersby. Students from a school in São Miguel, Azores Islands, where we had the opportunity to present the project, were unanimous in identifying the species - Whale - once they identified it with the whale rock existing in São Miguel (e.g. Fig. 19b).

(a)



(b)

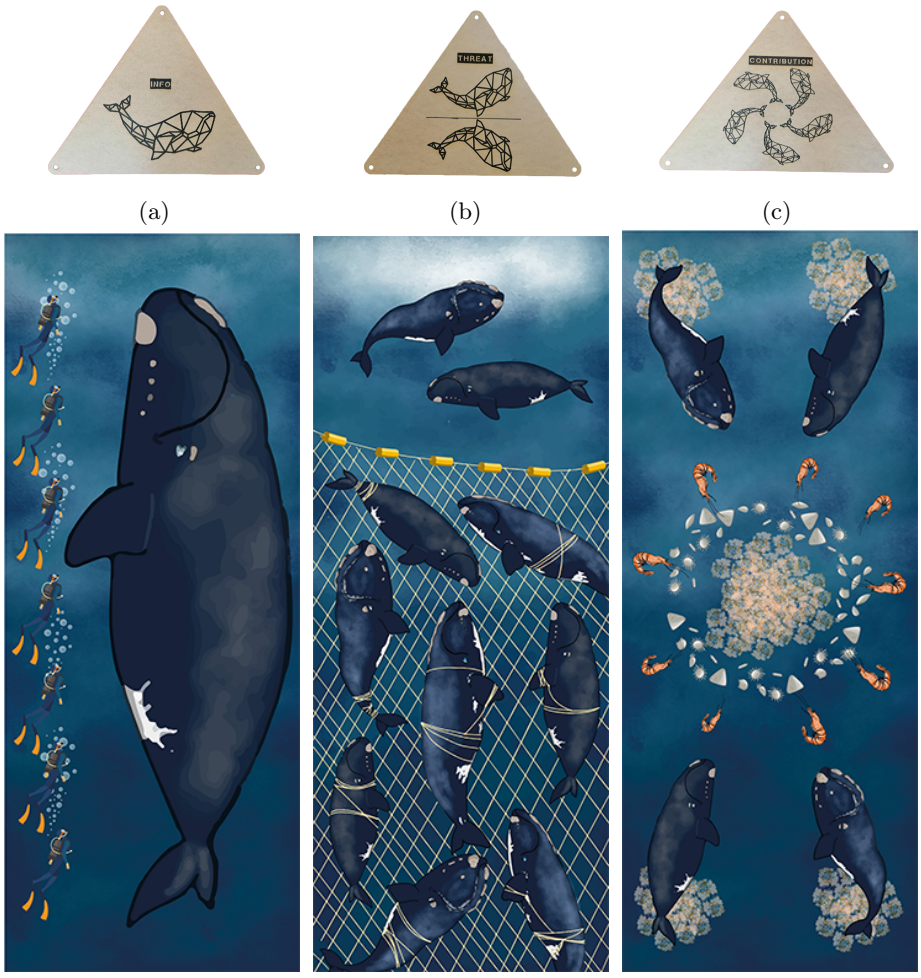
(c)

(d)

(e)

(f)

Fig. 12: (a) Smaller Dome. (b) Assemblage of smaller whale structure. (c) Smaller dolphin Dome. (d) Smaller Closed Dome. (e) Whale Dome construction. (f) Covered Whale Dome.



(a) (b) (c)

(d) (e) (f)

Fig. 13: (a) MDF Info trigger. (b) MDF Threat trigger. (c) MDF Contribution trigger. (d) Info Poster. (e) Treat Poster. (f) Contribution Poster.

3.10 Exp 4 - Smaller Closed Geodesic Marine Species in Wider Public

The constraints we went through led us to rethink the structure. It proves that the installation needed to be safer to leave in an urban environment available to the general public. Decreasing the size of the wood and increasing its thickness adds strength and security to the entire structure. The new dimensions of the Dome offered us greater robustness. However, the smaller

(a)

(b)

(c)

Fig. 14: (a) Assembling process of Whale Dome in Praça do Povo. (b) Fin building of Whale Dome in Praça do Povo. (c) Whale Dome in Praça do Povo interaction.

sizes reduced space availability and made it difficult to circulate inside, so we impaired the interactive activity (e.g. Fig. 14a). For the activity of Ciencia Viva, the structure was available for five working days without surveillance

between 17:00 and 10:00 the next day. The Ciencia Viva activity took us to Praça do Povo in downtown Funchal in July 2022 (e.g. Fig. 14b). This activity aimed to show the happy combination between the geodesic structure of the whale and the ARDome App developed to offer the cycle life of whales, to inform about their importance for the ecosystem, and to alert them to the dangers they face, namely concerning fishing nets (e.g. Fig. 14c).

It was imperative to leave the Dome completely covered by Mdf panels, making it impossible to enter the structure and ensure it would not vandalize. For this activity, we designed the frame covered with Mdf panels, and some of these panels would have engraved pictograms, visual elements, and QR codes that would lead the user to the ARDome App download page. We intend to measure the interactivity of traffickers with the Dome in a public space. The structure exposed to the outside has the purpose of instilling interest and action in the users without needing help. The interaction analysis took place in three ways: by the interest shown by users about the Dome, by the number of downloads, and by the study of AR activity.

3.10.1 QR Poster Design

The posters vectorized using Adobe Illustrator are elements of augmented reality presented in the interactive experience. The main feature of the signs is the North Atlantic Right Whale, and secondary details differ depending on the information we want to convey. The Info poster (e.g. Fig. 13d) shows the approximate size of the whale about the diver. The Threat poster (e.g. Fig. 13e) indicates the number of whales caught by fishing nets during their lifetime, and finally, the Contribution poster (e.g. Fig. 13f) shows us who eats who, in this cycle North Atlantic Right Whale Life.

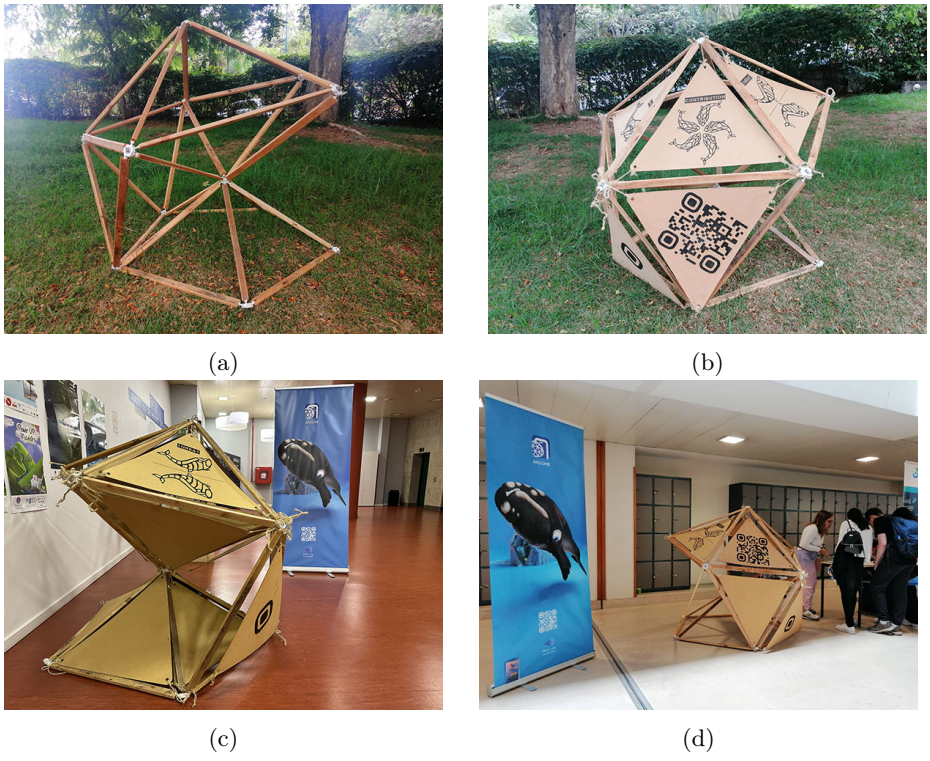
For this experience, we combined a structure covered by MDF panels, some with printed elements, such as QRCode that gives access to the ARDome App; three Info-graphs, Info (e.g. Fig. 13a), Threat (e.g. Fig. 13b), and contribution (e.g. Fig. 18c); and finally, decorative elements, without any interference in the interactive experience. These infographics serve as a trigger for informative posters that appear in augmented reality to the user during the activity.

3.10.2 ARDome AR App - Whale Mode

The experience consists of using a mobile phone to scan a QR Code printed on the MDF panels that cover the Dome and provide an interactive augmented

reality experience. We invite users to install the ARDome App. After answering the first questionnaire about the life of whales, he had the augmented reality experience by reading the pictograms printed on the Mdf triangles. Posters virtually immerse themselves in the cell phone screen with information about this species of mammals of the cetacean family. The experience continues with the questionnaire that makes it possible to correct the answers that could initially raise doubts. It ends with the presence of a whale in augmented reality floating on the mobile device's screen.

3.11 Exp 5 - Smaller Geodesic Structure



(a) (b)

(c) (d)

Fig. 15: (a) Smaller structure construction. (b) Smaller structure cover process. (c) Small structure covered with MDF triangles. (d) Smaller Structure on Macaronight 2022.

While a geodesic structure for the Turtle ARDome activity was necessary, it was not for the NARW experience. We can be creative in building the new

construction because the action depends on reading pictographic triggers placed on it. Of course, it follows the same principles of appealing design and security. The structure redesign has the usability purpose in the Macaronnight of 2022 in the interior space of the University of Madeira (e.g. Fig. 15d). The fact that the ARDome Whale App uses the infographic triangles that we place outside the structure as triggers mean that it does not need to follow the geodesic dome format, which is why we have freedom of construction. We built the new system in the shape of a regular polyhedron that brings us back to childhood memories. The spinning top is a toy that cuts across all generations, gender, age, and social class, which is why, in our view, it is effective in interacting with users (e.g. Fig. 15c). We used three pentagons in the structure's design, two connected at the ends in a diamond shape and a third used as a base (e.g. Fig. 15a). The frame, reinforced with wooden slats, secures the lot of the rhombus to the bottom and strengthens security. After being built, the form is covered with MDF triangles with infographics and QRCode to make the structure more attractive and appealing (e.g. Fig. 15b).

(a) (b) (c)

Fig. 16: (a) Project presentation to High school Students from Açores Island. (b) Project presentation to Order of Engineers Group. (c) Project presentation on Macaronight 2022.

3.12 ARDome Experience Validation

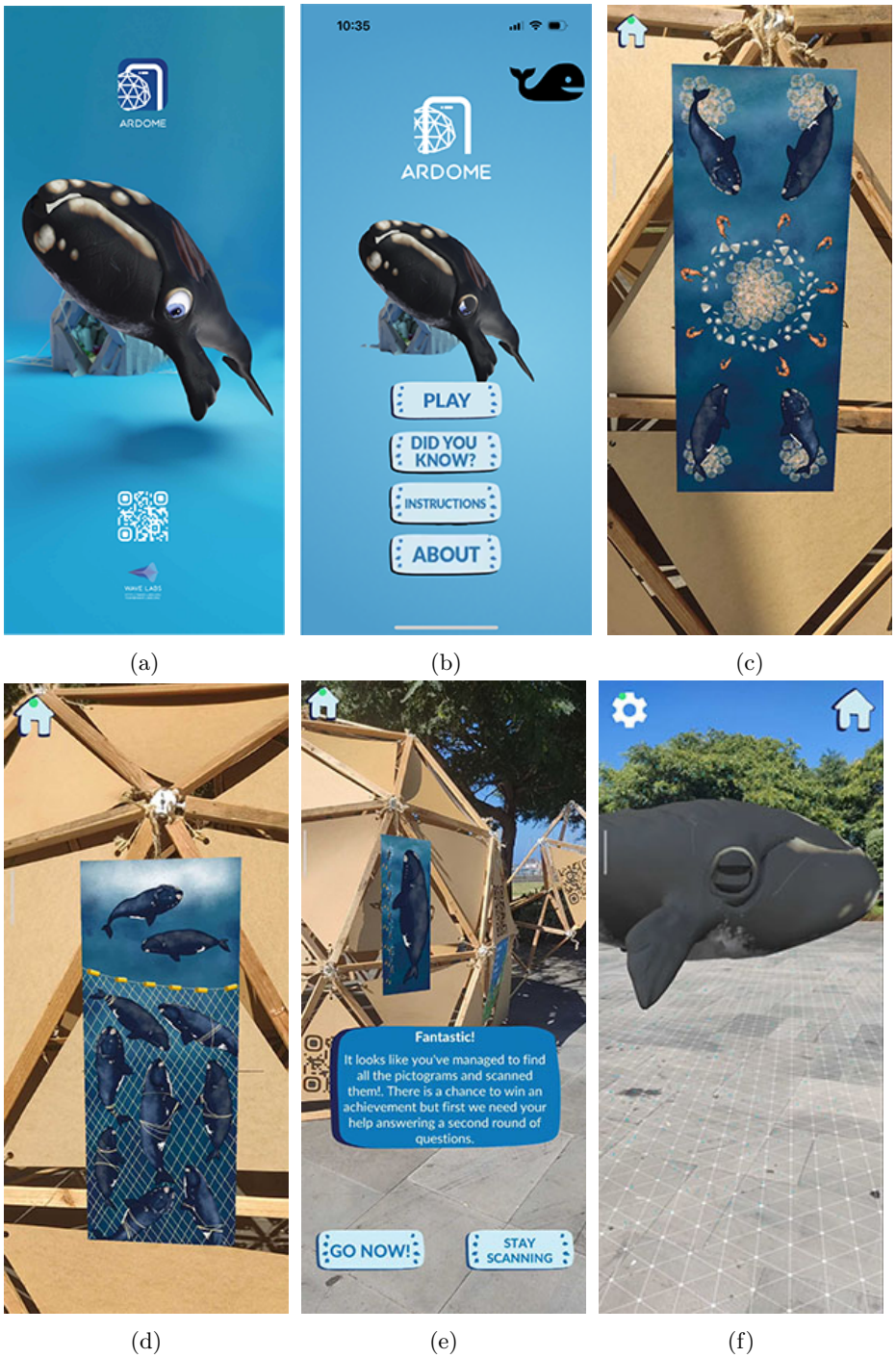
We participate in several school educational activities with high school classes, university education, and presentations of research projects developed by ARDITIT. In these activities, we show the importance and the interconnection of the geodesic structure with the ARDome application to call users' attention to marine issues and have their feedback on the Dome and the Augmented Reality experience. Meanwhile the initiative, we invite users to answer a

questionnaire that measures the interest, importance, and usefulness of the experience and structure.

Graciosa Basic and Secondary School, Santa Cruz da Graciosa, Ilha Graciosa - Azores. A group of 24 students from the 12th grade from the Graciosa Basic and Secondary School, Santa Cruz da Graciosa, Ilha Graciosa - Azores, participated in the ARDome activity in the scope, Citizenship, and Development area has been developing over the three (3) years of Secondary Education. The "Literacy of the Oceans" project," culminates in a visit to Madeira island and Madeira Oceanic Observatory. Have participated in the ARDome activity on the 4th of July, 2022, in the atrium of the University of Madeira (e.g. Fig. 16a).

The visit of some members of the national management and the regional coordination of the North and Center of the College of Informatics of the Order of Engineers to the Arditi facilities allowed us to present the ARDome (e.g. Fig. 16b). Part of the INTERAQUATICA Project, which aims to design and produce interactive experiences based on geodesic structures inspired by species of marine biodiversity relevant to our ecosystem, as a way of increasing society's awareness of the importance of marine and species conservation for the common good, preventing ecological collapse.

We participated in the 2022 Macoronight activity (e.g. Fig. 16c), a European project for disseminating research projects to bring Macaronesian researchers closer to citizens to make their work known on the -1 floor of the University of Madeira. Due to the limited available space, we had to redesign and redefine our interactive structure. This experience was inspired by the North Atlantic Right Whale, whose objective is to raise awareness of marine conservation issues that affect species and the ecosystem resulting from anthropological activities, for which we are all responsible.



(a) (b) (c)

(d) (e) (f)

Fig. 17: (a) App ARDome Whale. (b) ARDome Whale Initial Screen. (c) Scanning Info info-graphic trigger. (d) Scanning Threat info-graphic trigger. (e) Scanning Contribution info-graphic trigger. (f) Augmented Reality Whale experience.

4 Results

The dissertation describes the results obtained from user tests and experiments conducted.

4.1 User Tests

We started the ARDome activity in September 2021 and extended it until October 26, 2022. We used consent forms to collect users' acceptance of participating in the studies. Students from the University of Madeira, primary and secondary school students, the general public, children, adults, scientific and academic community participated in the tests.

We obtained the results from several studies carried out in different stages of development of the project, the geodesic structures, and the ARDome app. We started user tests with the structure of the marine species uncovered. First, we tested the framed Turtle Dome erected on the Universidade da Madeira patio. Second user test, we evolved into the covered Turtle Dome. We redesign the Domes and marine megafauna species in the following user tests. The structure was assembled and tested in Praça do Povo, Funchal, a trendy public place, which aroused immense curiosity and interaction. We tested the ARDome App development and transformed the structure giving it a new purpose in the interactive experience. It is exciting to work on, and it is in continuous development.

4.2 Experiment 1 - Open Geodesic Marine Species

We did the first user test on the University of Madeira patio during the Macaronight activity of 2021. We present the structure of the turtle and a square marked on the floor in front of the Dome. The test consisted of doing the activity of the Turtle's ARDome App inside the Dome, repeating it outside, in the square delimited on the floor, and measuring the interaction and interest of the user.

Participants completed a survey before and after the activity. We used this questionnaire to measure the mood and emotional state of the participant. We collect data on nationality, gender, age, and the quality of the experience. Bearing that certain factors are relevant and impact the evaluation, we attempt to measure their impact on the user.

We describe the ARDome as an Interactive Augmented Reality Experience inspired by endangered marine species, and we design it to enroll attention to the ongoing ecological issues. By completing a provided form, users automatically agree to participate in the anonymous study and provide the necessary personal data, which would be processed and used to evaluate the experience. At any time, users can stop voluntary research. There were no correct answers, and they should reflect users' opinions. We divide this study into two forms, Pre (e.g. Fig. 18a) and Post (e.g. Fig. 18b) experiment. In this user test, we are interested in understanding the Dome's influence on the ARDome App's interactive experience, and it is in our interest to find answers to the following questions:

4.2.1 Q1 - Were participants pleased by the ARDOME experience?

We use the AR app within the DOME as an experience in the first question. Users using a mobile device download the ARDome App. In front of the Dome, at the stipulated distance, the user's camera is pointed to the defined space, and virtually, the structure becomes a cave. A turtle covered with a fishing net hovers at the entrance to the Cave. This game/interactive experience aims to release the turtle after collecting all ten garbage specimens inside the Cave. Once released, the turtle emits sounds of contentment and swims away, accompanied by the user.

The Dome delimits the experience space, emphasizing the interactive environment. Built with the appearance of a Turtle, the organic Dome with considerable volume is appealing, conveys lightness, and reflects serenity. The geodesic Turtle dome is a space that transmits a feeling of warmth, welcome, and well-being. It is an ample space that conquers the user and increases the sense of comfort and security. Whose main objective is to guarantee the satisfaction and well-being of those immersed in the augmented reality experience.

We compare emotional states before and after the experience. Our sample size is 20 participants from two independent groups. We used a two-tailed test to determine if there is any emotional state difference in pre- and post- among two groups of users. We find that the averages diverge between both groups. The analysis of the users' responses shows an emotional difference in the pre and post-stages of the activity. There is an improvement in the emotional state provided by the experience inside the Dome (e.g. Table. 1).

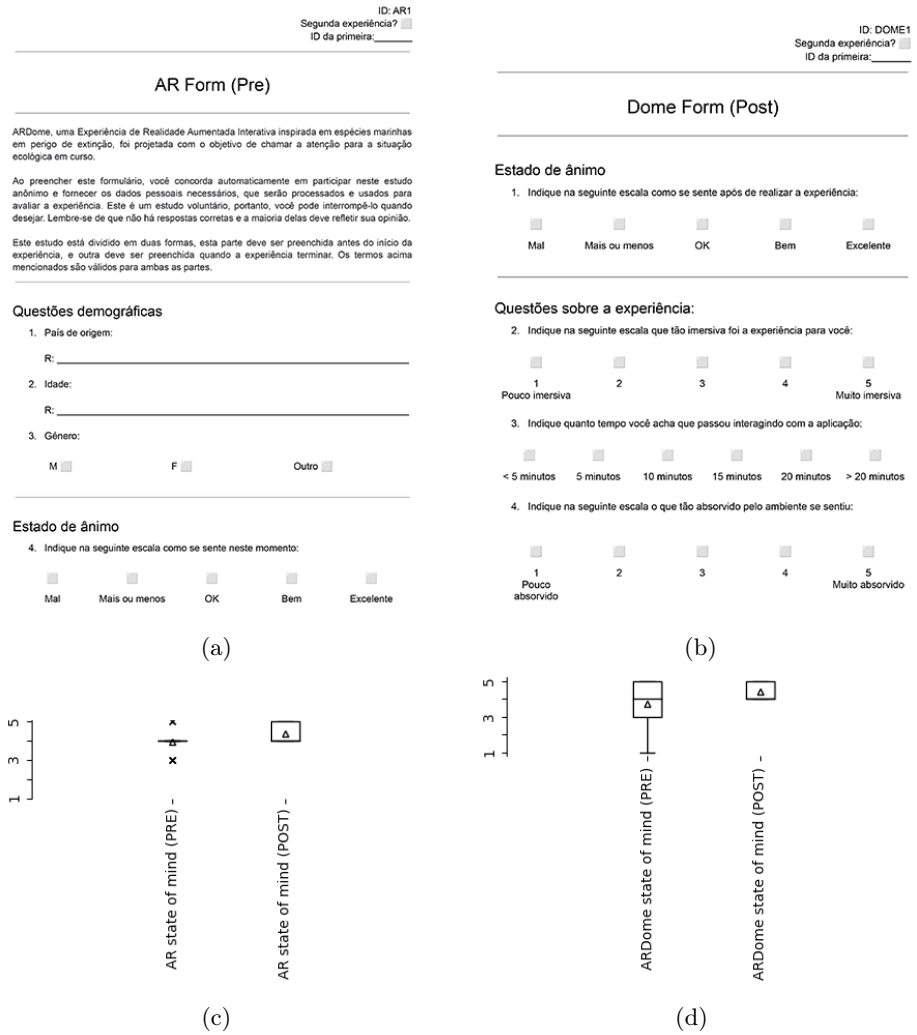


Fig. 18: (a) AR Pre-Form survey. (b) ARDome Post-Form survey. (c) AR Pré-Post state of mine results. (d) ARDome Pré-Post state of mine results.

The graphics (e.g. Fig. 18c) and (e.g. Fig. 18d) show the user's emotional state analysis. In the fourth question of the pre-activity survey, we asked users about their mood and rated it on a scale of 5 different emotional states. In the post-activity questionnaire, we repeated the same question in field number one. We evaluate the state of mind according to the emotional difference registered by the users in the questionnaire. In the AR and ARDome activity, we have a

neutral state of mind in the Pre-questionnaire, and the Post-questionnaire shows us an emotional difference through the alteration of the graph.

Comparing pre vs post within ardome as pleasure

	PRE	POST
Mean	3.75	4.25
Variance	1.460526316	0.8289473684
Observations	20	20
Pearson Correlation	0.8251204038	
Hypothesized Mean Difference	0	
df	19	
t Stat	-3.248931448	
P(T<=t) one-tail	0.002111925466	
t Critical one-tail	1.729132793	
P(T<=t) two-tail	0.004223850933	
t Critical two-tail	2.09302402159635	

Table 1: t-Test: Paired Two Sample for Means showed statistical significance ($p<.05$), suggesting that people changed their emotional state when participating in this experience.

4.2.2 Q2 - Were participants pleased by the AR?

We use an AR app without the DOME experience in the second question. The AR activity without the geodesic structure took place with the delimitation of the activity space on the floor using adhesive tape. The procedures followed the same as for the dome activity. At a preset distance, the user points the mobile phone's camera at the limited space, and a virtual cave appears on the mobile phone's screen. The shelter opens as the user approaches, and he emerges in the garbage collection activity for the release of the Turtle. We faced a considerable number of users exceeding the limited space, which contributed to the failure of some experiences and some discomfort for users. We compare emotional states before and after the activity. Our sample size is 20 participants from two independent groups.

Despite some constraints, the AR activity without using the Dome improved users' emotional state between the pre and post-interactive experience. This study shows that the AR mobile application interferes and positively changes the user's emotional state. On the Paired Two Sample t-Test we have a statistical significance because the p value is lower then 0.05, suggesting that

the AR interferes and positively changes the users emotional state comparing previous and post-state in the experience.

The interactive experience per se with the Turtle covered by the fishing net at the entrance to the virtual cave encourages the user to participate. The shelter opens on the mobile device screen. Once inside, the fish and the marine environment come to life. The user has a leading role in collecting the garbage floating on the floor, hidden behind the rock, and is responsible for releasing the Turtle. As in the Pokemon Go game, the release of the Turtle is the users' responsibility(e.g. Table 2).

Comparing PRE vs POST within AR as pleasure

	PRE	POST
Mean	3.95	4.4
Variance	0.2605263158	0.2526315789
Observations	20	20
Pearson Correlation	0.4923659639	
Hypothesized Mean Difference	0	
df	19	
t Stat	-3.942772444	
P(T<=t) one-tail	0.0004365969623	
t Critical one-tail	1.729132793	
P(T<=t) two-tail	0.0008731939246	
t Critical two-tail	2.093024022	

Table 2: t-Test: Paired Two Sample for Means showed statistical significance ($p<.05$) suggesting that people changed their emotional state when participating in this experience.

4.2.3 Q3 - Did DOME influence the emotional state?

In the third question, we use AR and ARDOME as experiences. Although there are emotional changes after each of the AR and ARDome experiences, we did not notice significant changes in their emotional states after a particular activity. The geodesic structure produced little changes in the users' dynamic(e.g. Table. 1). Our sample size is 20 participants from two independent groups. On the Paired Two Sample t-Test we have a statistical significance because the p value is lower then 0.05, suggesting that the ARDome interferes and positively changes the users emotional state comparing previous and post-state in the experience.

Comparing emotional state using ARDome vs AR

	ARDome	AR
Mean	4.25	4.4
Variance	0.8289473684	0.2526315789
Observations	20	20
Pearson Correlation	0.1150109266	
Hypothesized Mean Difference	0	
df	19	
t Stat	-0.6789082722	
P(T<=t) one-tail	0.2526912479	
t Critical one-tail	1.729132793	
P(T<=t) two-tail	0.5053824959	
t Critical two-tail	2.093024022	

Table 3: t-Test: Paired Two Sample for Means did not show a statistical significance ($p>.05$), suggesting that the dome did not make an effect on participants when participating in this experience.

4.2.4 Q4 - How immersed were they in the experience?

In the fourth question, we compare AR and ARDOME as experiences themselves. We compared the immersive states of users after the experience, and we did not notice significant changes in their immersive conditions after a particular activity. As we see in Table 4, both activities were sufficiently immersive, and none stood out from the other. Our sample size is 20 participants from two independent groups.

4.2.5 Q5 - How absorbed were they?

We compare AR and ARDOME as experiences. Table 5 summarizes the users' absorption states after the activity. On the Paired Two Sample t-Test, we found no significant differences because the p-value is greater than 0.05. The result suggests that the dome did not affect the users' absorption state when participating in this experience with our sample size of 20 participants from two independent groups.

4.2.6 Q6 - Did the persons lose track of time spent on the activity?

We compare the time spent on the bough's activities, AR and ARDOME. In this study, reflected in Table 6, we note statistical significance in the time spent on each experiment. The experience inside the Dome was notably inferior to the AR. This study shows us that the physical limitations of the structure

Comparing immersive state using ARDome vs AR

	ARDome	AR
Mean	4.3	4.2
Variance	0.3263157895	0.3789473684
Observations	20	20
Pearson Correlation	-0.329276387	
Hypothesized Mean Difference	0	
df	19	
t Stat	0.4620423639	
P(T<=t) one-tail	0.324648878	
t Critical one-tail	1.729132793	
P(T<=t) two-tail	0.649297756	
t Critical two-tail	2.093024022	

Table 4: t-Test: Paired Two Sample for Means did not show a statistical significance (p>.05), suggesting that the dome did not make an effect on participants when participating in this experience.

Comparing absorption state using ARDome vs AR

	ARDome	AR
Mean	4.15	4.2
Variance	0.3447368421	0.6947368421
Observations	20	20
Pearson Correlation	-0.172072856	
Hypothesized Mean Difference	0	
df	19	
t Stat	-0.2034559793	
P(T<=t) one-tail	0.420470909	
t Critical one-tail	1.729132793	
P(T<=t) two-tail	0.840941818	
t Critical two-tail	2.093024022	

Table 5: t-Test: Paired Two Sample for Means did not show a statistical significance (p>.05), suggesting that the dome did not make an effect on participants when participating in this experience.

reduce the activity time spent, unlike the AR activity, where users lose the notion of space and lengthen the experience. Our sample size is 20 participants from two independent groups. On the Paired Two Sample t-Test we have a statistical significance because the p value is lower then 0.05, suggesting that the time spent on ARDome was lower than the time spent on AR.

Comparing time spent on ARDome vs AR

	ARDome	AR
Mean	1.85	2.45
Variance	0.9763157895	0.4710526316
Observations	20	20
Pearson Correlation	0.1823830137	
Hypothesized Mean Difference	0	
df	19	
t Stat	-2.449489743	
P(T<=t) one-tail	0.01208729852	
t Critical one-tail	1.729132793	
P(T<=t) two-tail	0.02417459705	
t Critical two-tail	2.093024022	

Table 6: t-Test: Paired Two Sample for Means showed statistical significance ($p<.05$) suggesting that people lose track of time when participating in this experience.

4.2.7 Field observations on ARDome Modality

ARDome was the most chosen, and it motivates teamwork. Users kept their positions at the center of the structure, but sometimes they felt free to move inside, looking for the trash they were missing. At least three people approached the Dome motivated by curiosity (two were participating in the study).

4.2.8 ARDome Modality Comments:

Below we list the obtained feedback from the participants: (i) "You should be considerate of the iOS users. We wish to have the app on our phones and interact with it."; (ii) "For a more immersive experience, you could cover the structure. I still see the people behind the structure. It would be better not to see them because the cave will be more realistic to our eyes."; (iii) "You should make this project a tourist attraction because the structures are beautiful. Make various of them so we can visit them in the future"; (iv) "You should do activities with schools and these structures. Kids will love the interaction and will learn about these subjects."

4.2.9 Field observations on AR Modality

Some users stopped at the entrance of the square. They received the indication that they were free to move in the space.

4.2.10 AR Modality Comments:

Obtained feedback regarding AR modality is further shown: (i) "The positive thing about doing without structure is that I can play again in my house.";(ii) "I suggest using this app on a tablet."

4.2.11 Team analysis

The team carried out an informal analysis, without following a pre-defined scale. We positively assessed the activity, where user feedback stands out with the interest shown. The activity had several unfavorable factors. The structure was erected in front of the University's main entrance in September, the beginning of the academic year when nobody knew each other. It became a hostile and intimidating environment for new students. The fact that we have a large number of individuals interested in participating in the activity, we concluded as being positive. We perceived that the light conditions and structure, open to the elements, make users feel insecure and uncomfortable. The AR activity without the geodesic structure makes the user feel lost because there are no physical limits, making the activity further challenging.

4.3 Exp 2 - Closed Geodesic Marine Species

In this experiment, we needed to evolve and develop the project. The next step that would be logical was to cover the structure giving it a new appearance and identity. Following user feedback regarding the first experience, we covered the Turtle Dome with MDF triangles. During the task, we analyzed the expressions of the traffickers who were interested, some of whom questioned us about the process and the structure's purpose. As part of the presentation of research projects by the MARE group, we presented ARDome. We showed the design structure and ARDome App evolution. The domes of marine species are only on wooden slats, and the wholly covered Dome of the turtle is with MDF triangles. We ask the audience about the Structures: (i) Which of the two domes is more appealing, slatted or covered with MDF? The response was unanimous. 23 out of 24 preferred the covered Dome; (ii) Which structure is easier to identify the depicted species? Again, 23 replies more easily identified the turtle species in the covered Dome. One of the participants wanted to avoid answering.

The two geodesic structures A and B. Figure A is the Dome framed with wooden slats, and B is the cupula completely covered by MDF triangles. The

two geodesic structures, A and B. Dome A, are composed only of wooden slats, and MDF triangles entirely cover dome B. Dome A is the turtle design we previously used in the first experiment, 2021's Macaronight. The B is Turtle Dome total covered with MDF triangles, and some graved with QR codes and interactive elements. Table 7 reflects the audience's choice of the structure they liked the most and identified it as a marine species. The answer was unanimous: The 24 researchers in the audience chose Dome B and identified it as a Turtle.

	Dome A	Dome B
Preferences	0	23
Species	-	Turtle

Table 7: Dome A - 0 (zero); Dome B - 23 (twenty three)

Such results demonstrate the preference for covered Domes with QR Codes and interactive elements. The audience choice is because it is more pleasant, appealing, and easier to identify.

4.4 Exp 3 - Smaller Closed Geodesic Marine Species

After redesigning the structure and reducing the dimensions of the woods, we rebuilt the Dome. The third experiment occurred between 23 and 29 May 2022. We add a fin to the Dome and transform it into a whale, increasing the user's interest and adding dynamic to the structure. The Dome has wholly covered with Mdf triangles, and added a fin using wooden slats, transforming the Dome into a whale(e.g. Fig. 19a).

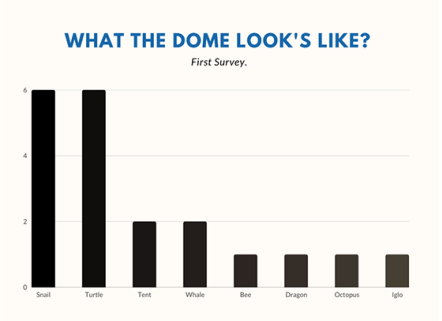
4.4.1 Test 1 - Visual Appearance

We roll with additional user tests. Asked passersby, and presented the project to a group of high school students from the Azores. We carried out two surveys on the appearance of the geodesic structure, first to 20 students from the University of Madeira and then to a group of students from the Azores.

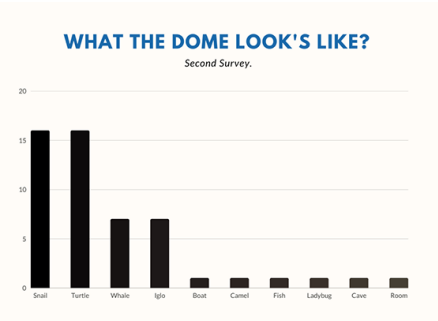
The activity questionnaire showed us that our geodesic structures went through some identity crises. It was identified as Snail and Turtle (e.g. Fig. 19c) when our intention was to build a Whale. Defrauded by the questionnaire results, the team had to change the configuration of the structure

(a)

(b)



(c)



(d)

Fig. 19: (a) Whale Dome. (b) Ilheu da Baleia - Açores. (c) First survey results. (d) Second survey results.

in order to achieve the desired result. We are aware that the necessary changes would affect the tail. It would be more realistic if the tail went to the top of the dome, but this will be challenging because of the weight.

4.4.2 Test 2 - Reiteration

Due to the poor results of the first user test, we needed to change the appearance of the Dome's tail and conduct a new evaluation with a group of 52 people. Despite the changes to the Dome, the new feedback from university students who passed around the structure fell short of expectations. The two most common, with 16 responses each, are the turtle and the snail. The next most voted are the whale and the igloo, with seven answers each (e.g. Fig. 19d).

4.4.3 Test 3 - Cultural Bias

- The high school students from Terceira Island: Azores were unanimously identifying the Dome as a Whale when we asked them what the Dome looked

alike. Our question was, "What does the Dome look like?". The 24 elements of the group, including the teacher, replied unanimously, "Whale." It was our first approach to the group, and the response took about 2 (two) seconds and was unanimous. Our second question followed: "Why did they respond so quickly and unanimously?" The answer was that there is an islet on Terceira island that looks like the Dome. It is called Ilhéu da Baleia, located in Santa Cruz da Graciosa (e.g. Fig. 19b).

4.4.4 Field Observations

The users' identification of the Dome as Tartaruga and Snail is due to what? Could the Tartaruga and Dolphin Domes, built for an extended period in the University's courtyard, influence the identification of new structures? Most people think the back is the front and suggested making the Dome flatter, less round, and longer. The tail was more prominent and less separated in the middle. There was also mention of painting, having bigger eyes and mouths. After the user's feedback about what the Dome looked like, we asked for suggestions on improving the design and making it unmistakably a whale dome.

4.5 Exp 4 - Smaller Closed Geodesic Marine Species in Wider Public

Coordinated by MARE and ARDITI - Agência Regional para o Desenvolvimento da Investigação Tecnologia e Inovação and in collaboration with the Pavilhão do Conhecimento, as part of the "Ciência Viva no Verão 2022" actions, we proceeded to assemble a geodesic structure in wood - Dome on the south edge of Praça do Povo, in an area of $4m$x$4m$, west side from the $19th$ to the $23rd$ of July.

The purpose of this action, open to the general public, is that, through the geodesic structure installed in this public space, visitors can use the Augmented Reality application to discover information, threats, and surprising facts about marine megafauna species.

This project focuses on constructing a 1 (one) geodesic structure (Dome) that represents the whale, exploring possible interactions between them and using interactive environments to raise awareness and marine concerns.

The interactive activity, with an informative nature, is about cetaceans and to increase awareness of the species for the ecosystem. They consisted of reading a

QR code printed on the panels of the structure, using a mobile phone, thus providing an interactive experience of augmented reality. We invite the user to install the ARDome application and then to answer a first questionnaire about the life of the whales. Later, moving on to the augmented reality experience, reading the pictograms printed on the structure, emerging information about a species of mammals of the cetacean family. The experience ends with the participant answering a questionnaire that allowed the correction of answers that initially raised doubts, ending with the presence of a whale in augmented reality floating on the mobile device's screen. The experiment aims to measure users' interaction with the Dome using a personal mobile device [20].

4.5.1 Public Activity

As part of the Ciência Viva activities in Summer 2022, promoted by ARDITI, we erected a geodesic structure with an end reminiscent of a whale's tail in Praça do Povo - Funchal, a busy place and a gateway to the boarding pier cetacean sighting boats. The Dome, covered by wooden panels (MDF) with engraved interactive elements, gives it an organic and dynamic appearance(e.g. Fig. 14a). It fits into the exposed place and arouses the curiosity of passersby, who approach and question its purpose.

The interactive activity "Marine Megafauna and Augmented Reality" was on display between the 19th and 22nd of July, informative about cetaceans. Our goal was to increase awareness of the species for the ecosystem, consisting of reading a QR code printed on the panels of the structure using a mobile phone, thus providing an interactive experience of augmented reality. We invited the user to install the ARDome application and then to answer a first questionnaire about the life of the whales, later moving on to the augmented reality experience by reading the info-graphs printed on the structure(e.g. Fig. 20a). Information about a species of mammals of the cetacean family emerged through cell phones(e.g. Fig. 20b) (e.g. Fig. 20c). To end the experience, the participant answered a questionnaire that made it possible to correct answers that initially raised doubts, ending with the presence of a whale in augmented reality floating on the mobile device's screen.(e.g. Fig. 20d).

Praça do Povo - Observation

[20] https://www.cienciaviva.pt/verao/2022/?accao=showactivitiesid$_{a}ctivity = 2054$

We observed people's interests as we proceeded with the geodesic structure assembly. When we applied the Mdf triangles to the Dome, the QR Codes, graphic elements, and pictograms increased the curiosity of passersby who passed by, looked, and questioned the reason and usefulness of the structure.(e.g. Fig. 14c).

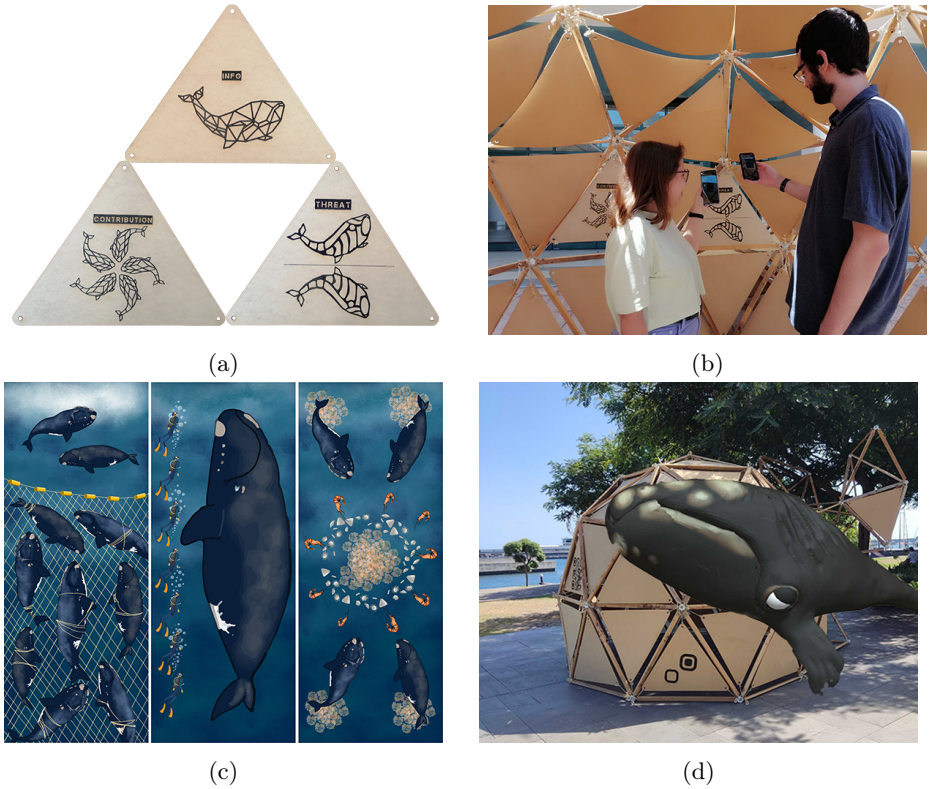
The activity had a considerable number of participants, and it is worth mentioning the participation in the evening hours, after the Ciência Viva activity, between 5 pm and 10 am the following day.(e.g. Fig. 21c).

In this activity, we were very far from the structure as we intended to measure the user's interactivity with the Dome and the ARDome App. Sometimes, as it was a Ciencia Viva activity, we had to intervene due to doubts about the functioning and objectives of the activity. In cases where mobile equipment was incompatible or users did not have internet access essential to the ARDome APP, the team intervened, showed how it worked, and invited users to participate.

Table 21a summarizes the Ciência Viva interactions during the day of July 19, 2022, from 10 am to 4 pm. The assembly of the structure began at 9:30 am on July 19. The Dome takes approximately 20 minutes to be completely erected. However, the tail presented some constraints and setbacks. Once erected, the appendices raised doubts about the characterization and identification of the Whale species we intended to portray. As such, we had to remake it. The Dome, as a result, was finished by 1:30 pm. Registered and validated interactions start at 11:28 am. It happened because passers-by showed interest and approached the team during construction.

We validated 18 interactions. The interactions are registered by reading the APP's QRCode recorded on the MDF panels scattered throughout the Dome. We divided the records into QRCode reading, APP download, and complete activity. Therefore, we have two interactions that are QRCode reading only. This fact may occur due to two conditions, one is the lack of Internet access, and another may occur due to the incompatibility of the mobile equipment with the APP ARDome.

Sixteen (16) users downloaded the ARDome App and completed the first part of the activity. After entering the Whale ARDome App, users started the activity. They answered the initial questionnaire about North Atlantic Right



(a) (b)

(c) (d)

Fig. 20: (a) MDF Pictograms Trigger. (b) ARDome Whale Augmented Reality interaction. (c) ARDome Whale Augmented Reality posters. (d) Augmented Reality Whale Interaction.

Whale life curiosities, consisting of three (3) questions, and read the three pictograms dispersed in the Structure.

The questions presented are: - How many North Atlantic Right Whale is caught by fish net at least once in their lifetime? - Who eats whom? - How many scuba divers are equivalent to the North Atlantic Right Whale?

Of this group, only ten (10) completed the activity, answering the final questionnaire, a repetition of the initial. It serves as a second opportunity to answer correctly since the answers are on the Virtual Reality posters that appear on the mobile device's screen when users scan the pictograms.

Table 21b Summarizes Ciencia Viva Interactions during the day on the 20th of July. On the 20th of July, we registered and carried out fourteen (14)

Interactions	Users	Day / Hour	Pre	Post
1	U1	2022-07-19 11:28:39	✓	✓
2	U2	2022-07-19 11:29:15	✓	✓
3	U3	2022-07-19 11:43:05	-	-
4	U4	2022-07-19 11:43:50	-	-
5	U5	2022-07-19 13:09:29	✓	-
6	U6	2022-07-19 13:21:52	✓	-
7	U7	2022-07-19 13:32:59	✓	-
8	U8	2022-07-19 13:55:40	✓	-
9	U9	2022-07-19 14:54:41	✓	✓
10	U10	2022-07-19 14:55:37	✓	✓
11	U11	2022-07-19 14:55:44	✓	-
12	U12	2022-07-19 15:10:31	✓	-
13	U13	2022-07-19 15:10:47	✓	✓
14	U14	2022-07-19 15:11:14	✓	✓
15	U15	2022-07-19 15:15:12	✓	✓
16	U16	2022-07-19 15:15:37	✓	✓
17	U17	2022-07-19 16:04:13	✓	✓
18	U18	2022-07-19 16:04:54	✓	✓

(a)

Interactions	Users	Day / Hour	Pre	Post
19	U19	2022-07-20 11:27:37	✓	✓
20	U20	2022-07-20 11:29:08	✓	✓
21	U21	2022-07-20 11:31:01	✓	✓
22	U22	2022-07-20 11:32:13	✓	✓
23	U23	2022-07-20 11:33:27	✓	✓
24	U24	2022-07-20 11:34:11	✓	✓
25	U25	2022-07-20 11:36:48	✓	✓
26	U26	2022-07-20 11:36:56	✓	✓
27	U27	2022-07-20 11:38:58	✓	✓
28	U28	2022-07-20 11:40:12	✓	✓
29	U29	2022-07-20 13:28:52	✓	-
30	U30	2022-07-20 13:30:26	✓	-
31	U31	2022-07-20 14:50:08	✓	✓
32	U32	2022-07-20 14:51:17	✓	✓

(b)

Interactions	Users	Day / Hour	Pre	Post
33	U33	2022-07-20 16:37:51	✓	-
34	U34	2022-07-20 17:54:06	✓	-
35	U35	2022-07-20 23:18:35	✓	-
36	U36	2022-07-21 09:46:23	✓	-
37	U37	2022-07-21 09:47:15	✓	✓
38	U38	2022-07-21 09:48:28	✓	✓

(c)

Interactions	Users	Day / Hour	Pre	Post
39	U39	2022-07-21 10:04:22	✓	-
40	U40	2022-07-21 10:42:58	✓	-
41	U41	2022-07-21 10:46:44	✓	-
42	U42	2022-07-21 10:47:37	✓	✓
43	U43	2022-07-21 10:51:31	✓	✓
44	U44	2022-07-21 11:14:55	✓	✓
45	U45	2022-07-21 11:16:04	✓	✓
46	U46	2022-07-21 11:16:47	✓	✓
47	U47	2022-07-21 11:18:03	✓	✓
48	U48	2022-07-21 11:19:07	✓	✓
49	U49	2022-07-21 11:20:15	✓	✓
50	U50	2022-07-21 13:35:25	✓	✓
51	U51	2022-07-21 13:39:52	✓	✓
52	U52	2022-07-21 14:41:55	✓	✓
53	U53	2022-07-21 14:44:27	✓	✓
54	U54	2022-07-21 15:21:00	✓	✓
55	U55	2022-07-21 15:23:45	✓	✓
56	U56	2022-07-21 15:25:10	✓	✓
57	U57	2022-07-21 15:25:44	✓	✓
58	U58	2022-07-21 15:55:36	✓	✓
59	U59	2022-07-21 15:57:18	✓	✓

(d)

Interactions	Users	Day / Hour	Pre	Post
60	U60	2022-07-21 17:13:59	✓	-
61	U61	2022-07-21 17:18:33	✓	✓
62	U62	2022-07-21 17:21:37	✓	✓
63	U63	2022-07-21 20:01:21	✓	-
64	U64	2022-07-21 22:52:27	✓	✓
65	U65	2022-07-21 23:04:49	✓	✓

(e)

Interactions	Users	Day / Hour	Pre	Post
66	U66	2022-07-22 10:03:08	✓	-
67	U67	2022-07-22 10:56:13	✓	✓
68	U68	2022-07-22 10:59:12	✓	✓
69	U69	2022-07-22 11:05:19	✓	-
70	U70	2022-07-22 11:35:57	✓	✓
71	U71	2022-07-22 11:37:47	✓	✓
72	U72	2022-07-22 12:14:36	✓	✓
73	U73	2022-07-22 12:16:44	✓	✓
74	U74	2022-07-22 13:28:53	✓	-
75	U75	2022-07-22 14:19:18	✓	✓
76	U76	2022-07-22 14:21:22	✓	✓
77	U77	2022-07-22 15:23:42	✓	✓
78	U78	2022-07-22 15:25:28	✓	✓

(f)

Interactions	Users	Day / Hour	Pre	Post
79	U79	2022-07-23 20:24:58	✓	-
80	U80	2022-07-24 14:56:25	✓	✓
81	U81	2022-07-24 14:57:07	✓	✓

(g)

Fig. 21: Ciencia Viva Interactions - List of Tables (from left to right): (a) Interactions during the day on the 19th of July; (b) Interactions during the day on the 20th of July; (c) Interactions during the night hours from the 20th to the 21st of July; (d) Interactions during the day on the 21st of July; (e) Interactions during the night hours from the 21st to the 22nd of July;(f) Interactions during the day on the 22nd of July ; and (g) Interactions after the 22nd of July.

interactions. Only two did not complete the activity, participating in the last questionnaire. We had an improvement over the first day.

On Table 21c we summarize Ciencia Viva Interactions from the 20th to the 21st of July during the night hours. We registered six (6) interactions at night;

of these, only two users completed the activity. After analyzing successful activities time, it is doubtful they had support from the team.

Table 21d summarizes Ciencia Viva Interactions during the 21st of July. On the third activity day, we registered an increase from the previous ones. We have twenty-one (21) validated interactions, of which only three (3) did not complete the activity. It was the day with the most significant movement and expression of interest by passers-by. Groups of friends and families approached us. Parents came on purpose. They had more doubts and asked about the experience and the marine species of the North Atlantic Right Whale.

Table 21e summarizes Ciencia Viva Interactions during the night hours from the 21st to the 22nd of July. The night schedule of activity on the 21st of July was advantageous. Of the six (6) validated interactions, only two (2) did not complete the game. Seeing that most users did the activity without the team's supervision is gratifying.

Table 21f summarizes Ciencia Viva Interactions during the 22nd of July. On the last day of the Ciência Viva activity at Praça do Povo, Funchal, we recorded thirteen (13) user interactions. Ten (10) users downloaded the ARDome App and completed the game, answering the second questionnaire, and only three (3) users did not complete the activity.

At last, Table 21g summarizes Ciencia Viva Interactions after the 22nd of July. After the end of the activity, we validated three (3) interactions, two of which concluded the interaction successfully. These recorded interactions refer to the download of the ARDome App, which possibly users would not have mobile data available at the time of the Ciencia Viva activity on Praça do Povo.

4.6 Test 4 - Smaller Geodesic Structure

Macaronight 2022 - European Researchers' Night The European Researchers' Night takes place annually on the last Friday of September. Within the scope of the Macaronight project, whose partners are the Canary Islands, Azores, and Madeira, to disseminate science, technology, research, and innovation developed in the Macaronesia region. Through ARDITI, we participated in the demonstration of the use of geodesic structures using augmented reality[21]. The space limitations for the activity provided a redefinition of the used structure.

[21] https://itecformadores.wixsite.com/macaronight2022

The regular pentagon is the geometric shape defined by the wooden slats used to construct the new format. It comprises three convex pentagons, two interconnected at the ends, overlapping, and connected to another in the center. It is a new structure of reduced dimensions. Non-geodesic design with the same purpose, to serve as a trigger for the interaction for the Augmented Reality experience provided by the Whale's ARDome App.

Moving away from geodesic design and thinking of Macaronight's activity inside the university building, we redesigned and erected a small structure in the gardens of the Madeira Tecnopolo building. With this new structure, we conducted an initial test with 18 students from the Digital Marketing course at the University of Madeira.

In this activity, we measure the interaction of users with the structure, and we intend to understand its relevance to the experience. We started with the presentation of the project and an explanation of the concept. We refer to the structure's purpose as an interactive element that expands the augmented reality experience. That users must read the QRCode and download the ARDome application. We create the app to raise people's awareness of marine life, namely the North Atlantic Right Whale and its importance to the ecosystem. Alone they opened the application and started the game. They answered the first questionnaire, read the pictograms triggering the trigger, and saw AR posters. Some elements raised doubts about the last questionnaire, as it needed to be clarified to them whether the game would continue or whether it would have ended. They left the game before answering the last questionnaire and did not have access to the final interaction of the AR whale on the mobile equipment monitor. After questioning whether they had seen the absolute whale, we needed to explain that the game only ended when the whale appeared. Thus, users who still needed to complete it on the first attempt repeated the interaction. We invite users to respond to a questionnaire where, on a scale of seven (7) values, we measured the various factors that we found relevant and essential for the study.

The survey we carried out aimed to understand the importance of the activity and the App's structure(e.g. Fig. 22b). We use the users' feedback to the evolution of the project.

During the entire development and presentation of the project, we engaged with the general public. Users constantly asked about the App; questionnaires

were in English when our audience is mostly Portuguese-speaking. It made us change the language of the questionnaire, but we could not change the language of the ARDome App.

In the presentation of the ARDome activity developed in the Garden of the Tecnopolo building, on a scale of 1 to 7, on how enjoyable the experience was, users evaluated it with average values greater than six values. In questions number 2 (I think the experience is essential), 3 (I find this helpful experience), 5 (I learned a lot from this experience), 8 (I recommend this experience), 9 (I think the structure stimulates interest) and 10 (I think the structure adds value to the experience) the average scores are slightly below six values, on a scale of 1 to 7. In questions 6 (I feel comfortable teaching others what I learned.) and 7 (I would repeat this experience), the average response is slightly over 5. In question number four, about the difficulty of the experience, we have an average of 3,5 on a scale of 7. The value reflects some difficulties that the activity represents. In the last question, which asks the user how far he feels from the whales, the average of answers is slightly below six values. This high evaluation leads us to infer that users feel far from the cetaceans despite the activity.

We performed the second study on Macaronight, 2022 activity in Universidade da Madeira. The structure arranged in the corridor on the -1 floor attracted numerous participants. They approached and explained the activity. After completing the game, users participate in the questionnaire.

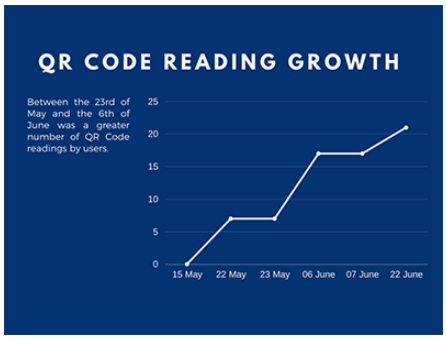
The graphs (Fig. 22c and Fig. 22d) shows that the results were similar on bought surveys, except for the last question, which misled users and needed to be adequately perceived. The misunderstood question is: How distant do users feel from whales? This question aimed to measure the AR whale's appearance on the mobile phone screen at the end of the application. The user's interest and connection to the animal.

4.6.1 QR Code Reading Analysis.

We measured users' interaction with the Dome by analyzing the number of QR Code readings. QR Code directs the user to the Wave Labs page and redirects to the App Store or Google Play, depending on the mobile phone version they have and which will allow the download of the ARDome application[22].

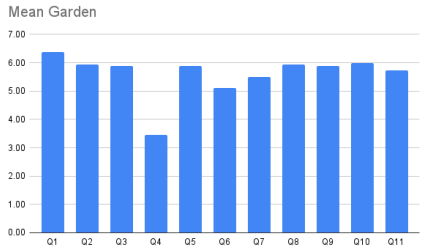
[22]https://wave-labs.org/kits/apps/ardome?id=1

Between days 16 and 22 of May 2022, seven(7) users made the QR Code reading of the Dome. With the Dome completely covered with Mdf triangles and added a fin using wooden slats, transforming the Dome into a whale, users scanned the QR Code ten (10) times between the 23 of May and the 6 of June. Between the 7 of June and the 22 of July, four (4) users scanned the QR Code. We registered a decrease in interactions and needed to understand the reasons for such behavior (e.g. Fig. 22a).

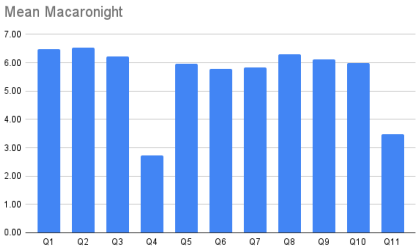


(a)

(b)



(c)



(d)

	id	dome_id	dome_interaction_id	counter	created_at	updated_at
Edit Copy Delete	1	1	1	342	2021-11-17 11:37:42	2022-11-20 15:39:17

(e)

Fig. 22: (a) QR Code reading activity betwen 15 of May and 22 of June. (b) Interwhale survey. (c) Mean results of garden presentation. (d) Mean results of Macaronight presentation. (e) Total QR Code Counter Interactions.

5 Discussion

This dissertation studied the role of geodesic structures in approaching the wider audience regarding marine concerns. Through iterative design and five experiments conducted, the geodesic structure has been validated in the field, analyzing the overall engagement by the audience.

The proposed experience provides a portal into the sea from the shore. We discuss the potential of developing an interactive activity that can promote awareness about sustainability issues of aquatic environments (such as megafauna concerns), making it available to all stakeholders, whether they are locals or tourists who visit our region.

5.1 Lessons Learned

In developing this project, we came across several positive factors and some drawbacks. In the positives, we refer to the public's interest in marine issues, the work we present, the structures, and the ARDome App. We noticed that when we started this project, like most people, we needed more knowledge about marine life and the marine species in question, such as the North Atlantic Right Whale and environmental issues. We knew we could not have a simplistic and superficial approach, as it would not have the intended impact and emphasis. In this era of excessive information, it is necessary to have a more material and structural approach. Geodesic structures or domes are thus important structures to inspire curiosity. They may have various applications and utilities as they are currently growing in the Glamping sector for short-term Local Accommodation (AL) rentals [23] for platforms such as Airbnb and Booking. The domes of Marine Megafauna become sufficiently appealing for users, arousing their attention and interest. Allied with the ARDome mobile application, we accurately and efficiently publicized the project. In the drawbacks, we outline the more immersive space as needed, including additional hardware components. Geodesic structures do not provide significant immersion, as too much light influences the space, resulting in exposed interactions.

In the initial design interventions, we outlined the objective of building geodesic domes of the different marine megafauna species to combine them

[23] http://www.soulglamping.com

with the applications of mobile AR. We develop an informative, coherent, attractive, straightforward interpretation and correct dissemination of the issues concerning anthropogenic issues (i.e. litter pollution, overfishing, noise pollution, etc.) and are environmentally friendly. Due to the excess luminosity inside the structure, which made the activity challenging, we had to cover it, increasing the conditions of the Dome for the realization of the interactive experience. The weather conditions collapsed the structures, jeopardizing their safety and that of the intervening parties. We had to redesign them in order to increase robustness.

In subsequent interventions, we focused on safety and species identification. We increased the robustness of the structures, reducing the length and increasing the thickness of the wood. We covered the entire Dome with MDF panels and added aesthetic appendages from the sculpted species. We started the development of the new mobile application, this time for Android and iOS devices on the North Atlantic Right Whale. We developed informative posters used in the App ARDome - Whale modality. We designed the infographics, QR codes, and interactive elements used as a trigger and link between the structure and the App. We carried out several user studies erecting the structure in public spaces, such as the cases of Praça do Povo, in Funchal, within the scope of the summer activity, Ciencia Viva, and we participated in the Macaronight 2022 activity at the University of Madeira. These activities were of great importance since the feedback from users is essential for the development and continuity of the project.

5.2 Research Contributions

Concerning the contribution of research in the development of the project, firstly, it should be noted that this is the continuation of the project previously started within the scope of INTERAQUATICA (the concept of interactive and aquatic experiences planned for on- and off-shore future installations). It is a significant project with great value and importance and encompasses the interdisciplinarity of elements and sciences. Our initial research was in the environmental field, with the mortality of species, namely Turtles and Whales. It led us to research the causes and consequences of pollution and the potential effect of ocean pollution on human health, marine species, and the planet's health. We researched the construction of geodesic structures, Human-Computer Interaction (HCI), and Human-Computer Biodiversity

Interaction (HCBI) to create interfaces capable of reducing the distance between users in an urban context and animals in their natural habitat. The work led us to research Tourism to understand its contributions and drawbacks to the local, regional, and international economies. We research the creation of an immersive digital environment and the influence of interactive experiences in valuing biodiversity.

5.3 Research Challenges

Environmental concerns and biodiversity sustainability challenged us to find ways to increase public awareness. This project aimed to create an interactive experience to positively affect users for the constraints of marine pollution and the species and instill healthy and beneficial habits for all actors in the ecosystem. We chose the geodesic Dome because it would be an asset to the whole experience, as it is an appealing structure that arouses curiosity. The Dome has a differentiating role, and as is the case, combined with a mobile App, it plays a relevant role in the interactive experience.

Is the Dome essential for the functioning of the ARDome App? The answer is no. The Dome is optional for the development of the interactive experience that is the ARDome App. However, it is an aesthetic element that attracts attention and positively influences the choice to do the activity.

Does the structure have to be exclusively a Dome? In this project, we showed that the structure format needs to be more relevant. However, as an interactive objective, it helps to increase the user's interest.

We see this project developing within the scope of emotion displays. Instigate the emotional side of the user by projecting smiles. For example, we have a study focusing on the displays of authentic and positive emotions by frontline employees. The display of positive or negative emotional states compromises service performance behaviors and influences customer choices [42]. Design can inspire and enable emotion-regulating activities. We can design interactions to support positive emotion regulation [43]. The development of emotion-based interactions positively increases long-term effectiveness responses in users.

5.4 Future Work

Fuller is a reference in our work, which significantly impacts today's world and continues to influence new generations of designers, architects, scientists, and

artists committed to creating a more sustainable and viable planet [44]. Several projects describe the development of an augmented reality experience for Marine Protected Areas. E.g. Alaeddin Nassani, 2019, reports on an experiment that focuses on a simplified version of the food chain in the Ross Sea [45].

Indeed, deploying and using new digital technologies can positively influence human-animal relationships [46]. Using new technologies, we can propose the human-animal encounter by simulating their natural habitat. We can consider using technology across multiple participants, multiplying interactions over time, and diversifying the performative nature of some human-animal encounters. Mobile augmented reality systems can enable the visualization of animal species in virtual environments [47]. For future work, envisage geodesic structures that house a mechanism (binoculars bridge San Francisco style) with a tripod with Augmented Reality glasses, with a cavity for placing the user's mobile phone, providing an interactive experience with the species of marine megafauna in its habitat. We would place these redesigned and structurally reinforced structures in public spaces close to the coast. All structures would offer different experiences and narratives according to the species of megafauna portrayed. Experience without costs for the resident public and charge a residual value to the tourist to cover expenses inherent to the operation and maintenance of the activity.

6 Conclusion

This dissertation developed a collective, multidisciplinary, interactive work for this dissertation with a common objective to efficiently, creatively, and interactively inform people about marine concerns. The dissertation combines the disciplines of Design and Computer Engineering, developing metaphors and interactive environments for a broad audience for marine megafauna and ecosystem issues.

Through this dissertation, we offer interaction opportunities with marine megafauna. We provide a service to people for the common good, the ecosystem.

In response to the questions we studied, we retained that in our user studies, they served to validate our project. In response to RQ1 about the interest that the structure arouses, we confirm that it indeed does. The structure arouses interest in the public and serves its purpose of attracting passers-by. In response to RQ2 on the value that structure adds to the experience. The structure adds value, but its format could be more predominant. On RQ3, the immersion of the experience, we found that the limited space inside makes the experience more engaging and effective. In response to RQ4, indeed, this experience is essential. We see the dome as a means to fulfill the experience of interaction.

The dissertation, in its efforts, does not find proof that marine animals' geodesic structures emotionally influence users. However, it continues to be an appealing, exciting structure capable of arousing the audience's curiosity.

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7 Supplementary Material

In this section, Is attached the most relevant documents for the project's development. We have attached the 3D drawings of the Geodesic structures, the photographs of the Dome, and the final structure. Attached are the mobile application's posters, posters, and infographics used as triggers. Attached are the questionnaires used to measure users' interactivity at different stages of project development, and finally, we added some more relevant photographs of the project presentation.

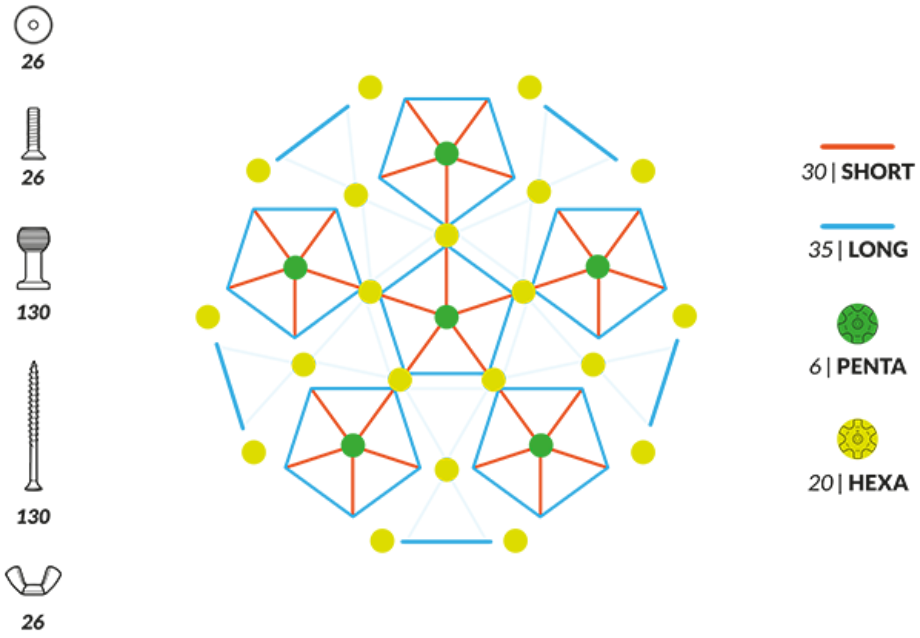

Fig. 23: Instructions of Smaller Dome

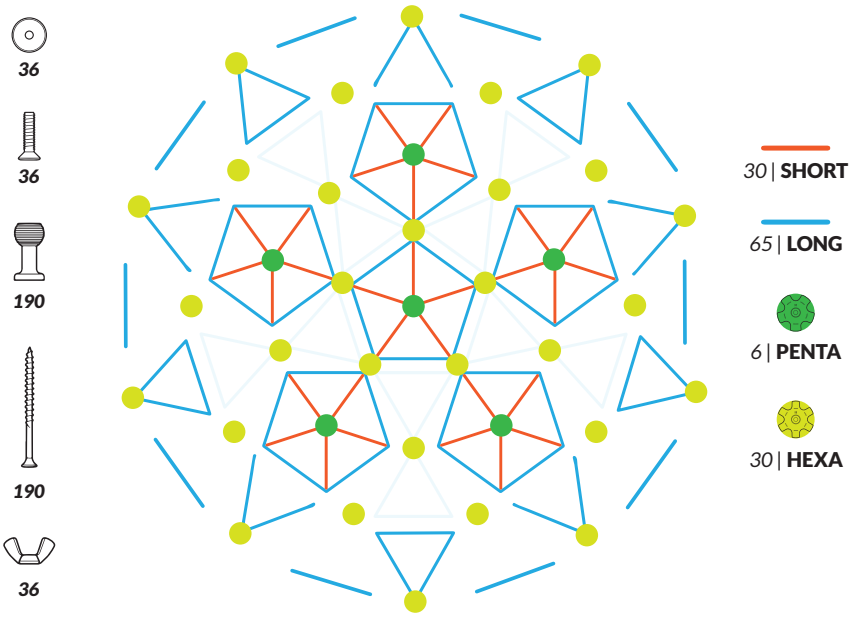

Fig. 24: Dome Instructions

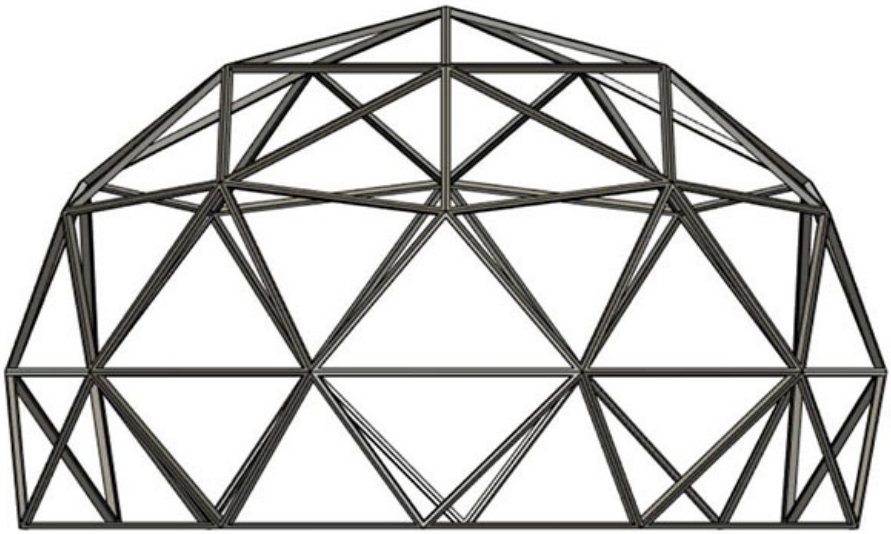

Fig. 25: 3D Dome

Fig. 26: Whale Dome

Fig. 27: MDF printed QR-code ARDome App

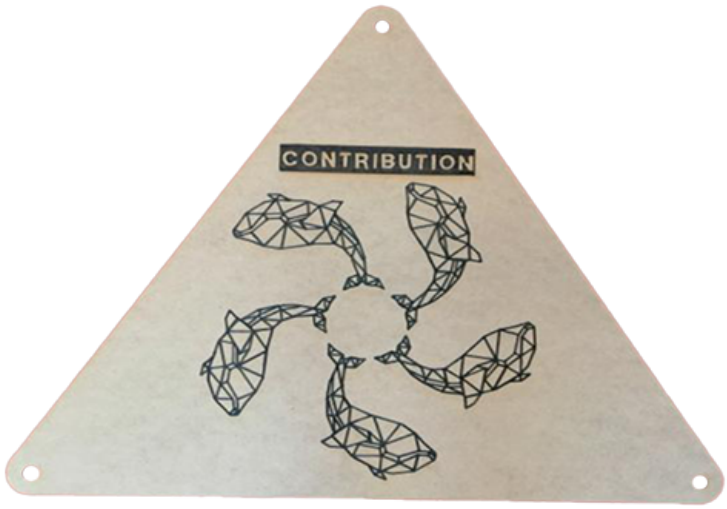

Fig. 28: MDF Contribution trigger

Fig. 29: MDF Threat trigger

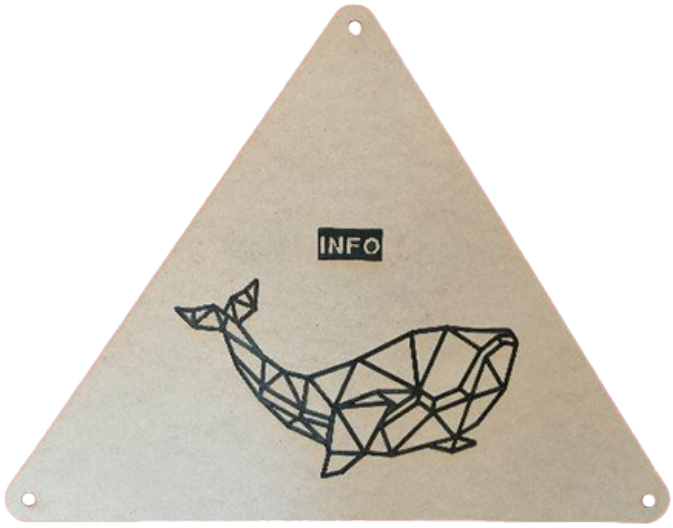

Fig. 30: MDF Info trigger

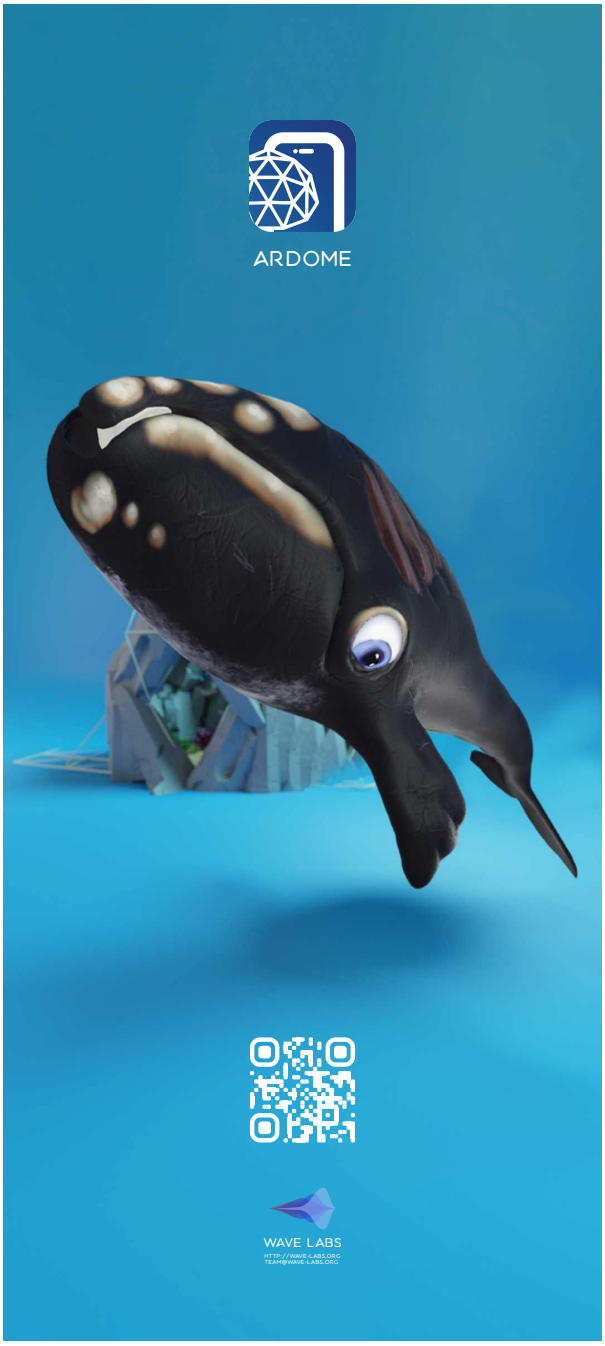

Fig. 31: Whale Poster

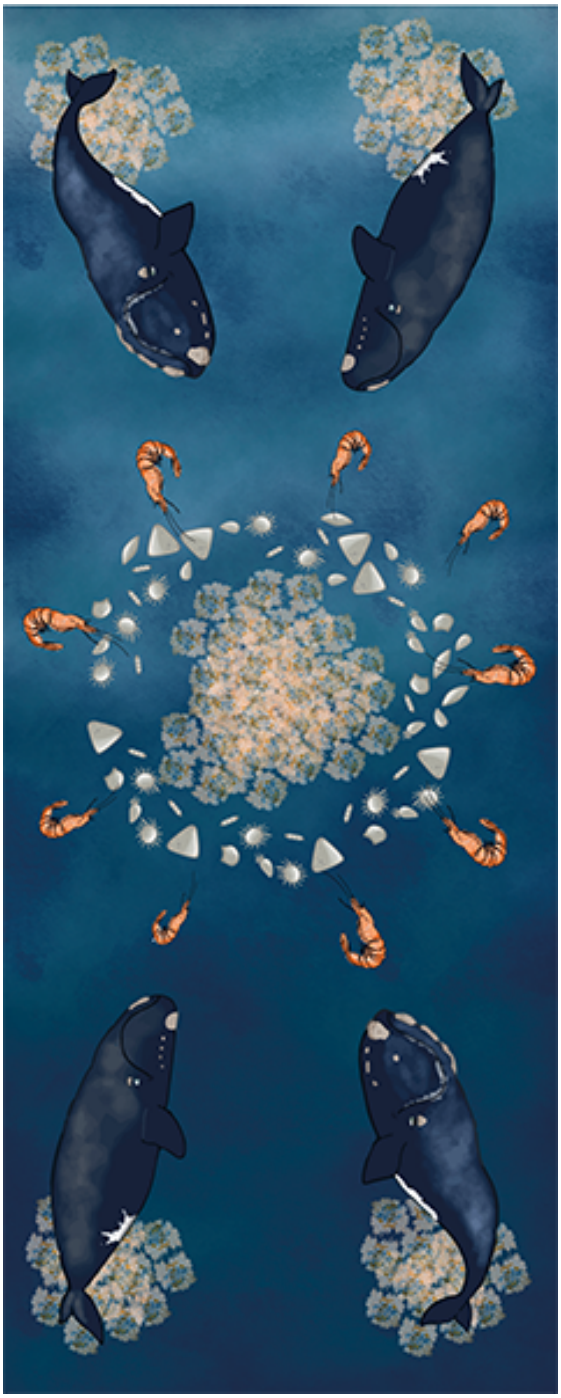

Fig. 32: Poster Contribution

Fig. 33: Poster Info

Fig. 34: Poster Threat

Fig. 35: Small structure

ID: AR1
Segunda experiência? ⬜
ID da primeira:_____

AR Form (Pre)

ARDome, uma Experiência de Realidade Aumentada Interativa inspirada em espécies marinhas em perigo de extinção, foi projetada com o objetivo de chamar a atenção para a situação ecológica em curso.

Ao preencher este formulário, você concorda automaticamente em participar neste estudo anônimo e fornecer os dados pessoais necessários, que serão processados e usados para avaliar a experiência. Este é um estudo voluntário, portanto, você pode interrompê-lo quando desejar. Lembre-se de que não há respostas corretas e a maioria delas deve refletir sua opinião.

Este estudo está dividido em duas formas, esta parte deve ser preenchida antes do início da experiência, e outra deve ser preenchida quando a experiência terminar. Os termos acima mencionados são válidos para ambas as partes.

Questões demográficas

1. País de origem:

   R: _____

2. Idade:

   R: _____

3. Género:

   M ⬜ F ⬜ Outro ⬜

Estado de ânimo

4. Indique na seguinte escala como se sente neste momento:

⬜	⬜	⬜	⬜	⬜
Mal	Mais ou menos	OK	Bem	Excelente

Fig. 36: AR Pre users Form

ID: DOME1
Segunda experiência? ⬜
ID da primeira:_____

Dome Form (Post)

Estado de ânimo

1. Indique na seguinte escala como se sente após de realizar a experiência:

⬜	⬜	⬜	⬜	⬜
Mal	Mais ou menos	OK	Bem	Excelente

Questões sobre a experiência:

2. Indique na seguinte escala que tão imersiva foi a experiência para você:

⬜	⬜	⬜	⬜	⬜
1 Pouco imersiva	2	3	4	5 Muito imersiva

3. Indique quanto tempo você acha que passou interagindo com a aplicação:

⬜	⬜	⬜	⬜	⬜	⬜
< 5 minutos	5 minutos	10 minutos	15 minutos	20 minutos	> 20 minutos

4. Indique na seguinte escala o que tão absorvido pelo ambiente se sentiu:

⬜	⬜	⬜	⬜	⬜
1 Pouco absorvido	2	3	4	5 Muito absorvido

Fig. 37: AR Pos users Form

INTERWHALE

Numa escala de 1 (discordo totalmente) a 7 (concordo plenamente), responda às seguintes perguntas marcando com uma X ou um círculo:

Achei interessante esta experiência.	1	2	3	4	5	6	7
Achei importante esta experiência.	1	2	3	4	5	6	7
Achei útil esta experiência.	1	2	3	4	5	6	7
Achei difícil esta experiência.	1	2	3	4	5	6	7
Aprendi muito com esta experiência.	1	2	3	4	5	6	7
Sinto-me confortável ensinando a outros o que aprendi.	1	2	3	4	5	6	7
Repetiria esta experiência.	1	2	3	4	5	6	7
Recomendaria esta experiência.	1	2	3	4	5	6	7
Acho que a estrutura estimula o interesse.	1	2	3	4	5	6	7
Acho que a estrutura adiciona valor à experiência.	1	2	3	4	5	6	7
Sinto-me distante das baleias.	1	2	3	4	5	6	7

Nacionalidade: _____

Gênero: _____

Idade: _____

ID: _____

Fig. 38: Interwhale users Form

Fig. 39: Presentation of the project to the Açores students

Fig. 40: Presentation of the project to the order of engineers

Fig. 41: Project presentation on Macaronight 2022