NOVA SCHOOL OF SCIENCE & TECHNOLOGY

DEPARTMENT OF COMPUTER SCIENCE

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BSc in Computer Science

TELL ME A TRAIL - AN INTERACTIVE RESPONSIVE TOOL TO SUPPORT A FULFILLING HIKING EXPERIENCE

MASTER IN COMPUTER SCIENCE AND ENGINEERING

NOVA University Lisbon
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Abstract

Hiking has experienced increasing popularity worldwide, with an array of physical and cognitive benefits cementing its appeal for a wide range of demographics. However, the existing landscape of hiking platforms often falls short in catering to a broader range of users, mainly due to the lack of inclusivity, comprehensive trail data, or engaging elements.

Seasoned hikers have issues with finding accurate trail information, while users with specific accessibility requirements are often deterred from participating in the activity altogether. On the other hand, people who express disinterest in hiking often claim lack of engagement with the experience. As such, the need for an integrated solution that caters to a wider range of hikers has been identified.

The developed solution for this problem involved the creation of an interactive interface encompassing detailed trail data, navigation tools, and interactive narratives to experience along the trails. A user-centric approach was employed, with user research and iterative testing phases guiding the development to optimize the experience across a wide demographic spectrum. The aim was for this thesis to extend beyond recreational benefits and encompass the promotion of accessibility considerations, the cultural and historical background of trails in Portugal, and the benefits of hiking as a whole.

Keywords: Hiking, Trails, Location-based services, Interactive narratives, Digital storytelling, User experience, Accessibility

Resumo

As caminhadas a pé têm vindo a usufruir de uma crescente popularidade a nível mundial, com diversos benefícios cognitivos e físicos a reforçar o seu apelo entre diversos grupos demográficos.

No entanto, o panorama atual de plataformas web ou móveis para caminhada frequentemente não atende a uma gama mais ampla de utilizadores, principalmente devido à falta de inclusividade, de dados abrangentes sobre trilhos ou de elementos interativos.

Caminhantes experientes têm dificuldades em encontrar informações corretas sobre os caminhos, enquanto utilizadores com requisitos específicos de acessibilidade são frequentemente dissuadidos de sequer participar na atividade. Por outro lado, pessoas sem interesse em caminhada muitas vezes alegam falta de envolvimento com a experiência. Assim, identificou-se a necessidade de uma solução abrangente que atendesse a uma gama mais ampla de caminhantes.

A solução desenvolvida para abordar este problema envolveu a criação de uma interface interativa que engloba dados detalhados sobre trilhos, ferramentas de navegação e narrativas interativas para serem experienciadas ao longo dos caminhos. Foi aplicada uma abordagem centrada no utilizador, com entrevistas e testes iterativos a guiar o desenvolvimento de forma a otimizar a experiência para uma maior amplitude demográfica. O objetivo foi que esta tese se estendesse para além de benefícios recreativos e abrangesse a promoção de considerações de acessibilidade, o contexto cultural e histórico dos caminhos de Portugal, e os benefícios da caminhada como um todo.

Palavras-chave: Caminhada, Trails, Narrativas Interactivas, Narrativas Digitais, User Experience, Acessibilidade

Contents

List of Figures ix

List of Tables xiv

Acronyms xv

1 Introduction 1
- 1.1 Motivation . . . 1
- 1.2 Context . . . 2
- 1.3 Problem Description and Objectives . . . 2
- 1.4 Main Contributions . . . 3
- 1.5 Document Structure . . . 4

2 Fundamental Concepts 5
- 2.1 Human-Computer Interaction . . . 5
  - 2.1.1 User Experience . . . 5
  - 2.1.2 Usability . . . 6
  - 2.1.3 Accessibility . . . 9
- 2.2 Geographical and Location Systems . . . 10
  - 2.2.1 Geographic Visualization . . . 10
  - 2.2.2 Location-Based Services (LBS) . . . 14
  - 2.2.3 Offline Navigation . . . 15
- 2.3 Interactive Narratives . . . 16
  - 2.3.1 Digital Storytelling . . . 16
  - 2.3.2 Gamification . . . 18
- 2.4 Discussion . . . 19

3 Related Work 20
- 3.1 Trail Platforms . . . 20
  - 3.1.1 AllTrails . . . 20

3.1.2 Portuguese Trails . . . 22
3.2 Interactive Narratives . . . 24
3.2.1 TrilhAR . . . 24
3.2.2 TravelPlot Porto . . . 26
3.2.3 Adventure Lab . . . 26
3.2.4 Sound Narratives - *Echoes* and *Voices from the Trenches* . . . 27
3.3 Discussion . . . 28

4 Solution Design **30**
4.1 Solution Requirements . . . 30
4.1.1 Empathy Maps . . . 30
4.1.2 Requirements . . . 32
4.1.3 Visual Prototypes . . . 37
4.2 Technologies . . . 38
4.2.1 Back-End . . . 38
4.2.2 Front-end Technologies . . . 41
4.2.3 Maps . . . 44
4.3 System Architecture . . . 45
4.4 Discussion . . . 46

5 Solution Implementation **48**
5.1 Mobile Platform - Tell Me a Trail . . . 48
5.1.1 Navigation Flow . . . 48
5.1.2 Persistence and State Management . . . 50
5.1.3 Map . . . 50
5.1.4 Trails . . . 54
5.1.5 Narratives . . . 61
5.1.6 Search and Filtering . . . 63
5.1.7 Navigation . . . 65
5.1.8 Narrative Navigation . . . 68
5.1.9 Favourites . . . 69
5.1.10 User Progress . . . 70
5.1.11 Offline Functionality . . . 71
5.1.12 Localization . . . 74
5.2 Narratives Database . . . 74
5.2.1 Data Model . . . 75
5.2.2 Back-Office - Narratives Manager . . . 77
5.3 Discussion . . . 84

6 Evaluation **85**
6.1 Methodology and Testing Reports . . . 86
6.2 First Phase . . . 86

6.3 Second Phase . . . 88
6.4 Third Phase . . . 90
6.4.1 SUS . . . 91
6.5 Usability Evolution . . . 95
6.6 Empathy Map Retrospective . . . 96
6.7 Discussion . . . 98

7 Conclusion and Future Work **99**
7.1 Conclusion . . . 99
7.2 Future Work . . . 100

Bibliography **102**

Appendices

A Portuguese Trails **112**

B Empathy Maps **115**

C Visual Prototype **121**

D Mobile Platform - Tell me a Trail **126**
D.1 Navigation Flow . . . 128
D.2 Map . . . 129
D.3 Trails Tab . . . 134
D.3.1 Trail Details . . . 136
D.3.2 Accessibility . . . 141
D.4 Narratives Tab . . . 143
D.4.1 Narrative Details . . . 145
D.5 Search and Filtering . . . 146
D.6 Navigation . . . 149
D.6.1 Intersecting Trails . . . 150
D.6.2 Narrative Navigation . . . 151
D.7 Favourites Tab . . . 153
D.8 User Progress . . . 154
D.9 Offline Functionality . . . 155
D.10 Localization . . . 156

E User Feedback Evolution for Features **157**
E.1 Features Introduced in Phase 1 . . . 158
E.2 Features Introduced in Phase 2 . . . 163

F Use Cases, Tasks and Testing Reports **167**

G Usability Questionnaire - Phase 1 **182**

H Usability Questionnaire - Phase 2 **187**

I Usability Questionnaire - Phase 3 **191**

J SUS Questionnaire **197**

Annexes

I Trail Characterization Guidelines **200**

List of Figures

2.1 Concepts of *Usability*, *Inclusive Design* and *Accessibility* encompassed within *UX design* (adapted from [39] to include *Inclusive Design*) 9
2.2 The Map Use Cube modeling visualization goals with respect to three dimensions (adapted from [49]) 11
2.3 Example of generalization in a 2D map, via the simplification of geographic borders [76] 12
2.4 Geographic Visualization of NOVA School of Science and Technology in *Leaflet* (left) and *CesiumJS* (right) 14
2.5 Example of *Botfighters* mobile interface [84] 18

3.1 Partial view of web page for a trail in *AllTrails* 21
3.2 Search results on mobile for routes around "Lagoa do Fogo", without any options to filter 22
3.3 Initial page of TrilhAR after clicking on a trail (left) and the extended trail information given when clicking on the information (i) button (right) [81] . 25
3.4 *Voices from the Trenches* - Belt used for proximity sensing (left), the historical clothing that inspired it (middle) and a participant using it in the ruins of an artillery site (right) [53] 27

4.1 Joëlette chairs being used in different types of terrain [25] [21] 35
4.2 Comparison between the map tab in the visual prototype (left) and the final app (right) 37
4.3 Example of data flow of request to narratives back-end which involves multimedia 40
4.4 Application build phases in Expo with EAS. For our platform, the final build resulted in an APK 42
4.5 Map component in the mobile client (left) and the narratives manager web platform (right) 44
4.6 System architecture 45

5.1 Flowchart illustrating the navigation flow between the main screens of the application . . . 49
5.2 Flowchart illustrating the navigation flow between the main screens of the map tab . . . 51
5.3 Flowchart illustrating the navigation flow between the main screens of the trails tab . . . 55
5.4 Some of the component in the trail's details page . . . 58
5.5 Flowchart illustrating the navigation flow between the main screens of the **Narratives** tab . . . 62
5.6 Search bar functionality in the trails, narratives and map pages . . . 64
5.7 Navigation Screen, and the resulting action from pressing two of the buttons on the right side . . . 66
5.8 Flow of navigation for a narrative . . . 68
5.9 Diagram sequencing the order of the download process . . . 72
5.10 Relational Data Model for the Narratives Database . . . 76
5.11 Initial state for the *Narratives Manager* - the back-office for the narratives back-end . . . 77
5.12 The back-office displaying a selected trail . . . 78
5.13 Forms and information to input for the narrative during **Step 2** (left) and respective stops, in **Step 3** (right) . . . 79
5.14 Narratives Manager before and after adding stops to a narrative . . . 80
5.15 Flowchart illustrating the sequence of requests and responses during the narrative submission process . . . 81
5.16 The newly added narrative in the *Narratives Manager* . . . 82
5.17 Map-related options available in each of the steps . . . 83

6.1 Age and Experience Distribution for the 1st Phase of Testing . . . 86
6.2 System Usability Scale (SUS) ratings for Phase 1 of testing, and general intuitiveness perceptions . . . 88
6.3 Age and Experience Distributions for Phase 2 of Testing . . . 89
6.4 General Intuitiveness Perceptions for Phase 2 of testing . . . 90
6.5 Age and Experience Distribution for the final phase of testing . . . 90
6.6 General Intuitiveness Perceptions for Phase 3 of testing, and the respective SUS ratings . . . 92
6.7 SUS Scores by participant, with average and minimum value threshold . . . 93
6.8 User answers from 1 (Strongly Disagree) to 5 (Strongly Agree) for questions 3 and 5 in SUS . . . 93
6.9 User answers from 1 (Strongly Disagree) to 5 (Strongly Agree) for question 7 of the SUS . . . 94
6.10 Correlation between SUS ratings and participant's experience level with trails applications . . . 94

6.11 Comparison between user's perceptions of the intuitiveness of the platform in the first (top) and last (bottom) phases of testing . . . 95
6.12 Comparison between user's perceptions of the design of the platform in the first (top) and last (bottom) phases of testing . . . 96

A.1 Portuguese Trails page when attempting to search for trails in Algarve . . . 113
A.2 Page for *Vereda do Areeiro*, a trail . . . 114
A.3 Search page showing there are no results for the search 'Areeiro' . . . 114
A.4 Map for a Trail in *Portuguese Trails*, showing the trail path but not any of the selected points of interest . . . 114

B.1 Original Empathy Map Template by *XPLAN* (adapted from [31]) . . . 115
B.2 Adapted Empathy Map Template . . . 116
B.3 Tatiana enjoys hiking as a hobby and uses a wheelchair . . . 117
B.4 Lucas enjoys hiking as a hobby . . . 118
B.5 Cristina is an Ultra-Trail runner . . . 119
B.6 Laura has no interest in hiking . . . 120

C.1 Initial pages for the *Trails*, *Map* and *Narratives* tabs . . . 122
C.2 Interaction flow for the *Map* tab . . . 122
C.3 Interaction flow for the *Trail* tab . . . 123
C.4 Interaction flow for the *Narratives* tab, including simulation of navigation . . . 124
C.5 Interaction flow between the three main tabs of the prototype . . . 125

D.1 Design for the logo of the platform . . . 127
D.2 The main screens of the app - Trails, Map, Narratives, Favorites and You . . . 128
D.3 *Toast* message warning users before they exit the application . . . 129
D.4 Initial loading and subsequent default tab: Map . . . 129
D.5 Example of layer selection on the map . . . 130
D.6 Selection of a trail on the map, displaying and zooming into the trail path and opening the bottom sheet with information . . . 130
D.7 Information in the bottom sheet for a trail without (left) and with a narrative (right) . . . 131
D.8 Showing the difficulty sections for a trail, along with the respective legend . . . 131
D.9 Showing the stops for a narrative in the map . . . 132
D.10 Showing directions to trail: clicking the button redirects to another application in the user's device, which will give directions to the trail's start point . . . 132
D.11 Selected trail in a typically 2D view (left) and with the map pitched, showing a 3D view (right) . . . 133
D.12 Map view of area around a trail before (left) and after (right) toggling various *Points of Interest*, such as Lodging, Parks and Landmarks . . . 133
D.13 Trails tab . . . 134

D.14 List of Trails as a result of pressing the title of the scrolling cards 135
D.15 Trails Details page, with respective sub-tabs - **Details** and **Accessibility** . . 136
D.16 3D Preview Page. Pressing the "Start Preview"will initiate an animation following the trail's linestring 137
D.17 Mini-map in the details sub-tab. Pressing it will show the trail on the **Map** tab 138
D.18 Interaction between the elevation graph and the Mini-map: pressing the graph will show the respective coordinates for that altitude on the Mini-map . . . 139
D.19 Button which redirects to another application which navigates to the trail's starting point 139
D.20 Weather component 140
D.21 Accessibility features displayed on the accessibility tab of the page for trail details 141
D.22 Interaction flow of the information on the sections of difficulty the trail is separated in, including an information popup for the terrain types 142
D.23 Narratives tab 143
D.24 List of narratives when pressing above scrollable cards (left) and when selecting a category (right) 144
D.25 Page for details of a specific narrative 145
D.26 Search bar functionality in the trails, narratives and map pages 146
D.27 Search functionality on the map, centering and zooming on the selected trail 146
D.28 Filtering modal 147
D.29 Result from applying filters in the trails tab 148
D.30 Navigation Screen, and the resulting action from pressing two of the buttons on the right side 149
D.31 Help Legend in the Navigation screen 149
D.32 Settings options in the Navigation Screen, enabling the option to show speed, altitude and the different trail sections classified by difficulty 150
D.33 Selecting an alternate trail to switch to during navigation 150
D.34 Flow of navigation for a narrative 151
D.35 Audio and Video Players for the application 152
D.36 Loading indicators for multimedia players while buffering 152
D.37 Favourites Tab, showing the bookmarks (left) and downloads (right) tabs . . 153
D.38 Process of adding or removing a bookmark/favourite, via the trail or narrative pages 153
D.39 User Progress tab, showing the option of starting to track a trail's narrative . 154
D.40 Different levels of progression for a narrative in the User Progress Tab . . . 154
D.41 Example of flow for trail download, allowing for the download to run in the background 155
D.42 Application behaviour when internet connectivity is severed 155
D.43 Example of language change in the platform, from English to Portuguese . . 156

E.1 Map Interaction . . . 158
E.2 Marker Differentiation . . . 158
E.3 Seeing trail on map . . . 159
E.4 Search Functionality . . . 159
E.5 Accessing Trail Information . . . 159
E.6 Accessing Narrative Information . . . 160
E.7 Accessing Difficulty and Terrain Type Information . . . 160
E.8 Accessing Accessibility Information . . . 160
E.9 Accessing Weather Information . . . 161
E.10 Handling Elevation Graph . . . 161
E.11 3D Visualization . . . 161
E.12 Trail Navigation . . . 162
E.13 Narrative Navigation . . . 162
E.14 Multimedia Interaction during Narrative Navigation . . . 162
E.15 Points of Interest . . . 163
E.16 Filtering . . . 163
E.17 Favourites . . . 164
E.18 Narrative Categorisation . . . 164
E.19 Downloads . . . 164
E.20 Offline Functionality . . . 165
E.21 Navigation Settings . . . 165
E.22 Intersecting Trails . . . 166

List of Tables

2.1 Nielsen's Usability Heuristics [63] [64] 8

3.1 Evaluation results for Portuguese Trails' usability 23
3.2 Comparison of Apps' Functionalities, including the application developed under this thesis: Tell me a Trail 28

4.1 Some functionalities present in the final platform which were inspired by the different needs of each interviewee from the Empathy Maps 32
4.2 Comparison between PWA, React Native, and Native Development 42

5.1 Most relevant changes made in the Map tab's components based on user feedback throughout development phases 53
5.2 Comparison between ISO 3021:2023 and Walk Hike Portugal difficulty classifications, and how it is mapped against the platform 61
5.3 Comparison of Search Bars Across Different Tabs 65
5.4 Examples of feedback mechanisms implemented in the *Narratives Manager* . 70
5.5 Different types of information present in the database and the object types used to represent them 75
5.6 Examples of feedback mechanisms in the *Narratives Manager* 83

6.1 Summary of each testing phase 85
6.2 Functionalities introduced in the first phase, and respective feedback 87
6.3 Functionalities introduced in the second phase, and respective feedback . . 89
6.4 Functionalities introduced in the third phase, and respective feedback . . . 91

Acronyms

AR Augmented Reality *(pp. 24, 25)*

FCMP Federação de Campismo e Montanhismo de Portugal *(pp. 2, 22, 55, 56)*

GIS Geographical Information Systems *(pp. 10, 39)*
GPS Global Positioning System *(pp. 14, 15, 26)*
GSM Global System for Mobile Communication *(p. 17)*

LBS Location-Based Services *(pp. 14, 15)*

OGC Open Geospatial Consortium *(p. 2)*
OSM OpenStreetMap *(p. 20)*

POI Points of Interest *(pp. 31, 32, 45, 53, 54, 73, 96)*
PWA Progressive Web App *(p. 41)*

SUS System Usability Scale *(pp. x, 85–88, 91–94, 96–98)*

UI user interface *(pp. 2, 6)*
UX User Experience *(pp. 5, 6, 9, 19, 22, 25, 28, 32–34, 47, 49, 59, 69, 84, 100)*

1

Introduction

This chapter begins by providing an overview of the motivation (Section 1.1) and context (Section 1.2) behind this thesis, as well as the problem being addressed (Section 1.3). It also outlines the expected contributions of the project (Section 1.4) and the structure of the document (Section 1.5).

1.1 Motivation

In Portugal and around the rest of the world, hiking has consistently ranked as one of the most popular types of outdoor activities [8]. Given its affordability and well documented positive effects on people's health [56], it has also stood as a forefront choice for tourism across all generations, to the significant benefit of smaller local economies [96].

However, with the growth of technology, we have ushered into an age where digital experiences have become increasingly woven into our lives, leading to different expectations from its users. With a constant need to innovate in order to promote the favourable perception of an experience, approaches that leverage the power of technology to make hiking more engaging are prioritized, even more so amongst younger generations [33].

When it comes to hiking in particular, its intersection with technology could come in different shapes for different demographics:

For a large number of people, being close to nature is a sufficient incentive to go hiking [48], as exposure to green spaces and landscapes has been shown to be associated with greater health and happiness [1]. In this case, the role of technology is informational, a way for hikers to discover new trails and obtain information about them.

On the other hand, there are people for whom hiking might not be of interest at first glance, but who could become interested if there was a more adventurous or interactive component to it. An example - though not the only demographic to whom this applies - would be younger generations: a 2019 online report by the Global Web Index [1], across 45 countries, stated that the average *Generation Z* respondent spent more than 4 hours per day on their mobile phones, with more than 60% admitting they were "constantly online".

[1] https://www.gwi.com/hubfs/Downloads/201920Q120Social20Flagship20Report.pdf

For these demographics, technology could support the creation of a tool through which to enhance the traditional walking experience. By incorporating interactive elements, such as narratives, it could make the experience more engaging, informative, and immersive [82].

Finally, if developed correctly, these technologies can be used to create a tool to help address accessibility concerns in hiking. The physical capabilities of hikers can significantly restrict their choices [57]. Therefore, for sections of the population with limited mobility or other impairments, providing information regarding which trails are accessible to them would be beneficial and allow a larger number of people to enjoy the hiking experience.

As such, this work was an effort to explore an approach to hiking web platforms which sought to leverage the power of digital storytelling and interactive narratives to enhance the way users interact with the trails they traverse, while taking into account the needs of different types of hikers.

1.2 Context

This thesis has been developed in sequence of A. Morais' thesis [58], who initiated the development of an integrated platform using standardized hiking data for Portugal, as well as its respective user interface (UI). The elements developed by Morais bore relevance to the upcoming project, but, given the different scopes of our theses, the similarities were tangential.

This thesis is also part of a broader project, developed under an ongoing partnership with the *Department of Sports Science of the University of Beira Interior* (UBI)[2] and the *Polytechnic Institute of Setúbal* (IPS)[3]. The project was collaboratively undertaken with my colleague Ana Tavira, who developed a parallel thesis in this ambit. The scope of her efforts was around the development of the platform's repository and API on hiking data, developed in agreement with the Spatial web service metadata standards created under the umbrella of the Open Geospatial Consortium (OGC). The other part of the project - which this thesis focused on - made use of this data while prioritizing user experience for diverse user profiles and the front-end development of the platform.

1.3 Problem Description and Objectives

Portugal has a very vibrant hiking community, with the Federação de Campismo e Montanhismo de Portugal (FCMP) having defined a standardized nomenclature for the hiking paths available in the country [26]: "Pequenas Rotas" (PR), "Grandes Rotas" (GR) and "Percurso Local" (PL)[4]. Because of both occasional hikers and as a result of the rising popularity of activities like Trail Running [43], there has been an increased awareness

[2] https://www.ubi.pt/Entidade/Departamento_de_Ciencias_do_Desporto
[3] https://www.estsetubal.ips.pt/
[4] PR - distance of up to 30 km, GR - more than 30 km and PL - most of the path in an urban environment

of the existence of these spaces, as well as further incentives for investing in them and in their cataloguing. "Turismo de Portugal" [5], the official governmental resource for travel and tourism in the country, has consistently considered these hiking routes to be instrumental for the national tourism market; their official tourism strategy for 2027 reflects a commitment to investing in this domain [92]. However, despite all this, there have not been many attempts to catalogue and provide availability to these trails in a consistent, integrated and standardized manner. "Visit Portugal" [6] (belonging to "Turismo de Portugal"), has a page dedicated to all of these trails, but it suffers from a lack of intuitive usability and standardized units, among other things detailed in the later section 3.1.2.

Moreover, a survey undertaken by the *University of Aveiro*, comparing Portuguese hikers against foreign ones, revealed that Portuguese hikers tended to prefer navigation and guided paths (which are lacking in tools like 'Portuguese Trails'), while also being more susceptible to feelings of 'boredom' in nature [75]. As such, issues like the absence of navigational tools or lack of engaging features could negatively impact these users' enjoyment of the hiking experience. The same applies for other demographics: for instance, the absence of accessibility information can potentially exclude users with mobility impairments from the experience altogether.

Given the presented problem, the main goal of this project was the development of an interactive platform for hiking paths in Portugal, which aimed to address the evolving expectations of different types of users. By including detailed trail data, guided navigation and an emphasis on interactive approaches, we aimed to showcase Portugal's hiking trails to a broader audience, including younger generations and people who may be deterred from hiking due to limited mobility or physical impairments.

1.4 Main Contributions

As a result of the work developed for this thesis, its contributions have been identified as the following:

- **Development of user friendly interface for a repository with standardized hiking data** from Portugal, mainland and islands, featuring detailed information about these paths, trail search and filtering, navigation, progress tracking and offline capabilities, as well as other key functionalities implemented throughout iterative phases of development;
  - **Integration of interactive narrative experiences** in the interface, with the use of multimedia elements to experience during trail navigation;
  - **Contribution to inclusivity** by addressing accessibility concerns and making hiking experiences accessible to a broader audience, via trail accessibility information and language customisation;

[5] https://www.turismodeportugal.pt
[6] https://www.visitportugal.com/pt-pt/content/passeios-a-pe

  - **Continuous testing and iterative development**, conducted across three phases, to gather user feedback, validate usability, and refine the platform's features based on real-world user behaviour and needs.

- **Development of a back-end system and back-office** to manage the narratives integrated into the mobile interface.

1.5 Document Structure

This paper is divided into 7 chapters, which are as follows:

1. **Introduction** This initial chapter provides an overview of the problem to be approached and the motivation driving its exploration. It also places the project within a broader context and outlines the objectives and contributions that this thesis aimed to deliver.

2. **Fundamental Concepts** This chapter presents the essential concepts crucial for the development of this project, focusing on aspects related to usability, geographical and location systems, and interactive narratives.

3. **Related Work** In this section, projects of relevance to the ongoing thesis are explored, with an emphasis in projects developed in Portugal

4. **Solution Design** This chapter outlines the process of designing the solution, detailing the application's requirements, the chosen technologies and frameworks, and the system's general architecture. It also explains how this architecture relates to the API developed by my colleague alongside this project

5. **Solution Implementation** Considering the requirements detailed in the previous chapter, the fifth chapter explains how the major system's functionalities were implemented, and how they evolved throughout the different development phases

6. **Solution Evaluation** This section encompasses a thorough explanation of the iterative usability testing carried out for the system, and how user feedback across three testing phases informed the development of the interfaces.

7. **Conclusion** The final chapter reflects on the outcomes of the project, summarizing the key contributions and discussing potential future evolutions for the developed system.

2

Fundamental Concepts

This chapter lays the theoretical foundation necessary for the development of this thesis. We explore core concepts related to the interactions between humans and computers, such as Usability and Accessibility. Following this, we analyse how these interactions can intersect with storytelling via Interactive Narratives. Considering the map-based interface developed in the hiking platform, we then go into detail regarding Geographical and Location Systems and Location-Based Services (LBS).

2.1 Human-Computer Interaction

In the digital era, the success of an application is not solely determined by its features or functionalities, but it also hinges on the seamless interaction between humans and software. Within this context, *Human-Computer Interaction* refers to the way users and machines interact with each other, taking into account the impact of interface design, Usability, and the overall User Experience [22]. As understanding these dynamics is crucial for shaping how individuals interact with the systems we develop, this section delves into its foundational elements.

2.1.1 User Experience

User Experience (UX), though complicated to officially define due to how multidisciplinary it is as a concept [6], encompasses all aspects of a user's interaction with a product, system, or service. It involves the user's perceptions, emotions, and behaviours as they engage with a given interface, device, or application. As defined by UX pioneers Nielsen and Norman, the goal of UX design is to craft experiences that not only fulfil the customer's needs, but which are also meaningful and enjoyable, ensuring that their needs and expectations are met while being satisfying to use [89]. The definition also emphasizes that, even though UX is directly tied to usability, they are different concepts, as explained in section 2.1.2.

An example of a few considerations relevant for UX design are:

- **Engagement** - Beyond functionality, creating experiences that captivate and hold

the user's attention is essential to UX design. [10]. Elements like gamification, storytelling, and interactive features, which will be explored in section 2.3, are examples of this;

- **Consistency** - Inconsistent design elements can be confusing and lead to decreased efficiency and unintentional errors [62], so prioritizing familiar and uniform elements is a critical aspect of the design process;

- **Accessibility** - Expanded in section 2.1.3, accessibility is about making digital platforms inclusive, considering the diverse needs of different types of users;

- **Aesthetics** - While a subjective point, user perception is strongly influenced by visual attractiveness of a design, and it often plays a pivotal role in shaping initial impressions, engagement, and overall user satisfaction [91].

2.1.2 Usability

Usability is a concept which inserts itself into the broader realm of *User Experience*, but is distinct from it. While UX encompasses the entire process of a user interacting with a product, usability focuses specifically on quality attributes of the UI, i.e. whether the system is easy to learn and pleasant to use [46].

Official definitions have varied throughout the years and, in the early 90's, there were already a host of different subjective views over how usability should be measured and defined. N. Bevan et al. [7] compiled these views as:

- *product-oriented* - usability should be mainly measured in terms of the attributes of the product being used;

- *user-oriented* - usability measured according to the attitude or effort of the user;

- *user-performance* - measurements based on how well the user actually interacts with the the product.

Therefore, a 1988 definition which stated "Usability is the degree to which users are able to use the system with the skills, knowledge, stereotypes and experience they can bring to bear" [24] would fit within the *user performance* view.

As the years passed, and with usability as a concept being applicable across so many different domains [15], the multitude of definitions kept increasing. Currently, the official ISO definition stands as "The effectiveness, efficiency and satisfaction with which specified users achieve specified goals in particular environments" [39], but a simpler concise definition would be that, in short, usability is a measure of how easy something is to use.

2.1.2.1 Usability Engineering

As usability is closely linked to a system's efficiency and the satisfaction users experience while interacting with it, there is a need for actionable insights into how to optimize the user interface. This is where usability engineering comes into play.

In his seminal book "Usability Engineering" [64], Nielsen delves into crucial methodologies and principles aimed at enhancing usability. In his framework, he emphasizes the significance of certain "measurable" attributes, which are:

- **Learnability** - How easily users can grasp and become proficient with the software. A highly learnable interface is crucial as it reduces time and effort for users;
- **Efficiency** - Takes into account how quickly a user can perform tasks in the system, once they have learnt it;
- **Memorability** - The ease with which users can remember how to use the software after a period of not using it;
- **Errors** - A measure of how many errors users make, how severe they are, and how easily it is to recover from them;
- **Satisfaction** - Beyond functional aspects, a subjective measure of how content users are with the software is also necessary.

While Nielsen's attributes provide a robust foundation, different ones that complement and extend beyond these principles have been proposed throughout the years [51], such as ISO 2510's "User Interface Aesthetics" and "Accessibility" [38].

In addition to evaluating an interface around these attributes, Nielsen also set a series of heuristics (Table 2.1) for developers to take into consideration, such as "Visibility of system status", stating that the system should always keep the user appraised of its status through proper feedback, or "Recognition rather than recall", which suggests that the system should present pertinent information in a format that is easily identifiable, so users do not have to memorize information.

Something to note is also the importance of concentrating usability engineering efforts during the design phase of the development cycle: In a literature review of 150 usability studies, around 71% of studies addressed usability related issues during the design stage [79], which highlights the importance of proactively addressing potential usability issues before they become entrenched in the development process.

2.1.2.2 The role of Users

While discussing usability engineering, one of the most important aspects underlined by Nielsen and others, is the role of the *user* [64].

The first step of the usability engineering process is "Know the User", since understanding the target audience - their technical expertise, cultural and economical background,

age group, among others - means designers can tailor the user interface to suit the users' specific requirements. This is directly tied to the importance of *User Research*, which was conducted in a small scale for this thesis in order to ascertain the needs of different types of potential groups who will use our interface.

Testing is also another major field where users can actively contribute to the refinement of a system, particularly through *Usability Testing*. It involves real users interacting with the system to identify potential issues and areas of improvement, which developers or experts might not have found given their familiarity with the system or ease at handling technology [77].

However, it should be noted that, as Nielsen mentions, "Users are not Designers": While users play a vital role in uncovering usability issues and providing valuable feedback, their input may not necessarily translate into design expertise. Design decisions often require a deeper understanding of usability principles and technical constraints, and users, despite their insights, might not possess the expertise needed to envision comprehensive design solutions, or foresee the implications of certain choices.

Heuristic	**Description**
#1: Visibility of System Status	Keep users informed of what is happening through appropriate feedback
#2: Match Between System and the Real World	Use words, phrases, and concepts familiar to the user
#3: User Control and Freedom	Provide ability to easily navigate back or undo actions
#4: Consistency and Standards	Maintain consistency across the UI, following established design patterns and industry standards
#5: Error Prevention and Recovery	Avoid possibility of errors via warnings and constraints
#6: Recognition Rather Than Recall	Minimize the need for memorization by making information visible and easily retrievable
#7: Flexibility and Efficiency of Use	Cater to both novice and expert users; E.g.: offering shortcuts for frequent tasks
#8: Aesthetic and Minimalist Design	Aim for a design that both visually appealing and minimalist
# 9: Help users recognize, diagnose, and recover from errors	The design should help the user identify and find solutions to eventual problems, as well as recover from them
#10: Help and Documentation	Provide clear and accessible help when needed (but also create an interface that is intuitive without relying on external assistance)

Table 2.1: Nielsen's Usability Heuristics [63] [64]

This highlights the importance of other types of usability evaluation methods, such as *Heuristic Evaluations*, where actual experts systematically assess the user interface against established usability principles or heuristics. One example of these are the aforementioned Nielsen Heuristics (Table 2.1) mentioned in the previous section. While there are many types of methods for evaluating usability engineering, *heuristic evaluations* and *usability testing* often play the major role, and the best UX results often result from incorporating both types of evaluation methods during the usability engineering process [36].

2.1.3 Accessibility

One of the usability attributes that the *International Organization for Standardization* has set in ISO 25010 is the concept of "Accessibility", defined as the "degree to which a product or system can be used by people with the widest range of characteristics and capabilities to achieve a specified goal in a specified context of use" [38].

Figure 2.1: Concepts of *Usability*, *Inclusive Design* and *Accessibility* encompassed within *UX design* (adapted from [39] to include *Inclusive Design*)

Comparative studies on usability and accessibility have drawn similarities between the two, while revealing that accessibility issues tend to be more frustrating than the usability ones: Lack of accessibility can often be a complete impediment to using the technology, while usability issues are often nuisances which "simply" necessitate a learning curve. In a study conducted with sighted and blind people interacting with two websites [72], the blind participants had considerably smaller success rates than their sighted counterparts, and noted many more issues. Many of those issues did not fall under the "usability" umbrella, but under the "accessibility" one, as they were specific to the blind participants and were of no consequence to the sighted ones.

These types of issues emphasize the importance of adhering to certain accessibility standards, which can ensure that digital platforms are inclusive for users with diverse abilities. *The World Wide Web Consortium* [1] offers a set of comprehensive guidelines in

[1] https://www.w3.org/

this domain, covering aspects such as text alternatives for non-text content, keyboard accessibility, and adaptable content. These features aim to create a universally accessible digital environment, particularly for those with visual, auditory, or motor impairments [17].

Concepts like *Inclusive Design* [71] - which involves considering the needs of all possible users throughout the design process - are also often used interchangeably with *Accessibility*, but while accessibility focuses on designing for disabled groups, inclusive design is meant to emphasize the need to consider people *with and without* impairments simultaneously. However, designing for the broadest range of users is a difficult endeavour because some user groups may have contradicting needs, specially in a platform related to hiking trails. For example, while an app with few options and simplified navigation benefits users with cognitive impairments or who are less technologically-savvy, inclusive design prompts the consideration of users who may seek advanced functionalities and more customisation options.

As Sauer et al. [80] notes "Designing for different user groups often requires a compromise. Such a compromise may be in conflict with the idea of designing for special groups of users. Therefore, it is important to determine whether designing for a specific user group will only provide benefits to the target group or whether other users (e.g. non-disabled users) would benefit, too."

2.2 Geographical and Location Systems

Creating an application that incorporates hiking data fundamentally revolves around geographical information, in particular the way it is presented. In the digital world, Geographical Information Systems (GIS) encompass the hardware and software which handle the way this geographical information is stored, managed and visualized [13], with Geographic Visualization being the cornerstone of GIS's ability to present data and Location-Based Services (LBS) facilitating real-world navigation of the maps that represent this data.

2.2.1 Geographic Visualization

Geographic Visualization involves providing tools for the analysis, exploration and presentation of geospatial data, using specialized techniques designed for spatial understanding. These can include approaches from exploratory data analysis (EDA), GIS, and cartography, among others [66] [50]. In the context of hiking apps, effective geographic visualization through cartography can aid users in understanding trail routes, terrain features, and points of interest, enhancing their overall navigation experience.

MacEachren and Kraak defined the goals of geographic visualization on the basis of 3 dimensions [49]. These are:

1. **interaction** - The degree of user control over the visualization and the ability to manipulate the data, ranging from *low* to *high*;

2. **audience** - The intended audience for the visualization, taking into account factors like their expertise. A *public* visualization is intended for wider audiences, while a *private* one is catered for specialized groups;

3. **information** - the level of detail and information known to the user. On one end users are directed towards revealing the *unknown*, taking on a more exploratory mindset and generating new information. On the other end, users are able to directly access already *known* spatial information.

Additionally, there are four visualization goals set diagonally across a spectrum, which contrasts interactivity and exploration with pure data presentation: on one extreme, *Explore* emphasizes providing users with a dynamic interface for discovering new geographical areas, with a particular focus in interactivity with visualization. Next, the *Analyze* goal addresses the need for the interpretation of spatial information (for example, clicking on map markers to see the details of a geographical point), while *Synthesize* focuses on the integration of multiple spatial data sources into a single, coherent view. Finally, the other end of the spectrum - *Present* - focuses on the actual visual presentation of the geographical data.

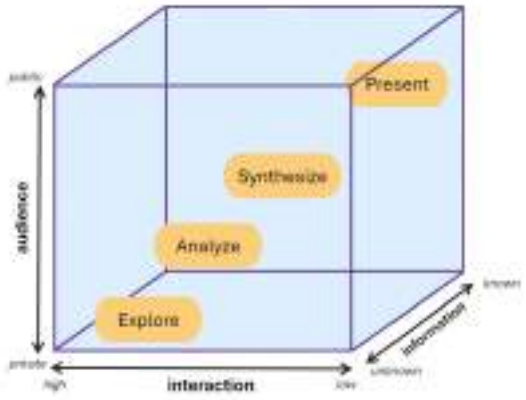


Figure 2.2: The Map Use Cube modeling visualization goals with respect to three dimensions (adapted from [49])

All of these aspects form the *Map Use Cube* (Fig. 2.2), which serves as a comprehensive framework that spans the spectrum of geospatial interaction and visualization. In the context of any geographical interface being developed, taking these elements into consideration allows developers to approach geospatial visualization from a broader perspective, taking into account not just visual appeal and other usability aspects, but also what they might want their interface to focus on. For example, the interface that was developed under this thesis occupies a space in the *Map Use Cube* with a high degree of user *interaction*, catering to a diverse and public *audience*, and providing known *information*.

2.2.1.1 Cartographic Design

An essential aspect of providing a map-based interface which conveys information effectively are the principles of Cartographic Design, which involves the art and science of how maps are designed. When developing a static map-based interface, considerations have to be taken into account regarding, for example:

- **Color** - Choosing colours that are distinguishable, but without overwhelming users with too many colours. Additionally, given that between 2 to 8% of men suffer from colour blindness worldwide [14], cartographic color design should also take this condition into account [40];
- **Symbolization** - Using recognizable and consistent symbology to represent different features (such as points of interest) can massively impact the user experience with the map [23]. In the same vein, proper typography improves readability of map labels and other writing;
- **Scale and Generalization** - Map Generalization involves adjusting the level of detail in maps based on the scale, ensuring that users receive clear and relevant information without overwhelming them. High-detail maps may be necessary for zoomed-in views, while broader overviews may require simplified representations. This relates to the concept of abstraction in maps. Since maps usually filter out unnecessary details of the environment in order to highlight interesting information, the challenge lies in striking a balance between realism and abstraction in geovisualization in order to provide the best experience [66];

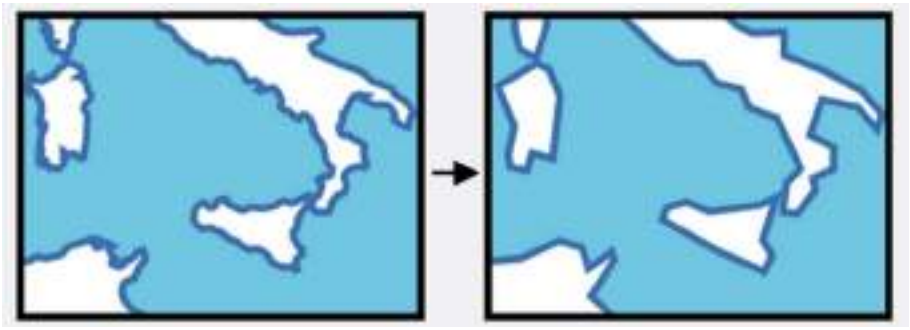


Figure 2.3: Example of generalization in a 2D map, via the simplification of geographic borders [76]

Many of these cartographic design principles relate to the aforementioned usability attributes and heuristics in section 2.1.2.1. For example, using recognizable symbols or consistent colouring patterns directly benefits the heuristic of "Recognition rather than recall" and improves the *Learnability* and *Memorability* of our interface.

However, when dealing with geographical visualization, the scope of cartographic design should extend beyond the limitations of static maps: this is when *interactivity*

can be implemented, in order to improve map interaction. This can encompass a range of functionalities: from simpler ones such as zooming in and out, to animation and 3D mapping [66]. J. W. Cranton [18] identifies 4 different interactivity types for geographic visualization:

- **Data** - Focuses on how to identify and select pertinent information and patterns in the geospatial data, via *Filtering*, *Highlighting*, and other functionalities;
- **Data Representation** - Showing different perspectives of the data, by *zooming in and out* or changing *map orientation*;
- **Temporal Dimension** - Incorporates the concept of a display continuously changing, usually in response to movement. The most prevalent example are maps with *navigation* features;
- **Contextualizing Interaction** - Places emphasis on the context in which data appears, and how that can affect decision-making. For instance, *combining layers* in a map or seeing *multiple views* of the same data can offer different insights.

Taking into account these interactive components, along with the map design considerations, will be crucial for optimizing map interaction within the context of the hiking platform.

2.2.1.2 Map Visualization Software

Leveraging tools focused on map creation and display can not only enhance the user's understanding of geospatial data, but also provide developers with increased customisation and flexibility. Many map visualization software platforms streamline the integration of diverse geographic features and data, offer various plug-ins and foster active user communities, all of which can significantly facilitate development.

For 2D Cartographic visualization, software such as *Leaflet* [2] can offer a lightweight and customizable solution for integrating maps into web applications. *Leaflet* is open-source and can be used in diverse applications to facilitate the development of map-based functionalities. Similarly, other software such as *Mapbox*[3] or *Google Maps Javascript API*[4] also offer geovisualization functionalities, in addition to various APIs for navigation and other features.

On the other hand, incorporating 3D terrain visualization is also a possibility, as it enhances the user's perception of the environment and can provide a more immersive and realistic experience of the locations, highlighting elevation changes, terrain variations, or other aspects. *CesiumJS*[5] is an open-source JavaScript library which can aid in this

[2] https://leafletjs.com/
[3] https://www.mapbox.com/
[4] https://developers.google.com/maps
[5] https://cesium.com/platform/cesiumjs/

respect, as it allows for the development of interactive 3D globes and maps with varying geospatial data. *Google Earth*[6] is also a powerful and popular tool for 3D visualization, as it provides detailed 3D models of maps and worldwide satellite coverage.

Figure 2.4: Geographic Visualization of NOVA School of Science and Technology in *Leaflet* (left) and *CesiumJS* (right)

2.2.2 Location-Based Services (LBS)

Location-Based Services (LBS) refer to technologies that leverage geographical information to provide users with information tailored to the location and context of the device [42]. Most of these services make use of location-aware technology, such as Global Positioning System (GPS), a satellite-based navigation system which detects accurate positioning anywhere on Earth. GPS still remains the cornerstone for the majority of applications employing LBS, as the majority of the world's states have invested and now heavily depend on the Global navigation Satellite System (GNSS) [35], to which GPS belongs.

However, other positioning technologies also exist, such as Wi-Fi positioning - which estimates a device's location based on nearby Wi-fi access points - or cellular triangulation, which utilizes signals from multiple cell towers. Currently, devices are able to provide location information through a combination of these various technologies [85]. In the context of mobile devices, the availability of these location-aware technologies translates into the ability of running applications which can then provide location-based services (e.g. GPS allowing for car navigation).

LBS can be applied across a variety of domains, which have only increased in number through the years. Huang et al. [37] list some of them as:

- **Transport and Navigation** - Car and walking navigation systems are among the most common and widespread types of technologies which employ LBS, allowing for real-time location information;
- **Gaming** - Related to the topic of gamification, games with LBS typically make use of a user's position to activate certain game mechanics and foster a more immersive location-based experience;

[6] https://earth.google.com/web/

- **Social Networking** - Social media platforms extensively employ LBS, particularly to allow users to connect with nearby friends or get location-based content and advertisements;

- **Fitness monitoring and healthcare** - Location-based services in a health context are common due to a variety of applications, watches and other devices which monitor user's location in order to provide fitness or health data;

- **Assistive Technology** - In the realm of accessibility, LBS can work to aid people with visual and mobile impairments, allowing for assisted navigation or obstacle detection, among others.

For a hiking app, Location-based services translate into opportunities to enhance the experience of the trails in various ways. For instance, LBS can provide real time trail navigation via GPS, suggest optimal hiking routes based on the user's current location, alert users about nearby points of interest, and even offer safety features like tracking lost hikers. Navigation, in particular, is of considerable relevance and can prompt the implementation of *Proximity Sensing* - the detection and measurement of the distance between a device and nearby objects - as interactive elements might need to be activated according to the proximity of the user to certain geographical points (i.e. points of interest, landmarks).

2.2.3 Offline Navigation

Offline functionalities involve the capability of a system or application to function without a continuous internet connection [95]. In the context of navigation, it allows users to access maps, routes, and location-based information even in areas with limited or no network connectivity, which might be a considerable concern for hikers [61].

In the context of a hiking application, *Offline Maps* and some sort of *Local Storage* can be applied. With the former, the application stores pre-downloaded maps on the device, while the latter involves storing additional navigation data, such as routes or points of interest. Each of these elements depend on the geographic visualization software chosen, as well as the client framework. For example, *Mapbox's* SDK downloads the map into phone storage, which can then be used in a map view later [47].

Offline navigation grants several advantages when it comes to hiking interfaces:

- **Offline Accessibility** - Facilitates navigation in trails and outdoor areas where internet connectivity is limited or unavailable. This can be particularly advantageous in remote locations;

- **Reduced Data Usage** - By using pre-downloaded maps and navigation data, offline navigation minimizes the need for continuous data streaming, resulting in reduced data consumption and fewer costs with mobile data

- **Improved Battery Life** - Since the device does not rely on constant data fetching, offline navigation can contribute to improved battery life during extended hiking trips. The device can focus on GPS functionality without excessive internet-related power consumption.

2.3 Interactive Narratives

Humans have a long history of sharing and being captivated by stories. Across cultures and civilizations, storytelling has served as a vessel for passing down wisdom and as a source of our collective identity as a species, with a massive role in shaping our societies and interpersonal relationships [83].

Over the years, as we transitioned into the contemporary era, storytelling underwent a digital renaissance, with one example being the emergence of interactive narratives - storytelling experiences that allow users to actively engage with a narrative.

Unlike traditional linear storytelling, interactive narratives allow users to enjoy an experience that goes beyond passive consumption, with great potential in driving interest and engagement in the digital domain [55].

Interactive narratives can also take many different shapes according to the context they are being applied to, but recent years have seen a surge of their application in historical or educational contexts [60], where they have been recognized as an effective method for the presentation of the past in a cultural heritage context [16]. In this context, interactive narratives hinge on engaging Digital Storytelling aspects, with elements of Gamification [68] aiding in their structure.

2.3.1 Digital Storytelling

Digital storytelling makes use of multimedia elements and technology to convey narratives. When implemented in a compelling manner, it can be a strong approach to promote engagement in certain activities, capturing the attention of users who might not otherwise have interest in them.

B. Robin has identified three main types of digital storytelling in an educational context [74]:

1. **Personal Narratives** - stories revolving around personal experiences, usually emotionally charged and personally meaningful

2. **Historical Documentaries** - stories which convey past events from history, frequently in a factual manner but also dramatized for audiences

3. **Stories that inform** - stories designed to factually inform or instruct the viewer on a particular concept or practice

Each type can be leveraged according to different contexts, with approaches ranging from pre-defined narratives with low degrees of interactivity to more dynamic experiences. A hiking app, for instance, might be adorned with narratives of all these types, which the user can choose according to their tastes: in this case, the benefits would be two-fold - the hiking activity is promoted, as well as the stories associated with the trail.

Pujol et al. [73] highlights the impact of these interactive narratives and storytelling for cultural heritage, as well as its effectiveness in promoting curiosity: even if a person might not be interested in museums or art (or, in this case, hiking), digital storytelling serves as a conduit for conveying information in a more memorable manner, inspiring users to experiment new things.

In the case of hiking, being in nature has been linked to numerous positive cognitive and health benefits [56] and it has been shown to evoke strong feelings of amazement and wonder [3]. These experiences, in turn, often translate into heightened levels of reported happiness and life satisfaction [78], so developing a platform which engages users with narratives on the trails might serve as a catalyst for more people to appreciate and value the hiking experience.

Finally, we should not be remiss to mention the possible impact of interactive narratives in accessibility. The inclusion of alternative mediums of interaction such as audio or transcripts of narrative elements are to be considered, as previously commented in section 2.1.3. However, under certain contexts, interactive narratives can also serve as tool to allow those with impairments to enjoy experiences they might not usually have access to. For example, a blind person may listen to a narrative retelling and immerse themselves in it, which is an experience usually visually-based [94]. Additionally, the inclusion of sound as a medium serves as an example of inclusive design, as it also enhances the experience of people without visual impairments by allowing them to focus on the hike itself, while enjoying the narrative.

2.3.1.1 Location-Based Storytelling

Digital interactive narratives are location-based, which means they are intricately tied to specific geographic locations. Whether in hiking platforms or otherwise, this concept allows for the integration of storytelling elements that unfold based on the user's location. As such, these narratives are directly tied to the concept of Location-Based Services (LBS), as various technologies (such as GPS, QR codes, and augmented reality) can be used to deliver stories and information relevant according to the user's surroundings.

One of the earliest examples of an app employing location-based experiences was *Botfighters* [67] [84], a 2001 mobile game where players used text messages to battle other players' robots on the streets, using the Global System for Mobile Communication (GSM)[7] network to locate and track opponents. *Botfighters* included some story elements, but they

[7] Unlike GPS's satellite navigation, a GSM network used cell towers with unique identifiers (CID) and estimated the approximate location of a mobile device by the tower it was connected to [59]

Figure 2.5: Example of *Botfighters* mobile interface [84]

were not central to the app and did not create a conventional narrative arc [86]. More recent location-based apps, such as the ones mentioned in the next chapter, make a more relevant use of the narrative aspect.

2.3.2 Gamification

In the competitive landscape of tech companies, efforts to develop engaging technology are a priority. Users often report a quick loss of interest when their online experiences are unsatisfactory, with retention rates being significantly impacted [2]. For example, in a 2023 report covering app installs across 17,000 apps, retention rates dropped from 25% in the first day of using the app, to less than 4% after a month of usage [34].

To address these issues, developers have often invested in persuasive and motivational technologies (e.g. gamification) [20], which involves integrating competition, rewards and challenges into non-game contexts to enhance engagement. Examples of this can be [19]:

- **Points and Rewards Systems** - Users earn points through their interactions or achievements, and these points can be redeemed for rewards or used to unlock additional features;

- **Levels and Progression** - Users advance through different stages or levels, adding a sense of continuous improvement which can encourage them to stay engaged [97];

- **Narrative Challenges** - Incorporate challenges such as solving puzzles or completing tasks within a narrative framework, adding a further interactive component;

- **Social Interaction and Leaderboards** - Displaying user achievements, progress, or scores on leaderboards can foster a sense of competition and motivating users engagement.

In a study attempting to use a gamified mobile app to increase student engagement, researchers at the Springer Open Journal [69] suggested that the introduction of a gamified app with badges and reward systems increased student retention rates and academic

performance. However, as the study points out, the "novelty effect" [8], might skew the results not just in their case, but in other types of applications with gamification elements.

On the other hand, different demographic needs will also result in different experiences regarding gamification. In [70], older groups had no interest in gamified elements and often found them intrusive, so a balance needs to be struck between driving engagement while listening to users and keeping our interfaces consistent with UX design principles. As A.F. Utami notes [93]: "Interactivity (...) emerges as a key vehicle for customer engagement but needs to be considered in conjunction with value judgments regarding the service quality.".

2.4 Discussion

In this chapter, the objective was to explore the fundamental concepts behind the trail platform developed for this thesis. The initial section discussed human-machine interaction, mainly how usability and accessibility can affect how users interact with software. Given the diverse number of factors to take into account when designing an interface (such as usability heuristics), it stands that incorporating user-centric principles in the development process should not be an afterthought, but part of the development process.

Next, we discussed concepts related to geographical and location systems, with an emphasis in geographic visualization and how it relates to map design and UX. Concepts relevant to location-based services were also mentioned, including offline navigation and its benefits.

The final section addressed interactive narratives, and how storytelling and gamification can create immersive experiences and impact accessibility. However, we also emphasized the importance of balancing these interactivity features with user preferences and adherence to UX design principles. The discussion also extended to how interactive narratives can inspire curiosity and engagement with hiking trails: given the many benefits of being close to nature, a platform intertwining narratives with hiking may lead more people to discover and appreciate those trails.

In the following chapter, these insights and concepts will be relevant for analysing, in a comprehensive manner, the works related to this thesis' project.

[8] Phenomenon in which individuals experience initial excitement or heightened interest when exposed to a new or novel stimulus

3

Related Work

Given the immense popularity of hiking worldwide, a diverse array of web interfaces and mobile applications have already been developed to cater to the needs of its enthusiasts. As such, this section aims to provide an overview of those interfaces, with section 3.1 focusing on software which provides information about hiking trails and their navigation, while section 3.2 addresses apps which implement interactive narrative elements in those trails, with a special focus in Portuguese examples.

3.1 Trail Platforms

This section will present platforms which aggregate information about hiking trails in Portugal. The initial focus will be on *AllTrails*, a globally-recognized platform, followed by *Portuguese Trails*.

3.1.1 AllTrails

AllTrails stands as one of the most popular hiking platforms, showing up as the first (non-sponsored) result in the *Play Store* and the *App Store* when searching "hiking" or "trails". It offers a vast database of trails, ranging from easy walks to challenging hikes and, given its availability for both desktop browsers[1] and mobile[2], it is convenient for planning trails and then exploring them via guided navigation.

Beside its extensive database, AllTrails also offers trail maps, elevation profiles, GPS tracking, weather warnings and other detailed trail information (Fig. 3.1). Additionally, 3D maps for a visualization of the trails and offline navigation are also available, though under a paywall.

From a usability perspective, AllTrails' interface is intuitive in both the website and app, with a simple but understandable design and a *Mapbox*-based Map[3] which uses OpenStreetMap (OSM)[4]. OSM is a collaborative open-source mapping project providing

[1] https://www.alltrails.com/
[2] https://www.alltrails.com/mobile
[3] https://www.mapbox.com/
[4] https://www.openstreetmap.org/about

free and open geographic data, with great utility in location-based services, where AllTrails is included.

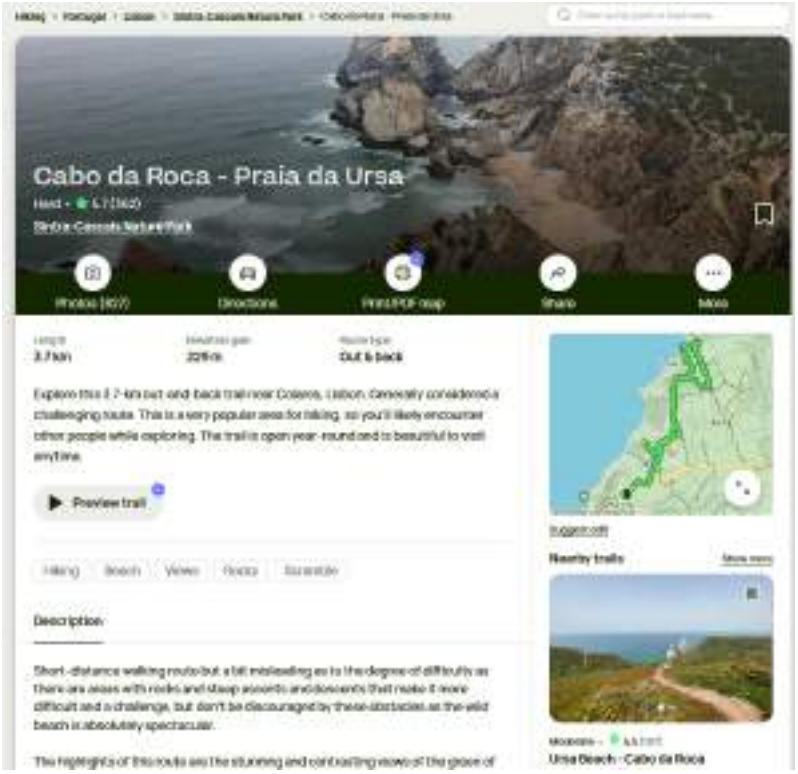


Figure 3.1: Partial view of web page for a trail in *AllTrails*

Another integral feature of AllTrails is its crowdsourcing aspect, allowing users to contribute with reviews and photos. However, since anyone can submit their trail data onto the platform, there is a lack of standardized trail information, with repeated trails and misinformation being a common occurrence.

As a result, when searching for a specific trail, the user can be faced with dozens of different options, some of them duplicated under different names. Moreover, the platform's very good and extensive filtering system (including options for trail difficulty, elevation and even wheelchair-accessibility), does not seem to be usable when making a specific search: For example, searching for hiking routes around *Lagoa do Fogo* (Azores Islands) yields dozens of results (Fig. 3.2), without any way to differentiate between them except by opening each one individually.

AllTrails also does not provide much accessibility information, or details about points of interest around the trails themselves. The user may also be reduced to using other navigation apps like *Komoot*[5] or *Gaia GPS*[6] in tandem with *AllTrails*, in order to overcome the navigation issues of the latter.

In conclusion, AllTrails is a successful resource in its genre and its accomplishments have informed the development of this thesis project, particularly in terms of trail data

[5] https://www.komoot.com/
[6] https://www.gaiagps.com/

Figure 3.2: Search results on mobile for routes around "Lagoa do Fogo", without any options to filter

and UX design. However, it lacks a dedicated navigation system and some important information, like accessibility details and points of interest. Additionally, some key functionalities remain locked behind a paywall.

3.1.2 Portuguese Trails

In Portugal, the most comprehensive platform dedicated to the country's hiking trails is *Turismo de Portugal*'s "Portuguese Trails"[7]. It is a platform fully usable in both desktop and mobile browsers, including information regarding cycling and walking trails in mainland Portugal and its islands. It was developed by Digital Works [8], under the financial backing of *Turismo de Portugal*, which is the official Portuguese tourism platform.

The platform follows the naming guidelines defined by the FCMP more strictly, presenting the trails more formally than in platforms like AllTrails. As such, the data for the trails is exhaustive, including distance, altitude, difficulty, expected completion time and a "rating" (although it is unclear how the latter is calculated). Trail pages also allow the download of the trail's GPX data and the visualization of a map with the trail path and nearby points of interest.

However, even though the platform seems without fault from a database perspective, there are a considerable amount of issues in the realm of usability and UX:

- Accessing the page of a specific trail involves multiple clicks and navigating through an increasingly larger page (as seen on Appendix A). The abundance of information can make navigation confusing;
- The search function does not seem to work correctly. For instance, when searching 'Areeiro' or 'Vereda do Areeiro', no results show up, even though *Portuguese Trails* has a page called 'Vereda do Areeiro', as seen on figures A.2 and A.3;

[7] https://www.portuguesetrails.com
[8] https://www.digital-works.com/en/case-studies/portuguese-trails/

- Feedback mechanisms are often small sentences which can be easily missed;
- Not all trail pages show its path on the map, nor its selected points of interest (Fig. A.4)

When examining these issues through the lens of Nielsen's heuristics (refer to Table 2.1), a considerable number of them are not being respected. For example, the first issue alone violates #1, #5, #6, #7 and #9 (Visibility of System Status, Error Prevention and Recovery, Recognition rather than Recall, Flexibility and Efficiency of Use, and Helping users Recover from Errors), with usability attributes of *Learnability* and *Efficiency* being strongly affected.

Given these issues, a small-scale informal usability evaluation of *Portuguese Trails* was conducted in person with 7 people: 4 of whom were ultra-trail competitors and 3 who were just occasional hikers . The results are detailed in table 3.1.

Person	**Age**	**Type of Hiker**	**Tech Expertise**	**Perceived difficulty**	**Reached trail page within 2 minutes**
1	26	Occasional	Medium	Hard	No
2	28	Occasional	High	Medium	Yes
3	53	Occasional	High	Easy	Yes
4	52	Ultra-trail	Medium	Hard	No
5	52	Ultra-trail	Medium	Hard	No
6	46	Ultra-trail	Medium	Hard	No (Gave up)
7	39	Ultra-trail	Low	Medium	No

Table 3.1: Evaluation results for Portuguese Trails' usability

The goal was for each person to find a trail of their choosing, either via the search function or through the main page, while being timed. The timing aspect was omitted so as to not create unnecessary pressure. Afterwards, they were asked to rate their perceived difficulty of the platform. As can be seen in 3.1, the majority of people found the platform hard to use, with 2 users finding it medium difficulty and only one - someone with high tech expertise - considering it easy. Apart from this person, difficulty in reaching the trails page was universal: Users would normally spend long spans of time trying different combinations of words in the search bar, or they would get stuck in a section called **Routes**, clicking on the *Directions* or *Link* buttons under the belief it would take them to the trail page.

Despite all this, however, it should be noted that everyone praised the actual content value of the application, as well as its aesthetic qualities and, in spite of some of its limitations, it remains a highly valuable resource for accessing comprehensive official information about hiking and cycling trails in Portugal.

3.2 Interactive Narratives

This section will explore applications which blend interactive narratives with location-based services in order to provide more engaging experiences. The first two examples will be Portuguese platforms, followed by a geocaching app, and concluding with platforms that use sound as a medium for storytelling.

3.2.1 TrilhAR

R. Silva et al. [81], from the Lisbon School of Engineering (ISEL) and with NOVA LINCS, developed a mobile application designed to guide visitors on hiking trails while providing interactivity through Augmented Reality .

The app, called *TrilhAR*, also provides information on the trails of Santa Maria Island in the Azores, which has seen an increase in tourism throughout the years. Though information about these trails is advertised in leaflets and signs throughout the island, they are often run-down by the sun and maintaining them can be challenging and costly. As such, the project was developed with three motivations, aligning closely to the ones in this thesis:

- Give access to **hiking information**;
- Offer **navigation assistance** for the hikes;
- Provide **interactivity** (through the use of Augmented Reality (AR))

While the focus on AR differs from this thesis' focus on narratives, the interactive component is present in both. Not only are the motivations for *TrilhAR* relevant to this project, but so are its main development phases: User Research, App Development and Evaluation Tests.

User Research Before the development of the app itself, a questionnaire was conducted with over 70 participants in order to ascertain their motivations. Most people indicated that they hiked infrequently, with one of the primary reasons being lack of information regarding the trails. Additionally, requisite preferences included guided navigation and text/audio information about points of interest, with augmented reality to a much lesser extent. The authors speculated this lack of interest could be linked to a limited understanding of the technology, although this remains a conjecture.

Development After conducting research over the best client framework for their particular case, development of the app was made using *Flutter*[9]. This decision was attributed to its multiplatform nature and superior performance. In terms of technological architecture,

[9] https://flutter.dev/

the app leverages mobile device sensors for navigation and uses *ARCore*[10], a Google-developed platform facilitating the creation and implementation of AR experiences.

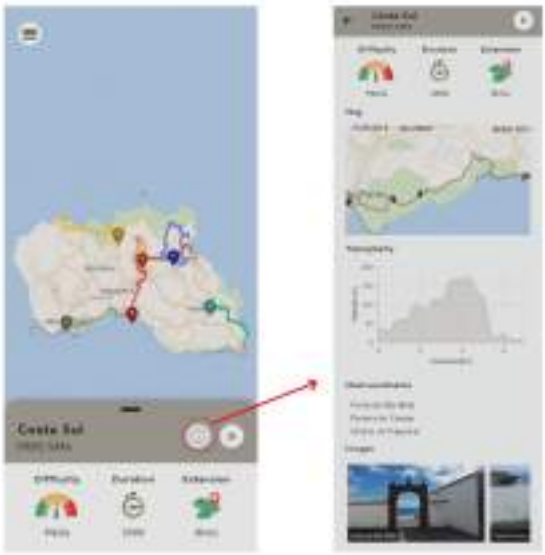


Figure 3.3: Initial page of TrilhAR after clicking on a trail (left) and the extended trail information given when clicking on the information (i) button (right) [81]

After a login page, Trail information includes details about trails' difficulty, duration, and length. The navigation feature enables users to start and complete hikes, save trails, and receive notifications for points of interest.

The Augmented Reality aspect involves two views: *Compass View*, when the user is not facing the object, so they know where to turn to, and *AR View*, where the virtual object is rendered. These objects are usually 3D models of historical items and informative text placards.

Finally, there are also completed trails displayed in chronological order, showcasing details such as trail name, start date and time, duration, and visited points of interest.

Evaluation As a final point, the authors conducted usability and application performance evaluations. The latter was marked by the varied rendering times of the AR elements, which often affected UX. Even so, usability of the app was measured very positively, with users highlighting strengths in design and innovation but mixed feedback on efficiency and dependability.

As the authors note, the application was successful as a "proof of concept", with emphasis on the importance of taking user feedback into account when developing it further. The project developed under this thesis shares some of the features developed for *TrilhAR* - hiking data, navigation and interactivity - while adding others, taking accessibility into account, and focusing more on the storytelling aspects of interactivity.

[10] https://developers.google.com/ar

3.2.2 TravelPlot Porto

TravelPlot Porto was a location-based interactive narrative project designed for exploring the city of Porto, Portugal. It showcased the potential for integrating interactive narratives with outdoor exploration, as users could pass through geographical points and see a story unfold. That story encompassed the history of Porto, its locations and its famous characters throughout different chapters that could be followed in any order, via a website or a dedicated app [28].

However, as *TravelPlot Porto* was designed as a pilot experience within a broader investigation into location-based storytelling, it ran for a limited time (between June and September of 2012), so most of the information comes from [28] and [29]. Both papers reveal the immense scope of the project, which involved social networking efforts, the printing of 2500 physical maps for greater exposure, and lengthy processes of user research, development and marketing. There were *Facebook*, *Twitter* and *YouTube* accounts, as well as live events with the participation of multiple people.

After *TravelPlot Porto* ended, user questionnaires and other feedback revealed that the project was seen as innovative, with particular praise going to the interactivity and narratives of the app. [29] The issues were mostly related to the design and "the lack of free Wi-Fi"; which can show the importance of balancing innovative features with usability and providing offline capabilities.

3.2.3 Adventure Lab

In the context of location-based activities, *geocaching* boasts great popularity and is an incentive for outdoor exploration, particularly with younger generations [33]. It involves community-driven treasure hunts where participants use GPS coordinates to hide and seek containers, known as "geocaches" or "caches," at specific locations marked on the map.

One notable example is the mobile application Adventure Lab[11], where the traditional geocaching activities are expanded to incorporate stories or challenges related to locations on a map. The app benefits from its simplicity by having a map of "geocaches" which, when clicked, show the potential narrative that will unfold when users reach them. The geocaches can be followed in different orders or have puzzles be integrated into them. Geocaching usually doesn't make frequent use of storytelling aspects, so *Adventure Lab*'s fusion of those two elements can serve not just as a way to imbue interactivity into outdoor exploration, but also provide a narrative context which keeps users engaged for longer.

From a usability perspective, *Adventure Lab* seems to work well and intuitively, with the developers claiming to have undertaken usability evaluations in the past. According to their official blog [44], the feedback received was used to overhaul the app design and improve its usability.

[11] https://adventure.geocaching.com/

3.2.4 Sound Narratives - *Echoes* and *Voices from the Trenches*

In the realm of interactive narratives, sound can play a very strong role for people who might not want to look at their phone so much while hiking, for people with visual issues, or just to instil a stronger sense of immersion in a narrative. It is apps like *Echoes*[12], which introduces an auditory dimension to the walking experience, that can fill this role.

Echoes activates audio based on a user's proximity to a location: as they reach certain areas, they hear immersive audio narratives, historical anecdotes or environmental sounds, among others. The titular "echoes" are sound-based, but can include images and text as well.

Another example of great interest, though in a smaller scope, was a project developed by Marshall et al. [53] as part of the *meSch project*[13]: *Voices from the Trenches*, an auditory narrative system at a war heritage site in the Italian Alps.

Figure 3.4: *Voices from the Trenches* - Belt used for proximity sensing (left), the historical clothing that inspired it (middle) and a participant using it in the ruins of an artillery site (right) [53]

The authors argued that museums often emphasize information over sensory interaction with the displayed objects, leading to a detachment from the possible emotional context of those objects. As such, they employed sound as a medium to convey that emotion and try to connect the visitors to the remains - trenches, artillery, among others - of a World War I zone.

The project was extensive, employing voice actors to portray soldiers talking and making use of personalization technology based on the user's movements. Additionally, it should be noted that it was not developed as a mobile app or any website, but instead the sound was activated through proximity, measured by a wearable belt. Even so, the project was a success in fostering greater interest in the historical content and it stands as a great example of the possibilities of sound as a medium in interactive narratives.

[12] https://explore.echoes.xyz/
[13] https://www.mesch-project.eu/

3.3 Discussion

In this chapter, we analysed examples of trail apps and platforms with interactive narrative elements, with a greater focus on Portuguese examples. While apps like *Alltrails* or *Portuguese Trails* do not include interactive narrative elements, they do have very robust structures for trail information and navigation. On the other hand, the platforms with interactive elements often trade-off navigation elements in favour of the narrative and interactivity aspects.

Table 3.3 compares the functionalities of the websites and apps discussed in the chapter, highlighting the aforementioned trade-offs. None of them include all the elements that this thesis' system - "Tell me a Trail" - does, but *TrilhAR* stands the closest: it offers trail data (though only for Santa Maria Island, and not the whole of Portugal), navigation, interactive narratives and good usability. While it lacks any accessibility features and offline navigation, it still stands as a very strong example. *AllTrails* stands close as well, lacking only in the narratives aspect. However, when considering platforms like *AllTrails* and *Portuguese Trails*, dedicated exclusively to trails, it is important to acknowledge how incorporating interactive narratives into a trail platform may require certain concessions for the sake of usability: Introducing a narrative element to a platform as complex as *AllTrails*, for instance, could lead to a confusing app, compromising UX. This prompts the consideration that an information level akin to *TrilhAR*'s might be more appropriate.

Thus, opting for a hybrid approach that incorporated the strengths of both types of platforms in their respective fields was the most promising direction when developing the application under this thesis.

App	**Trail Data**	**Navigation in-app**	**Interactive Narratives**	**Usability**	**Accessibility Features**
AllTrails	Yes	Yes, incl. offline	No	Good	Some
Portuguese Trails	Yes	No	No	Mixed	Some
TrilhAR	Yes (Sta. Maria only)	Yes	Yes	Good	Some
TravelPlot Porto	No	No	Yes	Mixed	No
Adventure Lab	No	No	Yes	Good	No
Echoes	No	No	Yes	Good	No
Tell me a Trail	Yes	Yes	Yes	Good (92 SUS score)	Yes

Table 3.2: Comparison of Apps' Functionalities, including the application developed under this thesis: Tell me a Trail

Finally, one notable gap in many of the apps was the lack of comprehensive accessibility features. *AllTrails* stands as the only one with information regarding wheelchair-accessible

trails, though this data is crowdsourced and subject to errors, while *Portuguese Trails* and *TrilhAR* only display trail difficulty. *Echoes*, with its audio-based content, could be helpful for those with visual impairment issues. The remaining platforms do not seem to offer relevant features, including any type of customization options.

Taking all this into account, the final result of this thesis was a platform that combined detailed trail and accessibility information, navigation tools, and interactive narratives into a unified experience. When compared to existing alternatives, "Tell me a Trail" offers a more comprehensive solution, not only enhancing user engagement through its multimedia storytelling but also addressing the needs of a wider demographic by prioritizing inclusivity.

4

Solution Design

In this thesis, the aim was to develop a mobile platform that showcased Portuguese hiking trails with interactive narratives, along with a system to manage these narratives. As such, this chapter details the design and architecture of the solution. The initial section outlines the project's requirements, including the Empathy Maps made to refine them, and the designed visual prototype. Following this, we delve into the technologies employed for the front-end and back-end services, highlighting how they complement the back-end work of A. Tavira[88]. To conclude, there is a section expanding on the system's overall architecture, and how its components interact with one another.

4.1 Solution Requirements

As mentioned in previous chapters, developing an interface with good usability is an effort that starts in the design phase and by taking into account the users' needs. As such, user research was conducted in the form of empathy maps, which helped identify key user preferences, difficulties and expectations. These insights directly shaped the system's requirements, including the types of narrative content included and required accessibility information. Additionally, the findings also informed the creation of a visual prototype, allowing for the demonstration of potential app functionalities before full-scale development began.

4.1.1 Empathy Maps

Empathy Maps are visual tools designed to help developers gain a deeper understanding of their target audience. This is accomplished by mapping out key areas related to a user's environment and behaviour [27], such as "Saying" and "Doing" (how the user behaves) or "Hearing" (what they hear and how it influences them).

While initial versions of the empathy map (Fig. B.1) were simpler and catered towards a more corporate setting [31], it has since evolved to be a useful tool in other domains [12]. As such, an adapted version of the empathy map [11] was used to research the needs of

different types of users in relation to a hiking platform. Four (4) people were interviewed, according to the following key areas of understanding:

- **Tasks** - what specific tasks is the user trying to accomplish?
- **Feelings** - what does the user feel about their current experience (with hiking, with hiking apps, among others)?
- **Influences** - What external factors might influence them?
- **Pain Points** - What difficulties do they experience?
- **Goal** - What is the overarching goal that the user is trying to achieve?

The interviews were carried out in Portuguese and without a structured line of questioning, as is often the case in Empathy Maps [27]. Questions were mostly open-ended in order to foster a more relaxed atmosphere where the interviewees could express themselves more freely and honestly.

The resulting empathy maps can be found in Appendix B. Four people were interviewed, each with unique relationships to hiking and trails:

- **Tatiana**, who enjoys hiking and uses a wheelchair (B.3);
- **Lucas**, who also enjoys hiking as a hobby (B.4);
- **Cristina**, who is an Ultra-Trail Runner[1] (B.5);
- **Laura**, who reports no interest in hiking or trails (B.6).

Amongst the hiking enthusiasts there were several shared grievances, particularly the inaccurate *trail information* and the *logistics* associated with trail preparation. *Points of Interest (POI)* were also emphasized, with a shared curiosity about exploring the nearby areas for historical or cultural reasons.

A prevalent influence across all cases were other people: friends, social media and family all impacted the relationships to hiking, for better or for worse. It is also noteworthy how all 3 individuals who enjoyed hiking expressed a sense of wonder or "awe" at being immersed in nature, with an emphasis on how they felt when reaching the end.

On a more personal level, people's wants varied according to their backgrounds: while *Lucas* - who hikes leisurely - complained about getting lost or wanting more information, *Cristina*'s issues mostly revolved around her trail competitions and associated logistics. On the other hand, *Tatiana* voiced frustration over how much time and effort she had to expend due to the common neglect of accessibility considerations. Finally, *Laura*, who expressed no interest in hiking, cited reasons such as boredom, time constraints, and a lack of engagement.

[1] Individuals who participate in runs longer than marathons (42km) on mountainous terrain

These interviews offered valuable insights for how to approach the platform's design process. Many of the voiced concerns reflected the need to invest in functionalities such as standardized *trail information*, *points of interest* and *navigation tools*. Tatiana's experience shed light on the need for *accessibility* considerations. The collective interest in exploring nearby areas suggested potential for integrating *historical and cultural narratives* into the platform. This also doubles as an engaging feature to attract individuals like Laura, who showed little interest in trails.

Name	**Relationship to Hiking**	**Accessibility Needs**	**Functionalities**
Tatiana	Hobby	Uses wheelchair	Accessibility details, terrain type information, weather predictions
Lucas	Hobby	-	Navigation, narratives with environmental and historical content, progress tracking
Cristina	Ultra-Trail Runner	-	POI, extensive trail details under one platform
Laura	No Interest	-	Difficulty Information, Narratives with engaging content

Table 4.1: Some functionalities present in the final platform which were inspired by the different needs of each interviewee from the Empathy Maps

Table 4.1.1 shows how the empathy maps informed the development of features which were, ultimately, included in the final version of the platform. Although multiple interviewees expressed interest in the same functionalities (e.g. POI and offline capabilities), the table highlights only the most relevant features associated with each individual.

Overall, there are outside factors which shaped and defined the interviewee's experiences with hiking: these are out of the developer's control. However, other aspects could be addressed and it was by tackling them that this platform aimed to provide an improved and inclusive user experience for a broader range of people.

4.1.2 Requirements

While exploring the platforms of the previous chapter, it was highlighted the importance of balancing the number of features with the overall usability of a platform. When developing an interface which incorporates hiking trail information with narratives, too many functionalities can compromise UX and usability. While it is tempting to cater to the needs of all users, such as those reflected in the Empathy Maps, it is crucial to ensure the platform remains intuitive. Therefore, the core requirements of the platform needed to encompass not just feature requirements, but also usability ones.

Based on this and the user research conducted via the *Empathy Maps*, the main functional requirements of the platform were identified as follows:

1. **Map with hiking trails** - for visualization of hiking trails in Portugal, mainland and its islands;
2. **Points of Interest** - display of notable locations on the map, such as lodging, landmarks, parking options, and rest areas, among others;
3. **Trail Search and Filtering** - based on criteria such as the trail's location, name, accessibility features and other details;
4. **Detailed Trail Information** - display of comprehensive data for a selected trail, including:
    a) *Trail Details* - distance, difficulty, elevation, expected time, inclusion of narrative;
    b) *Accessibility*: see further information in the below accessibility requirements section;
5. **Navigation** - both online and offline GPS navigation of selected trails and narratives;
6. **Interactive Narratives** - inclusion of narratives with multimedia content to be experienced in eligible trails;
7. **Progress Tracking** - provide means for users to check their completion of trails or narratives;
8. **Accessibility Options** - besides providing information about trail accessibility, also offer language customization within the app.

Conversely, from a UX perspective, the aim was to enhance usability through an intuitive design. This required following usability principles, such as Nielsen's heuristics (detailed in table 2.1), or improving usability attributes like the ones mentioned in the "Usability Engineering" section.

For example, it was important to develop robust **feedback mechanisms**, which are in line with heuristics #1 and #9 (the importance of *system status visibility* and *facilitating error recovery*). Similarly, offering an intuitive **navigation flow** with different options allows users greater *freedom and control* over their experience, aligning with heuristic #3. Heuristic #2 (*Match between system and the real world*), was addressed by incorporating **symbols and terminology related to the hiking world**. Efforts to maintain heuristic #4 (*Consistency and Standards*) included **consistent colour-coding**, such as using the same red colour for narrative content. Overall, efforts were made to align with most of the heuristics.

4.1.2.1 Conventions for Trails Apps with Digital Narratives

It should be noted that following heuristics is not all that is needed to achieve good usability in an app. Nielsen notes that heuristics are a mostly informal evaluation method [65], so design approaches should be adapted to the software being developed.

As such, this project adhered to some of the conventions established by N. Basaraba et al. [61], who developed a series of guidelines for trail apps with digital narratives, based on their analysis of 55 Android mobile apps. Their focus was on heritage trail apps, which integrate historical and cultural narratives into the trail experience, so the insights were relevant for this project. Some of the conventions they define and which were followed in this project are:

- **Naming guidelines** - for instance, keep trail and narrative names shorter and descriptive;
- **Trail Data** - provide extensive trail information beyond the usual, such as environmental notices and location of nearby facilities such as lodging and restaurants;
- **Navigation** - provide GPS navigation and options to preview trails prior to the physical visit;
- **Offline and downloadable content** - include not only offline navigation, but also make all content downloadable (for free when possible);
- **Design Suggestions** - for example, include instructions over how to use the interactive content, use distinct colors for map markers, follow existing storytelling conventions in the narratives for greater consistency, include separate tabs for different types of content;
- **Accessibility** - provide personalization options, such as different languages, and the possibility of captions in the case of audio-based content.

Another notable mention is how most of the narrative content in the analysed apps took the shape of purely informational text-based content, with only 17% of apps employing any extra form of interactivity or even gamification. This once again highlights the value that an application with more interactive storytelling, such as the one developed under this thesis, adds. However, as previously mentioned, these aspects had to be balanced with UX and accessibility considerations.

4.1.2.2 Accessibility

As elaborated in greater detail in Chapter 2, designing with accessibility in mind often requires a balance between the needs of different types of users. In the context of this project, the emphasis was placed on trail accessibility, with the goal of providing comprehensive and detailed information about the accessibility of trails, all while adhering to the principles of good UX.

For that effect, the ongoing collaboration with the *Departamento de Ciências do Desporto da Universidade da Beira Interior* (UBI) proved invaluable, as they provided critical insights into inclusive tourism. Additionally, members of the *Federação Portuguesa de Desporto para*

Pessoas com Deficiência (FPDD) also graciously contributed additional expertise concerning accessibility guidelines in the context of sports, including hiking.

Figure 4.1: Joëlette chairs being used in different types of terrain [25] [21]

With this combined input, as well as Tatiana's interview in the empathy maps, the accessibility requirements for the trails were characterized as follows:

- **Difficulty** - Segmented into different sections of the trail, to cater to varying levels of physical ability;
- **Terrain Type and Slope** - Description of the type of surface throughout the trail (e.g. sand, gravel, snow);
- **Slope** - Altitude changes throughout the trail;
- **In-trail Accessibility Features:**
  - **Trail Assistants** - Presence of personnel available to provide assistance of various types throughout the trail;
  - **Joëlette Chair**[2] - Whether the trail provides Joëlette chairs (see figure 4.1) or other types of specialized mobility equipment;
  - **Braille Signage** - If trail signs or plaques include *Braille* for visually-impaired hikers;
  - **Assistants fluent in sign language** - if any of the assistants know sign language to aid hearing- impaired users;
  - **Rest Areas** - Availability of areas with seating for hikers who may need to take breaks;
  - **Shade and Shelter** - Availability of sheltered areas to protect hikers from sun or other weather hazards;
  - **Water Stations** - Availability of water stations along the trail.

[2] A Joëlette Chair is a one-wheeled chair designed to be used in rugged terrain, allowing people with mobility impairments to be transported by one or two assistants

4.1.2.3 Narratives and Multimedia

When implementing interactive narratives, defining the most suitable mediums depends not only on the nature of the application, but also on user preferences. Some people might prefer visually rich content - images and videos - while others might only want short texts or audio that do not distract from the hike. Additionally, in the case of visual, hearing or cognitive impairments, the existence of different media types might ensure users have alternatives.

The type of platform also plays a crucial role: for instance, mobile platforms can leverage greater interactivity with the surroundings, unlike the desktop experience. For activities like hiking, mobile users may also lean towards "bite-sized" content that can be consumed on the go, while desktop users might engage more with long-form content due to their stationary nature.

Since the main focus was the development of a mobile app, it was decided that, while navigating through a narrative, various types of multimedia content would be unlocked as users arrived at specific locations. Upon reaching these points, the unlocked content would provide additional context or information to further the narrative being told. This multimedia content was classified into 4 types:

1. **Text**;
2. **Image** - photographs, illustrations, among others;
3. **Audio** - spoken narrations or ambient sounds;
4. **Video** - short-form animations or video content.

Categorizing the narratives was also relevant, so users could find content aligned with their interests. The goal was for these categories to encompass both fictional and non-fictional content. Fictional stories could involve mystery narratives which incentivised exploration, or dramatized retellings of historical events. On the other hand, non-fictional stories had to be relevant to their specific trail, offering additional historical, cultural, or environmental background.

With these goals in mind, and while incorporating accessibility considerations and the narrative types outlined in the digital storytelling section of Chapter 2, the narratives were divided into five distinct categories:

1. **Historico-Cultural** - Narratives that recreate or delve into historical events and landmarks, as well as local cultural practices, traditions and legends;
2. **Environmental** - Narratives of a more educational nature, focusing on local flaura and fauna, geological features or the trail's ecological significance;
3. **Fictional Storytelling** - Stories mostly or entirely fictitious, to dive into worlds and characters born from creativity;

4. **Trail Guidance** - Guides and information on the physical challenges of the trail, and how to traverse its more difficult paths;

5. **Other** - Narratives that do not fit neatly into the other categories.

4.1.2.4 Characterizing a Trail and a Narrative

As highlighted in the preceding sections, comprehensive accessibility information and narrative details are essential in this project. Therefore, in collaboration with A. Tavira, a document was formulated detailing guidelines for the characterization of trails and their respective narratives. It is available in Annex 1, and it provides a thorough framework for collecting the necessary accessibility information mentioned in the above accessibility section (e.g. terrain type, difficulty). It also explains and provides recommendations for crafting narratives that align with the information presented in the previous narrative section.

4.1.3 Visual Prototypes

To simulate basic interactions and present a design proposal for the mobile platform, a visual prototype was developed, as seen in Appendix C. Using the prototyping tool *Marvel*[3], three main tabs of the app were designed - *Map*, *Narratives* and *Trails* (C.1) - each with some interaction flows.

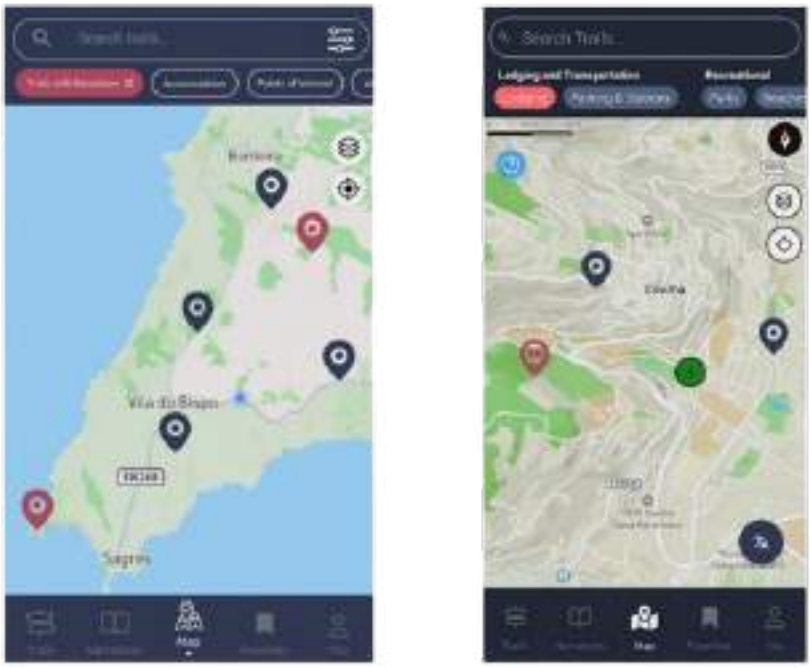


Figure 4.2: Comparison between the map tab in the visual prototype (left) and the final app (right)

[3] https://marvelapp.com/

The tabs could be cycled through via the bottom navigation bar. For the *Map* tab (C.2), there were two represented flows: using the search function and selecting a trail from the map to see some of its details. Then, for both the *Trails* and *Narratives* tabs (C.3 and C.4), the flow involved selecting a specific trail or narrative and seeing its detailed information, including distance and expected time. The *Narratives* interaction flow also showed an example of navigating through a trail with a narrative. Figure C.5 shows the combined interaction flow between all three tabs.

It is important to note that this prototype was purely visual and primarily designed to simulate user interaction and propose initial design choices before actual development commenced. Several features were not fully represented at this stage, including advanced filtering options, full trail navigation, and accessibility-related details. This was intentional, as the prototype aimed to gauge usability and confirm core design decisions before delving into more complex features.

Figure 4.2 shows an example of the differences between the map tab in the prototype and in the final product. Many of the final product's functionalities evolved or were introduced during testing phases. As detailed in later chapters, user feedback during these phases informed iterative adjustments and the development of new features which were not present in the prototype.

4.2 Technologies

As the back-end providing the trails for this project was developed under the scope of another thesis [88], this section will start with only a brief overview of that system. The primary focus, however, will be on the technologies used to develop the platforms under this thesis: the database and backend for the narratives, as well as the front-end for both the mobile app and web-based narratives management platform. Finally, the map-based technologies used in both client platforms will be explored.

4.2.1 Back-End

The back-end infrastructure of the platform supports two core functionalities: handling trail data and managing narrative-related content. This section will focus more on the latter, as it was the back-end functionality actually developed under this thesis.

4.2.1.1 Trails Back-end

As already mentioned, the development of the **Trails Back-end** was undertaken as part of a parallel thesis project developed by A. Tavira [88]. The database was built using *PostgreSQL*[4] and enhanced with the *PostGIS* extension [5] to efficiently handle spatial data,

[4] https://www.postgresql.org/
[5] https://postgis.net/

such as trail coordinates, GeoJSON features, and elevation information. *Node.js*[6] and *Express*[7] were also used as server-side technologies to facilitate communication with the trails database. Additionally, *GeoServer*[8], an open-source server adhering to standardized geospatial protocols, was used to serve spatial data to the front-end. The accessibility information for each trail was also stored in this back-end's database.

4.2.1.2 Narratives Back-end

The narratives database for this project needed to store three main types of information

- **Narrative Metadata** - Information on each narrative, including titles and descriptions, and other relevant details for each stop along the trail;
- **Geospatial Data** - Coordinates for each stop of the narrative;
- **Multimedia Content** - Video, audio and image files associated to the narrative and its stops.

To address these requirements, the database was, similarly to the trails back-end, built using *PostgreSQL*, an open-source relational database known for its extensibility, standards compliance and frequent use in GIS systems. Given the need to store, query, and manage geospatial data, *PostgreSQL* provided one of the best options, especially when paired with the *PostGIS* extension. This combination introduced support for geographic objects, allowing the database to handle the coordinates' spatial data. Additionally the choice was also motivated by *PostgreSQL* with *PostGIS* often outperforming alternatives in terms of speed and scalability [5], while also providing a more comprehensive set of functionalities for spatio-temporal data operations [52].

For handling large multimedia files, such as videos, audio, and images, *Appwrite*[9] was chosen as the multimedia storage solution. *Appwrite* is an open-source backend-as-a-service platform that allows for secure and scalable storage of large files. Instead of storing multimedia content directly in the *PostgreSQL* database, each file (whether an image, audio recording, or video) was uploaded to *Appwrite* and assigned a unique ID. This ID was then stored in the *PostgreSQL* database, linking each multimedia file to the corresponding narrative.

As such, we had a *PostgreSQL* database whose primary role was to store narrative-related metadata, geographical information, and the multimedia IDs. The actual multimedia content - videos, audio, images - was then stored separately in *Appwrite*, ensuring a clearer distinction between lightweight, frequently queried information and larger files that were not always needed. This design was particularly useful given the potential large

[6] https://nodejs.org
[7] https://expressjs.com/
[8] https://geoserver.org/
[9] https://appwrite.io/

size of multimedia files and the need to store them efficiently without overwhelming the main database.

Initially, the database was managed through *pgAdmin*, a popular open-source management tool that simplifies creating, modifying, and querying the database. However, to streamline the process of inserting and removing narratives, the back-office tool mentioned further below in 4.2.2.1 was later developed.

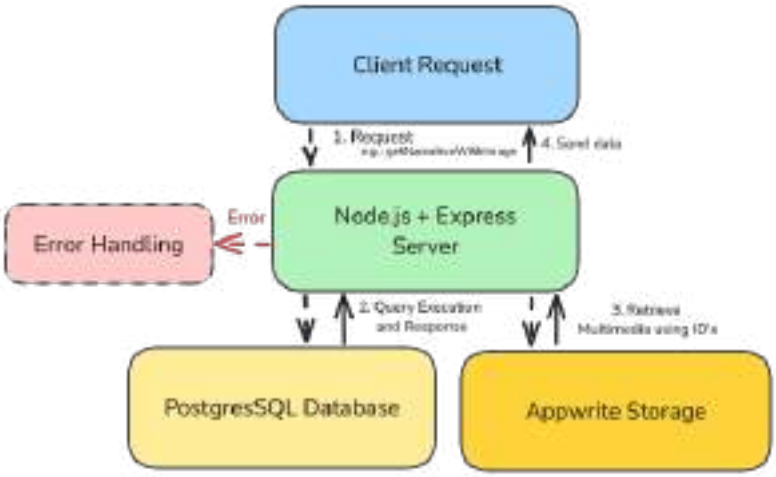


Figure 4.3: Example of data flow of request to narratives back-end which involves multimedia

Server Side On the server-side, the back-end was coded using *Node.js* with the *Express* framework, allowing the communication between the *PostgreSQL* database and the clients. The *Node.js* runtime environment was chosen for its scalability, asynchronous nature, and ability to efficiently handle numerous concurrent connections [90]. Below is a brief breakdown of how the server-side code functioned, as seen in Fig. 4.3

1. **Database Connection** - A connection was made to the database by using credentials stored in environment variables, ensuring that sensitive information was not hard-coded into the the application. Using the pg package[10], a connection client object with all necessary parameters was then created;

2. **Query Execution** - Depending on the client request, asynchronous queries were executed to retrieve the data requested by the front-end. If the client requested multimedia content, then another query would be made to *Appwrite*, using the file IDs. After delivering the result to the client, the connections were then properly closed;

3. **Error Handling** - In the case of an issue during connection or query execution, such as invalid SQL syntax or a non-existent table, the error was logged, with a message being sent back to the client indicating the failure.

[10] https://www.npmjs.com/package/pg

Deployment To make the back-end accessible beyond local development environments, it was necessary to deploy the database and services to a cloud infrastructure. While the *Appwrite* storage was already accessible externally, the *PostgreSQL* database was migrated to *Supabase*[11], an open-source database infrastructure built on top of *PostgresSQL*. Finally, for deployment, *Render*[12] was selected as the cloud platform to host the database and back-end services. This choice was made due to *Render*'s scalability and affordability when compared to alternatives, its automation of key deployment tasks when using *Node.js*, and seamless integration with *GitHub*.

4.2.2 Front-end Technologies

The platform's front-end was developed with a mobile-first approach, but, additionally, a separate web-based platform was built to serve as a back-office for the previously mentioned Narratives Server, allowing for the management of narrative content.

4.2.2.1 Mobile Platform

The mobile app is the main component developed under this thesis, necessitating the development of various features to support its diverse use cases.

Throughout development, consistent testing of iOS functionality was hindered by the author's lack of access to an iOS device and the challenges associated with using iOS emulators outside of macOS. Consequently, the focus shifted towards enhancing the Android experience. However, when considering the technologies to use for the platform, long-term goals and eventual scalability were taken into account: in the future, further developments of this project would benefit from the possibility of having a thoroughly tested iOS build, as well as a web version of the platform.

Given this cross-platform nature, consideration was initially given towards developing a Progressive Web App (PWA). PWAs are applications developed using web platform technologies (HTML, JavaScript), but which provide a user experience similar to that of a platform-specific app [45]. They are able to run on multiple platforms under a single codebase, including mobile devices (where they model the feel of a native app), and can provide functionality like offline access [87]. However, when it comes to mobile, a PWA still can not offer all the functionalities of a native app. Additionally, they have limitations in terms of performance, particularly when it involves hardware interaction (e.g. GPS) [41], which was indispensable for our platform.

A better option was to either implement a *native* solution in the mobile app, or to consider using a *framework* with a shared codebase in both mobile and web versions, such as *React Native*[13] or *Flutter*[14]. Native development (i.e. using tools specifically designed for

[11] https://supabase.com/
[12] https://render.com/
[13] https://reactnative.dev/
[14] https://flutter.dev/

Aspect	PWA	React Native	Native Development
Codebase	Single codebase	Single codebase	Separate codebase for each platform
Performance	Slower	Near-native performance	Optimal performance as code is platform-specific
Offline Access	Yes, but with caching limitations	Yes	Yes
Hardware Access	Limited in terms of performance	Yes	Yes
Platform Support	Cross-platform	Cross-platform	Limited to one platform type

Table 4.2: Comparison between PWA, React Native, and Native Development

a single platform) boasts performance advantages [9], but limits the app to either *Android* or *iOS* and requires separate web development. Alternatively, a cross-platform framework such as *React* or *Flutter* offers near-native user experiences and significant code re-use for eventual web and mobile platforms, though the final choice of framework hinges on a platform's specific needs [32]. Given this information, and the author's greater familiarity with *Javascript* and *React*-based technology when compared to *Flutter*'s *Dart*, *React Native* was chosen as a framework for the platform. In *React Native*, the code is built on the foundation of components, which are reusable pieces of the user interface defined using JSX - *JavaScript XML* which allows developers to write HTML-like syntax directly within JavaScript. Components are also self-contained, maintaining their own internal state over time.

Adding to *React Native*, the development environment for the mobile app also leveraged *Expo*[15], a framework that simplifies the development process by providing some built-in tools, services, and libraries. One of its most valuable features throughout development were *Expo Application Services* (EAS), which facilitated the integration of native code and automated the process of building APK (Android) binaries.

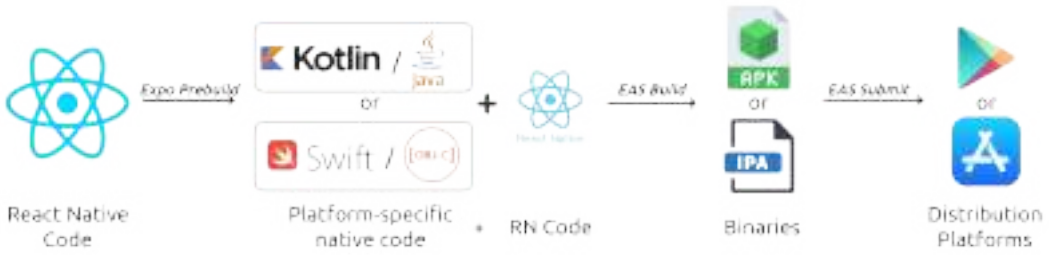


Figure 4.4: Application build phases in Expo with EAS. For our platform, the final build resulted in an APK

[15] https://expo.dev/

For instance, throughout development, there was the need to incorporate some libraries with native Android or iOS code into the *React Native* workflow, to improve platform-specific functionalities. Previously, Expo required 'ejecting' an application in order to integrate native code, which implied manually handling the native code for both Android and iOS. With the new *EAS Build*, however, this was simplified, with the build working with any type of native code by first 'pre-building' the app. This involved converting the *React Native* project into a structure that can interact with platform-specific native code - *Swift* or *Obj-C* for iOS, *Kotlin* or *Java* for Android. A build is then run, packaging the app into its binaries (e.g. APK for Android). This process is illustrated in the diagram in Figure 4.4.

Finally, while Chapter 5 will delve into the specifics of the app's functionalities and expand upon many of the smaller libraries, it is pertinent to highlight the major foundational libraries that, from a high-level perspective, underpin the app's core functionality:

- **Redux**[16] - A React library which allows for a global state to be maintained across the app, allowing for a simpler and more efficient data flow between different components;
- **Redux Persist**[17] **with React Native AsyncStorage**[18] - Ensures that specific parts of the app's state are stored locally on the mobile device using *AsyncStorage*, allowing data to persist between app sessions;
- **React Navigation**[19] - Library enabling the app to support stack navigation (i.e., moving between screens) as well as tab-based navigation;
- **React Native Vector Icons and React Native Elements UI (RNEUI)** - Libraries which provided a set of pre-built, customizable icons and UI components;
- **Turf.js**[20] - Geospatial analysis library which was crucial in performing calculations on geographic data (e.g. finding distances from points);
- **Expo-Av**[21] - An expo module which allows for playback of video and audio files in the device.

4.2.2.2 Narratives Web Platform

The narratives web platform serves as a back-office for managing narrative-related content, enabling administrators to add and remove narratives from the database. It was built using *React*, a JavaScript library for building user interfaces, which, like *React Native*, follows a

[16] https://redux.js.org/
[17] https://github.com/rt2zz/redux-persist
[18] https://github.com/react-native-async-storage/async-storage
[19] https://reactnavigation.org/
[20] https://turfjs.org/
[21] https://docs.expo.dev/versions/latest/sdk/av/

component-based architecture and uses JSX syntax. *React* was chosen to ensure coherence across the development stack, as both the mobile and web platforms utilize React-based technologies.

The platform leverages React's state management to handle form inputs for narrative metadata - such as titles, descriptions, and geospatial coordinates - while also supporting file uploads for multimedia content. It then communicates with the *Narratives Server* to add or remove narratives and their associated media files from the system.

4.2.3 Maps

Geographic visualization played a crucial role in this project, as both the mobile and web platforms needed to provide an interactive map with trails. For this end, there were a number of options to choose from, such as the previously mentioned *Leaflet*, *Google Maps*[22] or *OpenLayers*[23]. While *Leaflet* stood as a strong contender, the final pick was *Mapbox*[24]. This choice was due not just to its high customizability, but also native support for *React Native* through its *rnmapbox* library[25], which was indispensable throughout the entire mobile development process. Additionally, *Mapbox* also sported 3D maps and some built-in offline features, which helped shape the experience of previewing trails and downloading them.

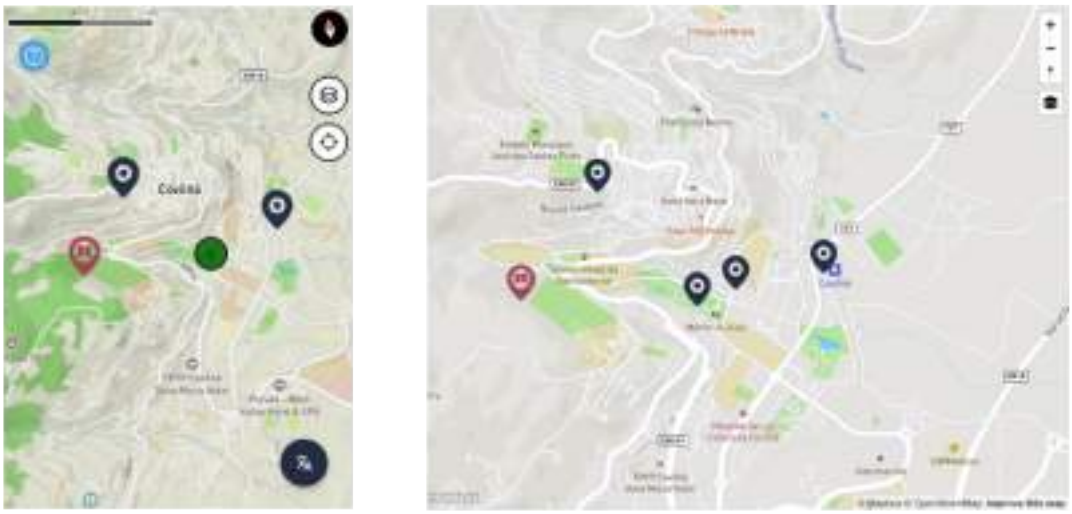


Figure 4.5: Map component in the mobile client (left) and the narratives manager web platform (right)

For the mobile app, the *rnMapbox* library integrated Mapbox's SDK into the React Native environment. While some features, such as navigation, required further custom

[22] https://developers.google.com/maps
[23] https://openlayers.org/
[24] https://www.mapbox.com/
[25] https://github.com/rnmapbox/maps

development, the library provided the core infrastructure for handling map interactions and rendering geospatial data. This included displaying routes and markers, tracking user location during navigation, and supporting offline map capabilities.

Mapbox Studio[26] was also used to design the map layers, leveraging the "Outdoors" Map style as a foundation. This allowed for the customization of various map elements and additional layers, like the POI layer.

On the web platform, Mapbox was also used, though its role was limited to visualizing trails, narratives, and their respective paths. Unlike the mobile app, the web version offered fewer interactive features and primarily served as a tool for administrators to preview and manage narratives. Figure 4.5 shows the map component in both these clients.

4.3 System Architecture

The system architecture for the project was drawn in connection with the aforementioned technologies, and according to a three-tier model, with a **Data Layer** (database), a **Logic Layer** (server-side), and a **Presentation Layer** (client-side). Each layer interacts with the others to ensure seamless data processing, presentation, and management of both trails and narrative content. The overall system leveraged the back-end developed in the context of the complementary dissertation [88], so the architectural diagram (Fig. 4.6) also illustrates how that back-end (Trails Database and Server) integrates into the system developed for this thesis.

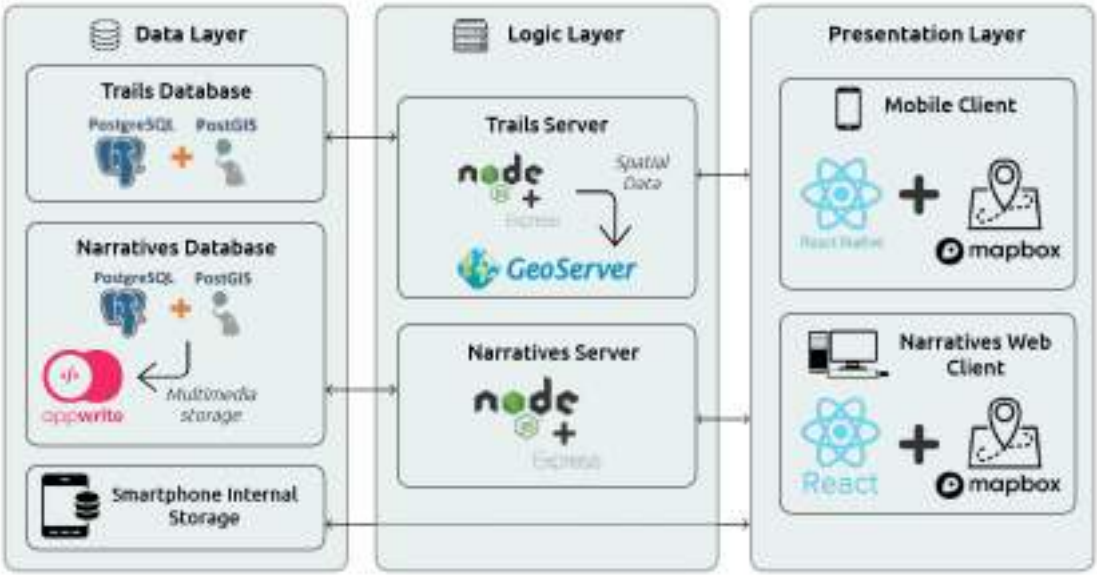


Figure 4.6: System architecture

[26] https://www.mapbox.com/mapbox-studio

Data Layer Responsible for housing the infrastructure necessary for storing and managing both trails and narrative data, this layer comprises two main databases, while also encompassing additional storage for offline data on users' mobile devices.

- **Trails Database** - The database developed by my colleague, which stores geospatial data related to hiking trails, including coordinates, trail paths, difficulty levels, and other trail-specific information;
- **Narratives Database** - Storing data related to the narratives and links to multimedia files, which are stored on *Appwrite*;
- **Smartphone Internal Storage** - For offline use, certain trails, narratives, and multimedia content can be downloaded and stored on the user's smartphone. This allows the app to function without internet connectivity.

Logic Layer Also referred to as the 'server layer', it handles all the business logic, data processing, and API interactions, facilitating communication between the data layers and the presentation layer. It consists of the two main servers - for trails and narratives - that process and deliver data to the mobile and web clients

- **Trails Server** - As explained in 4.2.1.1, developed by my colleague and responsible for managing the requests for trail data;
- **Narratives Server** - Handles requests for narrative metadata and multimedia content.

Presentation Layer The Presentation Layer consists of the two front-end interfaces developed for this project: the mobile client and the narratives web client. Both clients communicate with the servers in the logic layer to fetch, display, and interact with data.

- **Mobile Client** - The application used by general users, where they can, amongst other features, visualize and navigate trails and narratives;
- **Narratives Web Client** - Used by administrators to manage the narrative content.

Overall, the system's architecture ensures collaboration between each layer while maintaining a clear separation of responsibilities. The **Data Layer** provides the foundational storage, the **Logic Layer** processes and serves data, and the **Presentation Layer** delivers the user interface for both administrators and end-users.

4.4 Discussion

The design of the solution, as outlined in this chapter, was grounded in a comprehensive understanding of both user requirements and the underlying technical framework. The main objective encompassed the creation of a platform that not only provided detailed

data on trails and hiking routes, but also integrated interactive narratives and prioritized accessibility for users with diverse needs.

For that end, empathy maps were employed for user research purposes, which provided insights into the platform's requirements for different users and helped shape the visual prototypes developed. This initial research was also further enriched by accessibility feedback from the *FPDD* and the *UBI*, ensuring that the platform was inclusive to different user needs. Both the technical backbone of the system and its overall architecture tie all these elements together, while also prioritizing UX.

Finally, it is important to note that the platform evolved in tandem with user needs throughout the iterative development of the application. While the core technologies and requirements remained consistent, additional functionalities and adjustments were introduced during the implementation of the solution, as described in the next chapter.

5

Solution Implementation

Building upon the requirements and technological specifications detailed in the preceding chapter, we now proceed to the implementation phase of the project's various components. The foremost among these is the mobile platform, where we highlight its main features and their evolution throughout development. Additionally, we will examine the narratives database, focusing on its data model and the details of its administration via the back-office.

5.1 Mobile Platform - Tell Me a Trail

Once again, the primary component developed under this thesis was a mobile platform designed to display comprehensive information about hiking trails, while also integrating interactive narratives and addressing accessibility considerations. For this, the development process adhered to an *iterative methodology*, wherein features were progressively implemented, tested with users, and refined before the addition of the next set of functionalities. This approach fostered continuous user feedback, leading to the evolution of functionalities throughout the entire development cycle.

As such, the testing of the solution and its implementation are inherently linked. While the next chapter will delve into the actual testing process, including methodologies, feedback and results, this section will focus on the technical implementation of the app's key features and their evolution over time.

Due to the platform's complexity, most images depicting its screens are located in Appendix D, so it is recommended that this section be reviewed with the appendix at hand for visual reference. For a visualization of the evolution of user feedback towards each feature throughout development, Appendix E may also be followed, although it will be mentioned again in the next chapter.

5.1.1 Navigation Flow

As defined in the initial visual prototypes, the mobile application consists of five distinct tabs, navigable via a bottom tab bar. The three primary tabs, broadly sketched in the prototype phase, are **Trails**, **Narratives**, and **Map**. In addition, there are still the **Favorites**

tab, which stores the user's bookmarked and downloaded trails and narratives, and the **You** tab for user progress. You can see these in Figure D.2.

Each of the tabs in the application features extensive navigation flows and sub-screens, with frequent cross-navigation between tabs. To visualize this complexity, a flowchart was constructed to depict the relationships and navigational redirections between the tabs and their respective sub-screens (Fig. 5.1). In addition to these internal connections, users can directly access any tab by selecting the corresponding icon in the bottom navigation bar. This dual structure, with both direct and indirect navigation paths, allows for a more seamless UX across the app's multiple screens and functionalities.

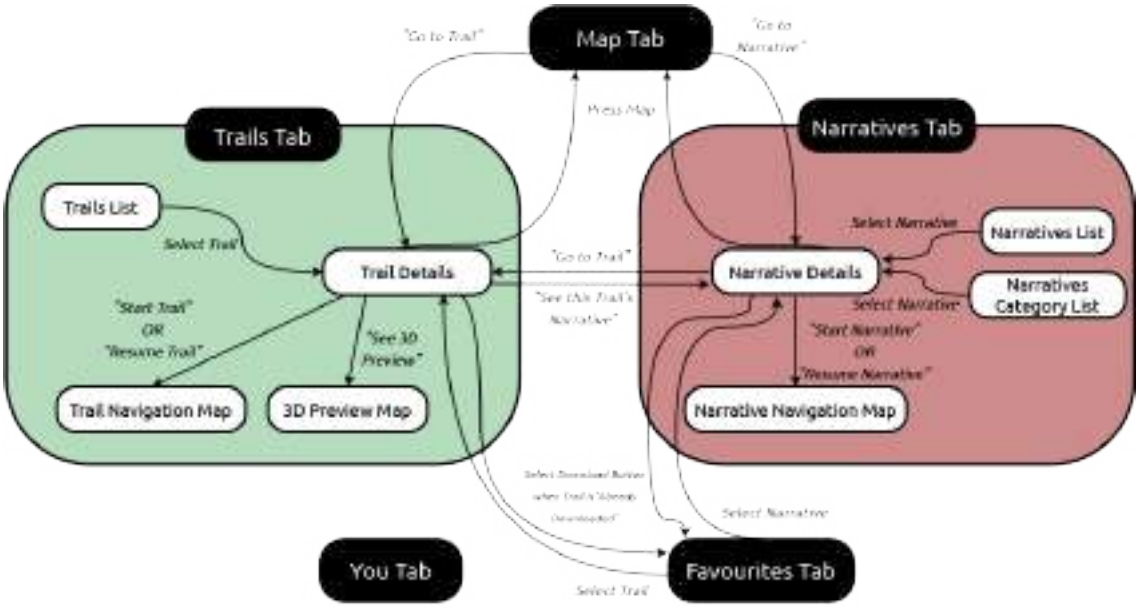


Figure 5.1: Flowchart illustrating the navigation flow between the main screens of the application

For a more comprehensive visualization of these flows, the later **Map**, **Trails**, **Narratives**, **Favourites** and **You** sections will start with a navigation flow of the focused tab using the actual application screens (Figures 5.2, 5.3, 5.5). These flows will not show every single detail and interaction in the tab - those will be in the Appendix - but only provide a more high-level view of the tab being detailed.

Finally, one of the few enhancements to the overall navigation system of the application, prompted by user feedback, was the implementation of an *exit warning*. Initially, pressing the back button at the root of the navigation stack for each tab would immediately close the application. This led to users inadvertently exiting the app when attempting to navigate back to the main screen. The initial proposed solution involved a modal dialogue with a "Yes" or "No" option to confirm the exit, but this approach was deemed cumbersome for users. Instead, the final solution adopted was to display a *Toast* notification with the message "Press back again to exit the app" (Fig. D.3), ensuring that users are warned before exiting the application unintentionally.

5.1.2 Persistence and State Management

Upon launching the application, the system retrieves and loads data from the *Trails* and *Narratives Servers*, incorporating all available trails and narratives into the app's state. As detailed in the previous chapter, the app is built using *React Native*, whose reliance on components means that, as the app grows in complexity and components interact with one another, managing state across various parts of the app can become increasingly complex.

To address this, the *Redux* library was used for state management, with the state being divided into distinct "slices", each responsible for handling a specific subset of the app's functionality. For example, individual slices were created for managing content related to maps, trails, and narratives. Each of them is responsible for tracking their own data, such as the currently selected marker on the map, the user's location coordinates, or the current stop of the narrative being navigated. Additionally, a global slice manages app-wide information, including loading states and the currently active tab or screen.

In addition to these slices, there is a mechanism to ensure the persistence of segments of the platform's data, even when the app is closed and reopened. This is where *Redux Persist* with *Async Storage* come in, ensuring that specific parts of the app's state, such as user-selected settings or bookmarked items, are saved persistently, preventing users from losing their data after restarting the app.

We will now expand upon each of the main functionalities of the app, and trace their development trajectory through iterative user testing.

5.1.3 Map

Once the app has completed its initialization process, the default interface presented to the user is the **Map** tab (Fig. D.4), which is presented with the appropriate request of location permissions. If granted, the map centers on the user's current position, otherwise the user is prompted to enable them for an enhanced experience.

Users can interact with the map through standard gestures, such as zooming and adjusting the pitch. The right-hand side of the screen contains three buttons: a compass icon to reorient the map to face north, a layer-change icon to toggle between three different map layers (*Default*, *Light*, and *Satellite* - Fig. D.5), and a location icon to re-center the map on the user's current location. When the layers modal is open, tapping anywhere outside the modal will automatically close it.

The default map layer is a custom 3D adaptation of the 2D *Mapbox Outdoors* layer[1], which provides topographical details, including altitude markers in elevated areas. When the pitch of the map is adjusted, these 3D elements become more visually prominent.

[1] https://www.mapbox.com/maps/outdoors

Figure 5.2: Flowchart illustrating the navigation flow between the main screens of the map tab

5.1.3.1 Markers & Clustering

There are two types of markers on the map: one for the **trails**, and the other for **trails which include narratives**. When zooming out, markers are clustered into **green circles** displaying the number of markers within that cluster. Pressing these clusters zooms the map into the corresponding area, while tapping on individual markers reveals a bottom sheet with detailed information about the selected trail and, where applicable, its associated narrative, as detailed further in the next section.

Throughout the iterative testing process, user feedback highlighted two key issues: first, users struggled to *differentiate between trail markers and narrative markers*, and second, some people *did not realize the markers were even clickable* and just ignored them. To resolve

these issues, the narrative marker's design was modified, changing from a red icon to a red icon with a book symbol. Additionally, a help legend was introduced to explain marker types, with its visibility being persistently stored based on the user's preference (refer to Table 5.1).

5.1.3.2 Trail and Narrative Information on Map

Selecting a marker centers and zooms the map to the corresponding trail, showing the trail's path as a LineString on the map. As mentioned above, it also opens a bottom sheet with trail information (Fig. D.6). If the trail contains a narrative, details about the narrative are also shown (Fig D.7). Buttons which redirect the user to the details page of the selected Trail (or its Narrative) - respectively in the **Trails** and **Narratives** tabs - are also shown in the sheet.

Additionally, the bottom sheet offers a few features, including the ability to toggle the display of trail difficulty levels. When enabled, the red *Linestring* representing the trail is replaced by segments of different colours, indicating varying levels of difficulty along the trail. A legend explaining the colour scheme is also displayed (Fig. D.8). Users can deactivate the difficulty display by toggling the option off or closing the bottom sheet. Similarly, a checkbox allows users to display the narrative stops along the trail (Fig. D.9).

In the later stages of development, a "Get There" button was also introduced, enabling users to open a GPS navigation app which, from their current location, will provide directions to the trail (Fig D.10).

The bottom sheet underwent some additional changes throughout development:

1. **Unintuitive slide** - By default, the bottom sheet opens in a minimized state, requiring users to pull it up to view additional content. Initial user testing revealed that the vast majority of users did not intuitively pull the sheet upwards, resulting in missed information. Various solutions were explored, but the most effective was a subtle animated prompt reading "Slide up for more", which expands and contracts until the user fully opens the sheet. Once the sheet is maximally expanded, the animation stops;

2. **Lack of feedback for checkmark toggling** - In earlier stages of development, users frequently failed to notice changes on the map when the bottom sheet was expanded. To address this, the sheet now automatically minimizes when difficulty or narrative stops are enabled, allowing users to immediately observe the changes on the map;

3. **Close Mechanism** - Originally, the sheet could be closed by tapping the map, but user feedback led to the addition of a dedicated close button for better usability.

Table 5.1 shows the evolution of these (and other) changes made in the map tab.

Change	Previously	After
Marker Change		
Legend Addition	No legend	
Bottomsheet Improvements		

Table 5.1: Most relevant changes made in the Map tab's components based on user feedback throughout development phases

Finally, it should also be mentioned that, given the default map layer being 3D, users can view the terrain's elevation around the trail by pitching the map (Fig D.11). This is only possible when the "Default" map layer is selected, however.

5.1.3.3 Points of Interest

One of the final map-related features in the app is the ability to toggle the display of various Points of Interest (POI), giving users granular control over the information displayed on their map (Fig. D.12). The categories for these POI underwent some name changes based on user feedback, with the final designations being as follows:

- **Lodging and Transportation**
  - **Lodging** - Includes hotels, hostels, and other accommodation services;
  - **Parking & Stations** - Represents parking lots and other transportation-related facilities.
- **Recreational**
  - **Parks** - Green spaces, gardens, and public parks;
  - **Beaches and Sports** - Beaches, sport facilities, and some other recreational activities.
- **Visitor Comfort**
  - **Water Stations and Rest Points**
- **Historical**

  - **Museums, Arts & Entertainment** - Museums, galleries, theaters, and other cultural venues;
  - **Landmarks** - Important or famous landmarks and building;
  - **Historic Sites** - Sites of historical significance, such as ancient buildings or memorials.

- **Commercial**
  - **Eating** - Restaurants, cafes, and other dining establishments;
  - **Groceries** - Supermarkets, convenience stores, and other places to buy food and essentials;
  - **Other Commerce** - Diverse commercial establishments, including banks or auto-mobile repair shops.

- **Medical**
  - **Medical Facilities** - Hospitals, clinics, pharmacies, and other healthcare facilities.

- **Other**
  - **Public Facilities** - Includes libraries, mail offices, police, other municipal services;
  - **Educational** - Schools, universities, and other educational institutions;
  - **Other Buildings** - Miscellaneous buildings that don't fit into other categories.

The POI are fetched and rendered through *Mapbox*'s internal POI layer, which is part of their vector tile service and specifically designed to display different categories of places. For example, it contains a set of pre-categorized points, such as parks, restaurants, and hospitals, which are displayed dynamically as the user zooms in and out on the map. These points are tagged with specific classes (e.g., *poi.lodging*, *poi.commercial_services*) that determine what kind of point is being rendered.

In this implementation, these classes are mapped to the above categories (e.g. "Groceries" is mapped to class *poi.food_and_drink_stores*), and are filtered in or out of the layer according to the categories toggled by user.

The activated POIs are one of the elements stored in persistent storage, allowing the app to keep the visibility preferences even when the app is closed and reopened.

5.1.4 Trails

The Trails tab is where the bulk of the information from the *Trails Server* is loaded and presented. Initially, users are presented with an overview of available hiking trails, grouped into various categories, which can overlap amongst each other (Fig. D.13). Each

Figure 5.3: Flowchart illustrating the navigation flow between the main screens of the trails tab

section features scrollable cards that display basic information such as distance, estimated time to complete, and an accompanying trail image. Categories include:

- **Offline Trails** - trails which the user has downloaded for offline use;
- **Nearby Trails** - trails within 30km of the user's current location;
- **All Trails** - All trails present;
- **Trail Types** - different categorizations of trails under the FCMPs nomenclature (*Pequena Rota*, *Grande Rota* e *Percurso Local*)

Each card shows a brief description of the trail's distance and average expected time. Clicking the title or the arrow above the cards will take the user to detailed list of trails within a specific category (Fig. D.14), while clicking the card itself will direct the user to the details page of the respective trail.

At the top, a search bar allows users to quickly find and filter trails based on names, locations, accessibility features and other criteria, and it is discussed in more detail in the respective later section.

5.1.4.1 Trail Details

The Trail Details (Fig. D.15) page provides a comprehensive overview of an individual trail, breaking down all the necessary information for hikers. As mentioned, the goal for this platform was to provide extensive information across a wider variety of demographics, so, beyond the information encompassing basic trail details such as distance and elevation - detailed in the **Details Tab** - there are also accessibility details presented in a separate **Accessibility Tab**.

Upon entering the page, the key information presented entails:

- **Title, Description, and Images** - To introduce the trail. The images use the *react-native-image-slider-box*[2] library, which allows for the user to slide between all the images for the trail;
- **Narrative and Accessibility Flags** - On the upper right hand corner, two icons can be visible: one if the trail has a narrative, and the other if the trail has some accessibility features;
- **Bookmark Symbol** - to add or remove trail to their favourites;
- **Basic Trail Information** - Including distance, expected time, its positive accumulated slope;
- **Secondary Trail Information** - The trail's path type (Circular or Linear) and its designation under the FCMP;
- **3D Preview Button** - A button which opens the 3D visualization of the trail, detailed in the next section;
- **Download Button** - for downloading the trail (and respective narrative, if applicable) for offline use. Also detailed in a later section;
- **"Start This Trail" Button** - Initiates trail navigation. If trail has already been started, it reads "Resume this Trail";
- **"See this Trail's Narrative" Button** *(if applicable)* - Navigates to the details page of the trail's narrative.

The specifics of the download button and navigation features are elaborated upon in subsequent sections of this chapter, as they constitute larger components of the platform which also include narrative logic. The 3D visualization is exclusive to trails, however, so it will be discussed next:

[2] https://github.com/intellidev1991/react-native-image-slider-box

3D Visualization A feature which was stressed to be of high importance among users, and which also aligns with the conventions for trail apps this platform is following, is the ability to preview trails ahead of time. Even though the default layer in the main tab is 3D, most users do not have the initiative to tilt the map in order to see the map's 3D features. Therefore this dedicated 3D preview page was provided for each individual trail (Fig. D.16)

This page presents the trail as a LineString and allows for layer selection. However, in order to add an improvement to the experience, the system introduces an **animated preview** of the trail, enabling users to see the path's progression from start to finish. This animated "journey" helps users visualize not only the elevation but also the route's trajectory through the terrain.

This animation works by moving the camera along the trail path in real-time using *Mapbox*'s **Camera** component. The coordinates for the camera's movement are dynamically calculated at each animation phase using *Turf.js*'s **along** function, which returns positions along the trail based on the distance already covered - this distance being proportional to the phase of the animation.

As the animation progresses, the camera then smoothly follows the trail at a speed pre-defined based on the trail's length: by dividing the total trail distance by a constant base speed, the animation adjusts to different trail sizes.

Additionally, users can control the pitch of the 3D view through a slider, and move the map at will while the animation runs.

A question arose during development regarding whether the camera should always face the trail's bearing during the animation, or allow users to freely rotate the camera. Ultimately, in the interest of greater user freedom, the latter option was chosen.

These elements, paired with the interactivity and novelty of a 3D map, led to this feature being one of the most consistently well perceived throughout entire development, with only slight layout modifications and a single change being implemented based on feedback: the opportunity to select the layers.

We will now move on to an overview of elements in the actual **Details Tab**

Mini-Map The initial component in the details tab is a miniature *Mapbox* map that displays the starting point of the trail, accompanied by a caption reading "See on Map". It shows the trail LineString, and pressing either the map or the caption will navigate the user to the trail on the map tab, opening its bottom sheet (Fig. D.17)

More notably, this map is also intrinsically linked with the elevation graph discussed below, with its view dynamically updating based on interactions with the graph.

Elevation Graph The elevation graph in the trail details page visually represents altitude changes throughout the trail. Using a *Line Chart* built with *react-native-gifted-charts*[3], the

[3] https://github.com/Abhinandan-Kushwaha/react-native-gifted-charts

graph dynamically plots the elevation points. It works by extracting the altitude coordinate values from the trail's *Geometry* object, and mapping them to a graph.

Figure 5.4: Some of the component in the trail's details page

When a user clicks on a specific point in the graph, the application triggers an animation that moves the above mini-map to the corresponding location on the trail using *Mapbox*'s **Camera** component, while also prompting a pop-up displaying the altitude at that point (Fig. D.18).

Initial versions of the graph *lacked an X-axis*, a prevalent criticism that was rectified with a custom-made X-axis displaying distances at regular quarter-intervals. Additionally, the *Y-axis* was also changed to automatically adjust based on the trail's minimum altitude.

Finally, to handle performance issues when loading altitude data for large trails, the altitude data coordinates are *downsampled*, reducing the number of points rendered on the graph to a maximum of one-hundred (100). This optimization is specially useful for "Grandes Rotas", which can contain thousands of coordinates.

Directions Information Similar to the "Get There" button located in the bottom sheet of a trail (in the **Map** tab), the trail details also provide a way of opening directions to the trail in an external application (Fig. D.19).

This was initially the only way of accessing this feature, though user feedback eventually resulted in the button also being added to the **Map** tab in order to provide greater flexibility to the users.

Weather Forecast Weather conditions can severely affect the enjoyment and state of a trail, and user research solidified the need to integrate some type of weather forecast in the platform. Thus, this component was designed to provide users with current weather conditions and a three-day forecast for the trail location (Fig. D.20). These are fetched dynamically from the *OpenWeatherMap*[4] API, and include data on temperature, wind speed, and humidity for the location the trail starts.

The forecast is segmented into tabs, allowing users to switch between "Today", "Tomorrow", and subsequent days for a detailed outlook, with an extra layer of granularity by also displaying the hourly forecasts for the selected day. The weather icons and descriptions, which correspond to nearly 80 different possible weather conditions, are translated and displayed dynamically using the app's localization system detailed later.

Two key concerns were raised during the development of this component:

- **Accuracy with Long Trails** - for long-distance trails, especially "Grandes Rotas" (trails exceeding 30 km) spanning multiple districts, the accuracy of the weather information would not reflect all the possible weather along a trail, since it uses the start point. In the end, the decision was made not to implement multiple forecast points along the trail as it would increase the complexity of the system, requiring significant additional API requests, data processing, and UI adjustments. Moreover, the precision of such forecasts might still be limited by the relatively small geographical differences between forecast points, potentially leading to only marginal improvements in accuracy. Given the increased resource demands and the diminishing returns on forecast precision, it was determined that using the trail's start point for weather information struck an acceptable balance between functionality and UX and usability;

- **Tab Location** - The decision regarding the placement of the weather component narrowed down to either the details. Early user testing indicated that participants overwhelmingly visited the Details Tab first, leading to delays and confusion when the weather information was located elsewhere. As such, the final decision led to the positioning of this component within that tab, resulting in much better feedback in later testing.

5.1.4.2 Accessibility Tab

The trail details page is divided into two primary tabs: the **Details** Tab, which has been discussed previously, and the **Accessibility** Tab, which contains some of the data most critical for users with diverse accessibility needs.

There are two main components:

[4] https://openweathermap.org/

Accessibility Information This section offers an overview of the accessible features available on a given trail and which were detailed in the previous chapter's section 4.1.2.2.

As per Figure D.21, features such as the availability of Joëlette chairs, trail assistants, Braille signage, and sign language support are displayed. For each feature, users are presented with an icon, a label, and a status indicator showing whether or not the feature is available on the trail. To improve clarity, a red check mark or a red cross visually indicate the presence (or absence) of each feature.

Each accessibility element also includes an information button. When pressed, an alert pops up to provide additional information about that specific feature.

Trail Sections and Terrain Type Most trail platforms provide accessibility information in a simplistic format, often reducing it to a single binary "Is wheelchair accessible?" field, which is an approach that often overlooks the diversity and complexity that can exist across different parts of a trail. Similarly, when trail difficulty is provided, it is often applied to the trail as a whole, ignoring the variations within specific sections.

To address these shortcomings, this component breaks the trail down into individual sections, offering detailed insights for each one. Users can view specific information (Fig. D.22):

- **Difficulty Level** - Ranging from Easy to Very Difficult;
- **Type of Surface** - From a total of ten alternatives;
- **Wheelchair Accessibility** - If that section is accessible to wheelchairs, strollers, or other types of wheel-based mobility equipment;

Each section is colour-coded based on its difficulty, and users can press an "information" (i) button for additional details about each surface type. An interactive map preview further enhances the experience, allowing users to visualize the trail sections and their respective terrains.

All these elements are evaluated based on the information in Annex I, where the difficulty and terrain categories are also laid out: In short, there are two main classification systems for the difficulty: *ISO 3021:2023* and *Walk Hike Portugal*. The ISO system categorizes trails from "Very Easy" to "Very Hard," while Walk Hike Portugal uses a different scale, from "Low Exertion" to "Extraordinary Exertion". The one that is more appropriate for classifying difficulty across different sections is the *ISO*, as the *Walk Hike Trails* only classification the trail's difficulty as a whole, based on its entirety.

Even though the primary difficulty data for these trail follows the *ISO* classification due to being section-based, the decision was made to adopt **nomenclature** more aligned with the *Walk Hike Portugal* system (Low to Very High Difficulty). as the terminology was perceived to be more intuitive for users. Table 5.1.4.2 shows how these classifications were mapped in the platform.

With this section-based system, the hope was to acknowledge the trail not as a single entity, but as a more nuanced experience where users can be better equipped to assess which specific parts of the trail meet their accessibility needs.

Difficulty Level on the App	**ISO 3021:2023**	**Walk Hike Portugal**
Very Easy	Very Easy	Low Exertion
Easy	Easy	Low Exertion
Moderate	Moderate	Moderate Exertion and Significant Exertion
Difficult	Difficult	Intense Exertion
Very Difficult	Very Hard	Extraordinary Exertion

Table 5.2: Comparison between ISO 3021:2023 and Walk Hike Portugal difficulty classifications, and how it is mapped against the platform

Finally, as already discussed in the previous chapter, the initial data chosen for both elements in this tab are reflections of discussions and resources provided by the *UBI* and the *FPDD*. However, as development progressed, significant feedback was gathered from users, notably from Tatiana, one of the interviewees who participated in the *Empathy Map* interview process. Tatiana, a wheelchair user, provided ongoing insights, highlighting additional accessibility features and suggesting improvements that were crucial to refining this component. Her feedback, along with the broader user testing, helped ensure that the platform's accessibility features were continuously extended and improved upon.

5.1.5 Narratives

The structure of the **Narratives** tab mirrors that of the **Trails** tab, intentionally designed with shared components to maintain consistency and facilitate a seamless user experience. Similar to the initial screen of the Trails tab, the Narratives tab presents the narratives in a scrollable card layout. These cards are grouped into three distinct sets (Fig D.23):

- Offline Narratives;
- Nearby Narratives;
- All Narratives.

Once again, pressing a card takes the user directly to the details page of that narrative, while selecting the title above a set redirects to a list view of all narratives within that particular set (Fig. D.24).

In addition to this familiar structure, the narratives can also be searched according to the different categories outlined in the previous chapter: *Historico-Cultural*, *Fictional*, *Environmental*, *Trail Guidance*, and *Other*. Each category is represented on the page with its own listing, and selecting it leads the user to a list of all narratives associated with that theme (Fig. D.24).

Figure 5.5: Flowchart illustrating the navigation flow between the main screens of the **Narratives** tab

5.1.5.1 Narrative Page

For a narrative, most of the essential hiking-related information is already provided on the corresponding trail page. As such, the content in the narrative's detail page is more concise, focusing on the narrative-specific elements. These key components include (Fig. D.25):

- **Title, Description and Image** - Given their similarity, these elements reuse components from the trail's details page;
- **Accessibility Flag** - Indicating if the narrative's trail includes accessibility features;
- **Bookmark Symbol** - to add or remove narrative to bookmarks;
- **Number of Stops** - amount of points along the trail where the user will stop to unlock parts of the narrative;
- **Basic Information** - Distance and expected completion time (calculated server-side based on the number of stops);
- **"Start This Narrative" Button** - Initiates the narrative, further detailed in section 5.1.7.

Similar to the trails page, the narrative detail page features a mini-map that links to the narrative's associated trail on the Map tab. The "Get There" component is also included, which opens external navigation applications to direct users to the starting point of the trail.

In terms of iterative development, the inclusion of the "Download" button was a significant addition based on user feedback. Initially, users were required to navigate to the trail's page to download the narrative, as downloading a narrative also necessitates storing its associated trail for navigation purposes. This led to confusion, with users struggling to locate the download functionality for a narrative. To address this, a "Download" button was added directly to the narrative page.

Furthermore, the display of the narrative's distance alongside the number of stops was another small change introduced, ensuring users have easy access to essential information without needing to switch back to the trail page.

5.1.6 Search and Filtering

No trails platform is complete without the possibility to search and filter. As such, in this project, we have three search bars: one for the Trails page, one for the Narratives page, and one for the Map page (Fig. 5.6).

The common search bar present in all three components has these base characteristics:

- **Filter by name** by checking which trail names include the search string;
- **Dropdown** - showing the filtered trails recommendations. It will close whenever one of its item is pressed, or when the keyboard is hidden;
- **Auto-fill the search bar** with the *first result* when pressing enter, or with the *result selected* from the dropdown;
- **Error feedback** whenever the user inputs a trail which is not present on the database.

In the case of both the **Trails** and **Narratives** tabs, the user search dynamically updates the scrolling cards to show the trails or narratives as the search string is input (rather than waiting for the query to be submitted). This was implemented as a way for the users to have immediate feedback on their queries. Alternatively, searching a trail in the **Map** tab selects that trail on the map (Fig. D.27).

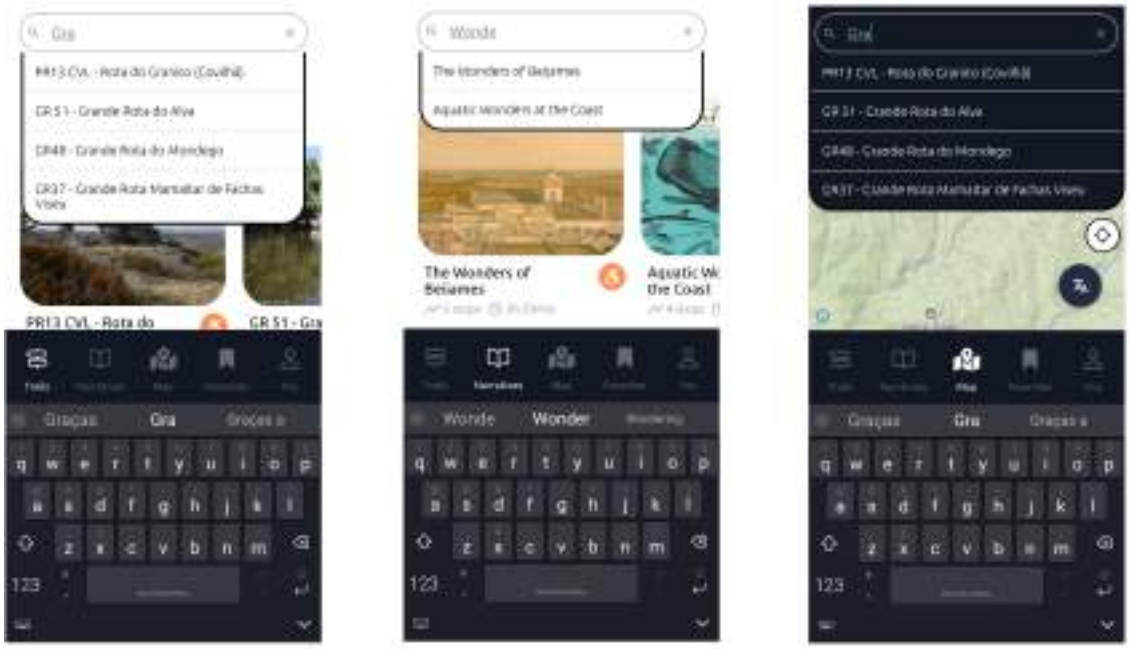


Figure 5.6: Search bar functionality in the trails, narratives and map pages

While all three bars share common functionality — enabling users to search through trails or narratives by name while showing a dropdown with the results — only the Trails tab search bar works in tandem with a comprehensive *filtering system*:

Filtering System In addition to the search functionality, the search bar within the Trails tab operates alongside a filtering mechanism enabling users to further narrow down their results based on a variety of criteria (Fig. D.28).

These are:

- Presence of Narrative;
- Location - district and municipality of the trail;
- Altitude Range;
- Distance Range;
- Expected Duration Range;
- Accessibility options.

When applied, the scrolling cards are updated, with the filters being displayed on the screen and able to be removed individually (Fig. D.29).

This filtering system dynamically filters trails based on active filter criteria. If there are filters currently applied, the search bar will only search from within the filtered results. The opposite is *not true*, however, as user testing proved it to be confusing: if there was already a search query on the search bar and filters were subsequently applied, many users encountered no results and did not realize that it was because there was a string input on the search bar.

Therefore, while the search bar is dependent on the filters, *the filters do not consider the search bar input*. Consequently, any text in the search bar is disregarded when filters are applied.

The differences between the search functionality in each of the tabs is detailed in the below table 5.3.

	Trails Tab	**Narratives Tab**	**Map Tab**
Search Scope	Filtered trails	Narrative titles	All trails
Search Target	Trail names	Narrative titles	Trail names
Filtering Applied	Yes	No	No
Dropdown Suggestions	Filtered trail names	Filtered narrative titles	Filtered trail names
Result Handling	Filter trail cards	Filter narrative cards	Zoom to trail on map

Table 5.3: Comparison of Search Bars Across Different Tabs

This was one of the components which underwent the most changes in the entire platform, as user feedback often resulted in the detection of various usability problems, as well as issues related to the interaction between the search bar and the filtering system in the trails page.

5.1.7 Navigation

For a trails app, navigation is a critical component that can dramatically affect the hiking experience. Accounts of people making a wrong turn or getting lost were a staple when doing user research, and it highlighted the importance of a solution where these issues could be addressed, while offering customisation options.

The navigation interface starts centered on the user's current location, visualized through a navigation puck that tracks the user's movement in real time. This functionality is powered by the *Mapbox* library (*rnmapbox*), specifically its "Location Puck" component. Along with the "Camera" component being customised to follow the user's movements and device orientation, the development of the navigation system was much more streamline thanks to this library.

In addition to the location puck, the map displays the trail as a LineString with directional arrows overlaid. These arrows were implemented directly in response to user

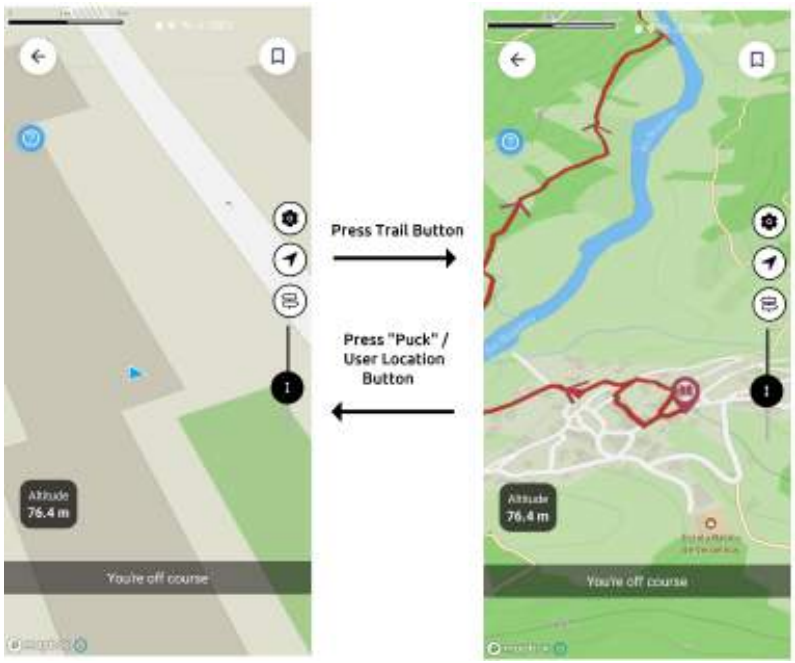


Figure 5.7: Navigation Screen, and the resulting action from pressing two of the buttons on the right side

confusion at which direction to follow in a circular trail (a trail which starts and finishes at the same point).

In addition to a bookmark button on top, three other buttons also appear on the right hand side. The first opens a settings modal, the second centers on the user's location, while the last one focuses on the trail's start point. A slider provides the option to change the map's pitch more easily, without relying on finger gestures (Fig. 5.7).

The settings modal, introduced as a direct user request, allows for some degree of customizability, showing three options (Fig. D.32):

- **Show Altitude** - Toggles the box showing the user's current altitude;
- **Show Speed** - Toggle the box showing the user's current speed;
- **Show Difficulty** - Shows the difficulty sections for this trail on the map;
  - **Difficulty Legend** - this option becomes available once the above is toggled, toggling the legend for the difficulty types;
- **Show Alternate Trails** *(if applicable)* - shows on the map other trails which intersect this one.

The application also continuously monitors the user's proximity to the trail in real time, leveraging *turf*'s functions. The user's current location, represented as a *Point*, is compared to the trail by first determining the nearest point on the trail using *turf.nearestPointOnLine*.

The distance between the user's location and this nearest point is then calculated using *turf.distance*, which measures the separation in meters.

This distance is recalculated every 10 seconds as the user's location is updated, with a banner displayed in the bottom of the screen saying "You're on track" if that distance is below 50 meters, and "You're off course" otherwise.

Finally, user testing revealed a frequent complaint regarding the screen turning off during navigation. To address this, the library *react-native-keep-awake*[5] was integrated, preventing the device from entering sleep mode during active navigation. Apart from this, the overall navigation component stayed generally consistent. The major changes were:

- **Addition of Settings modal**, with various options, including the display of the trail's difficulty sections, eliminating the need to navigate back to the trail page (Fig. D.32);
- **Help Legend** - See Fig. D.31;
- **Bearing Arrows** - Arrows over the LineString, showing its direction;
- The option to **change navigation to an alternate trail**, as detailed in next section.

5.1.7.1 Intersecting Trails

A staple of hiking is often adventure and discovery of new paths. As users navigate through a route, they may frequently encounter intersections with other trails and wish to explore them. To capitalize on this aspect, a feature was implemented allowing users to seamlessly switch to any intersecting or adjacent trail (See Fig. D.33)

These intersecting trails are not computed on the client side; rather, they are represented as an array of trail IDs included with the trail data retrieved from the *Trails Database* maintained by A. Tavira [88].

Using the ids from this array, each of the intersecting trails (if any) are fetched from the database and their respective GeoJSON LineStrings displayed on the map, in a grey color consistent with the conventions of similar platforms.

When pressing one of the grey lines, the user is prompted with a modal confirming if they wish to switch to that trail. Upon confirmation, the new trail's LineString becomes the primary route ready for navigation, and new intersecting trails are recalculated for the new trail and displayed on the map.

The only significant change implemented in this component, as a result of user feedback, was a loading screen during the transition to the new trail. Previously, users experienced a lack of feedback while the new trail was loading, leading to repeated selection attempts and confusion regarding the status of the change. As such, the loading overlay was implemented.

[5] https://github.com/sayem314/react-native-keep-awake

5.1.8 Narrative Navigation

For the location-based interactive narratives present in this platform, navigation is pivotal, as it relies on the user's current location to trigger a stop's content.

Figure 5.8: Flow of navigation for a narrative

The navigation system for the narratives integrates four key elements:

1. **Trail Navigation** - The core navigation elements from the trails system are retained for narratives, with the exception of switching to alternate trails. The map interface, navigation codebase, and settings are shared between both systems to maintain consistency;

2. **Stop Tracking** - Users are guided to follow a trail and unlock content at designated stops. This system calculates the user's proximity to each stop and prompts them to engage with the content once they are within a specified range;

3. **User Freedom** - Beyond the customisation options present as default for the navigation, it was important to allow users to revisit previously unlocked stops or start the narrative from any point on the trail;

4. **Progress Tracking** - The system tracks narrative progress, allowing users to resume from their last stop and visualize their overall journey (see section 5.1.10).

The narrative navigation component is built around a bottom sheet that dynamically updates based on the user's location: Every 15 seconds, the system calculates the distance between the user and the next stop and, if the user is within 30 meters of a stop, an "Unlock" button appears on the bottom sheet (Fig. D.34). When pressed, the content for that stop is revealed, with the user's progress being updated accordingly in state.

If the narrative is ever abandoned halfway through, progress is stored persistently, with users being given the option to either restart it or continue from where they left off. All previously unlocked content remains accessible.

5.1.8.1 Multimedia

As users travel along the stops and unlock their content, they can encounter text, images, audio or video. While displaying text and images was relatively straightforward, the implementation of audio and video required custom development of media components:

These *VideoPlayer* and *AudioPlayer* components (Fig. D.35 and D.36) make use of the media playback library *expo-av*, while the actual player controls were all custom-developed to allow users to play, pause, and seek through media content, as well as enter full-screen mode. Both players feature buttons for skipping 10 seconds backward or forward, and a progress bar reflects the current playback position, allowing users to jump to specific points in the media. Playback continues even when the screen is off.

The loading of multimedia content follows a specific logic, with two distinct modes of operation:

1. **Regular Mode** - When a narrative is initiated, a request is sent to the server to retrieve URLs for all multimedia content stored in *Appwrite*. These URLs are then associated with their respective Stop object. As users unlock content, audio, video, and images are loaded from these URLs in real time;

2. **Offline Mode or Downloaded Trail** - Instead of using the regular URL's, the Stop object stores URLs pointing to local storage on the device, leading to an almost instantaneous loading of the multimedia. It should be noted that this always happens for a downloaded trail even if the device is *not* offline, in order to provide better UX

The narrative navigation component underwent massive changes during development, especially given its complexity and central importance to the platform. Table 5.4 outlines some of the additions made in response to user feedback and testing.

5.1.9 Favourites

The favourites tab is fairly straightforward, displaying two sub-tabs: one for bookmarked (favourite) trails and narratives, and another for downloaded trails (Fig. D.37). Bookmarks can be easily added and removed directly from the trails page by pressing the respective symbol (Fig. D.38), with the removal option also being provided in the Favourites tab itself. Selecting a downloaded or bookmarked trail or narrative will navigate the user to the respective details page.

The downloads tab shows trails (and narratives) which have been downloaded for offline use, while also allowing for their removal.

Finally, for a better experience, all information within these tabs is stored persistently.

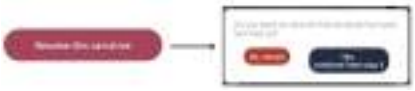
Issue	Explanation	Examples
Users did not interact with the bottom sheet due to its initial hidden state	Raised the initial position of the bottom sheet to make it more prominent	-
Users missed stops when distracted	Added device vibration when near a stop	-
Users requested full-screen video playback	Implemented full-screen functionality for video content	-
Media player controls were too small	Enlarged the media controls	-
If users missed previous stops, they had to walk all the way back to the previous one	Introduced the option to unlock all stops prior to the user's current position	
Progress was lost if users exited the app or screen	Implemented a "Resume Narrative" feature, enabling users to continue from their last unlocked stop with their progress saved	
Lack of feedback during buffering led users to think the video had paused	Added visual feedback, including loading indicators and a buffering state on the play/pause button	

Table 5.4: Examples of feedback mechanisms implemented in the *Narratives Manager*

5.1.10 User Progress

To introduce a certain degree of progress tracking within the application, a dedicated "User Progress" tab was developed. This tab allows users to monitor various trails and narratives they have started, providing an overview of their completion status and overall aiming to foster a more continuous engagement with the trails and narratives of the platform (Fig. D.39)

In here, users can view all the trails they are currently tracking, along with any narratives associated with these trails. Both trails and narratives are automatically added to the list once the user starts navigating them. However, since a trail can be initiated without an associated narrative (but not vice versa, as narratives are inherently tied to trails), starting a trail does not automatically add its related narrative to the tracking list. As such, the platform includes an option through a checkbox labelled "Don't ask to add narratives," giving users the freedom to decide whether they want to be prompted to add narratives when starting new trails.

Trail are automatically marked as complete if, while navigating it, the navigation map detects the user location is within 100 meters of the end point. On the other hand, narratives are marked as complete as soon as the final stop is unlocked. However, once again, users have the freedom to mark them as complete or incomplete at their discretion (Fig. D.40).

Beyond tracking progress, the tab enables users to manage their experience by removing trails or their respective narratives from the list. Users can also manually mark trails or narratives as complete. In the case of the narratives, however, it was argued whether they should be allowed to be marked as complete manually, since it would automatically unlock its content for the user to see even if they had not physically experienced the narrative.

Ultimately, in the interest of enhancing user flexibility and accessibility, it was decided to retain the option for users to manually mark narratives as complete. The decision was taken to reflect the understanding that there are numerous legitimate reasons why a user might be unable to fully experience or complete a narrative. Beyond mobility constraints, which are particularly relevant for users with accessibility needs, other factors such as time limitations, unforeseen circumstances, or logistical challenges may prevent users from visiting all the physical stops associated with a narrative. While the narratives in this project are predominantly designed as location-based experiences, it is important to acknowledge that not all users will have the capacity (or opportunity) to engage with them in their entirety, and forcing them to do so may create unnecessary barriers to engagement.

5.1.11 Offline Functionality

A key feature of the mobile platform is its offline functionality, which enables users to download hiking trails and narratives for offline use. This was an essential functionality as hiking often involves being in areas with limited or no connectivity. Additionally, the streaming of the narratives multimedia content in real time can also incur elevated data costs to the users.

The implementation of this feature relies on the use of Expo's *FileSystem* API, which facilitates the downloading and storage of trail data, images, and narrative content directly onto the user's device.

Upon initiating a download, users are presented with a modal indicating the download stage, while a progress spinner visualizes the current status of the download operation.

However, to prevent the user from being blocked from taking any other action while the download happens, the app allows for the download to occur in the background, with a pop-up warning when it has finished (Fig. D.41).

The offline functionality follows a structured download process, which is displayed in chart form in Figure 5.9

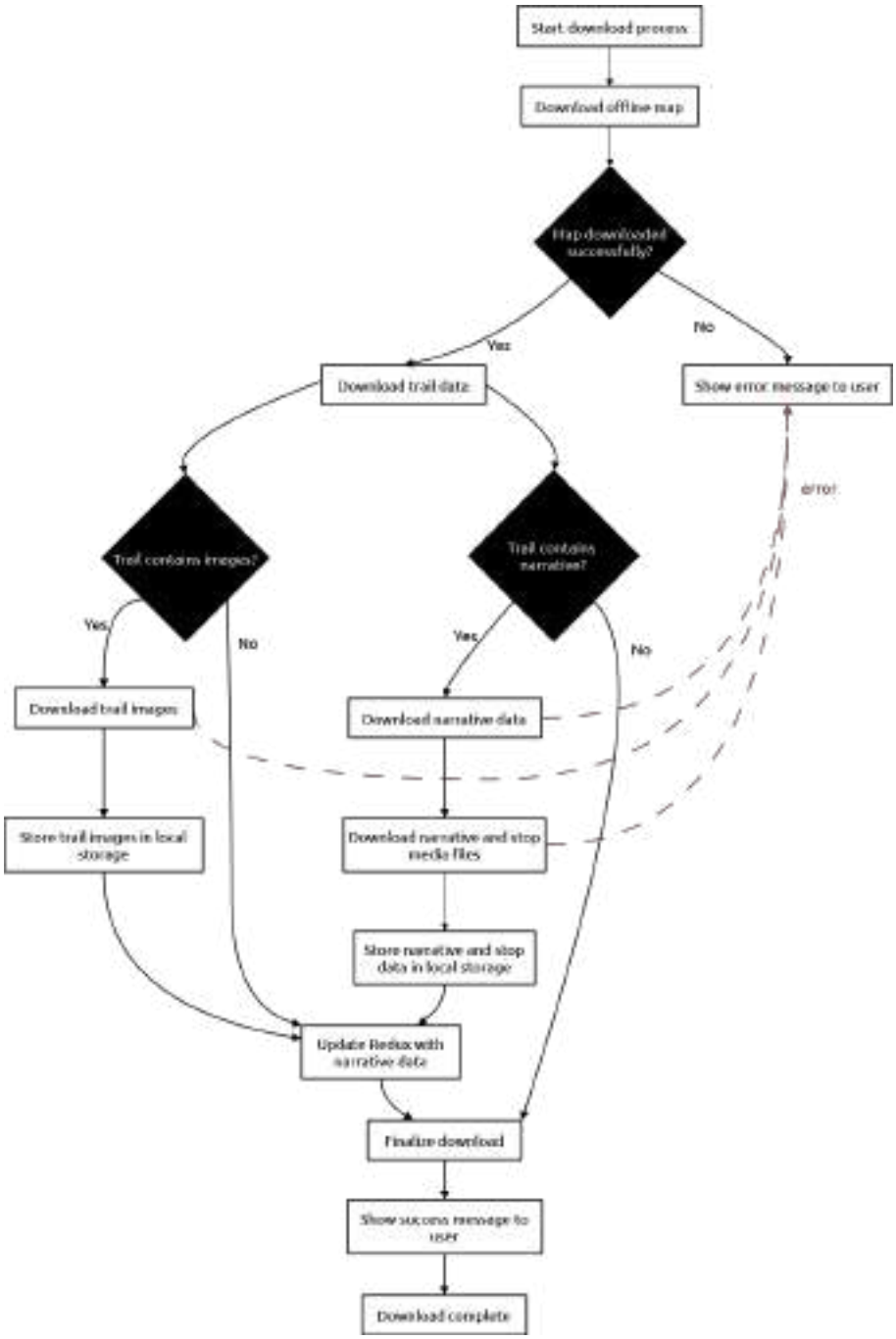


Figure 5.9: Diagram sequencing the order of the download process

The process begins by downloading the offline map data, using a bounding box calculation to define the geographical area surrounding the selected trail. The application

leverages *Mapbox*'s offline manager to download map tiles, enabling users to view and interact with the map without needing an active internet connection. This is achieved by specifying the bounds, zoom levels, and style of the offline map pack.

Once the map download is complete, the system proceeds in downloading trail-specific data asynchronously, including images associated with the selected trail.

For trails that contain narratives, the application further downloads narrative-specific content, such as images and media associated with each narrative stop.

It should be noted that the application was designed to ensured that all relevant files are saved locally using a structured directory system within the device's storage, thereby organizing downloaded content into distinct folders based on the trail or narrative. For example, the video for the second (2) stop in a narrative with id 5 will be stored in the URI *"@LOCALFILEDIRECTORY/narratives/5"*, with the name *"stop_2_video"*.

To ensure a consistent user experience, the app manages the state of the download process through *Redux*. As files are downloaded, their URIs are dynamically updated in the *Redux* persistent store.

The application also includes error handling to account for potential issues during the download, like network interruptions. In such cases, the user is notified, and the system reverts to the original media file URL if the download fails.

Once the files are downloaded, the platform will automatically use the files stored in the device instead of streaming them while navigating a narrative, regardless of the device's connectivity.

App Functionality in Offline Mode When a user's device loses connection, the app immediately shows a warning saying so (Fig. D.42). Then, nearly the entire platform is still usable, though with some limitations:

- **Trails and Narratives** - The only trails available to see on the app will be the downloaded trails and respective narratives;
- **Map** - Since the offline maps downloaded only correspond to the bounding area of the downloaded trail, the remainder of the map locations will have fewer tilesets and will not show any POI. The only exception to this is if *Mapbox* automatically cached that location previously (from the user having interacted with it recently), in which case that location and respective POI will be visible normally. Additionally, since the offline map only downloads the default map style, the ability to change map layers has no effect, and the button to change them is removed from the map temporarily;
- **Favorites and User Progress** - The Favorites screen will now only show the *Downloads*, and not the *Bookmarks*. The User Progress tab, however, will stay intact.

When the connection is restored, all the trails and narratives are automatically reloaded from their respective databases.

5.1.12 Localization

One of the final features implemented in the mobile platform was the integration of a translation and localization system, with the aim of supporting multiple languages in the platform, and thus increasing its availability to a broader user base.

To achieve this, a localization system was developed using *i18next*[6], an internationalization framework that supports multiple languages and allows for dynamic language switching.

The mobile platform supports **English**, **Portuguese**, and **Spanish**, with all text translations stored in JSON files. These resource files house the language-specific content, making it simple to expand the app's multilingual capabilities in the future.

Upon first use, the application identifies the device's language settings and attempts to match them with the available language options. If no match is found, or if the user has not selected a language previously, English is set as the default language.

Once a language is detected or chosen, all the content of the app, including menus, buttons, and even details such as weather descriptions, are dynamically updated.

The language selection feature is accessed through a *Floating Action Button* (FAB) with a language icon which, when activated, displays three language options (Fig. D.43).

Initially, this button was only available on the **Map Tab**, based on the assumption that, since the Map tab is the default view upon opening the app, users would prefer to have the language options readily accessible without having to navigate the interface in an unfamiliar language

However, user testing revealed that, contrary to this assumption, most users instinctively navigated to the **"You" tab** when attempting to change the language settings. Consequently, an identical FAB was added to that tab to accommodate this behaviour, while retaining the original button in the Map tab for convenience.

5.2 Narratives Database

The trail and narrative data shown on the platform come, respectively, from the trails and narratives back-end. The trails database and the detailed data for the trails was developed under A. Tavira's parallel thesis [88]. As it is under the scope of another thesis, this section will instead focus on the database actually developed under this thesis: the narratives database

As mentioned in the previous chapter, the narrative's database is built using *PostgreSQL* with *PostGIS* for managing geospatial data, while *Appwrite* stores multimedia files

The database was designed with three main types of information in mind: Narrative Metadata, Geospatial Data, and Multimedia Files. Table 5.2 outlines these different types of information stored in the system, with the corresponding object types used to represent them.

[6] https://react.i18next.com/

For the narrative metadata — which includes key information about each narrative and its respective stops — traditional data types such as *varchar* and *int* were employed. Additionally, references to other tables were established to manage relationships between narratives and their associated stops efficiently.

When it came to geospatial data, *PostGIS* included the data type *geometry*, which was used for the representation of stop coordinates, specifically through *Point* objects. These correspond to a set of geographic coordinates (latitude and longitude).

Finally, multimedia files were managed separately from the core database, via *Appwrite*. This decoupling meant that the database only stored references to each file through a *varchar*, representing the Appwrite ID.

Information Types	**Attributes included**	**Object Type Used**
Narratives and Stops Metadata	title, text, description, among others...	*varchar* and *int*
Geospatial Data	Stops: coords	*Geometry* object as *Point*
Multimedia References	Narratives: mainImageId Stops: imageId, audioId, videoId	varchar referencing the *Appwrite* ID

Table 5.5: Different types of information present in the database and the object types used to represent them

When it came to operations on the database, the platform followed standard **CRUD** (*Create, Read, Update, Delete*) functionality to manage the various types of data stored in the system, leveraging the server-side technology detailed in chapter 4.

5.2.1 Data Model

Figure 5.10 represents the relational model for the database, comprising four main tables: **Narratives**, **Stops**, **Category** and **UserAccount**. Below is a detailed description of the data model and each of its key tables.

5.2.1.1 Narratives

The Narratives table serves as the central entity, representing the storytelling aspect of the app. Each narrative is tied to a specific trail (stored in the trails database), and linked to its respective category and stops. Additionally, it contains additional metadata information. The table's attributes are:

- **id** - unique identifier for the narrative;
- **trailId** - foreign key referencing the id of the trail in the trails database;
- **createdBy (fK)** - links the narrative to the UserAccount table, signifying the user (admin) who created the narrative;

Figure 5.10: Relational Data Model for the Narratives Database

- **mainImageId** - ID reference to the image stored in *Appwrite*;
- **categoryId (fK)** - foreign key to the **Category** table, indicating the type or theme of the narrative;
- **Title, text, time, and nStops** - additional metadata for the narrative.

5.2.1.2 Stops

Narratives must have stops, representing the key locations along the trail. The Stops table store both textual and optional multimedia content associated with each stop:

- **id** - unique identifier and primary key for each stop;
- **narrativeId (fK)** - links the stop to a specific narrative;
- **text, title, count** - additional metadata of the stop; *count* tracks the order of the stop within the narrative;
- **coords** - geometry object storing the *Point* (latitude and longitude) of the stop;
- **imageId, audioId, videoI** *(optional)* - references the multimedia files associated with the stop.

5.2.1.3 Category

The table storing information on the categories is more straightforward, sporting a unique **id**, along with the **title** and **description** for each of the categories.

5.2.1.4 UserAccount

Although the system was designed with only a single administrator during development, the structure of the database allows for the eventual inclusion of additional users, who have administrative access to the back-office of the database. Besides the primary **ID** and unique **username** and **email**, some other details can be stored, including **first** and **last name**, **gender**, **birthdate** and a **password**.

5.2.2 Back-Office - Narratives Manager

The back-office component of the narratives database - named "*Narratives Manager*" - is a React-based web platform introduced to facilitate the process of creating and removing narratives from the database, sparing administrators the complexity of directly handling *SQL* code or using tools such as *pgAdmin*.

The interface features a sidebar - for the input of narrative data through forms - and a *Mapbox*-integrated map which enables users to select a trail or narrative and pinpoint the locations for narrative stops.

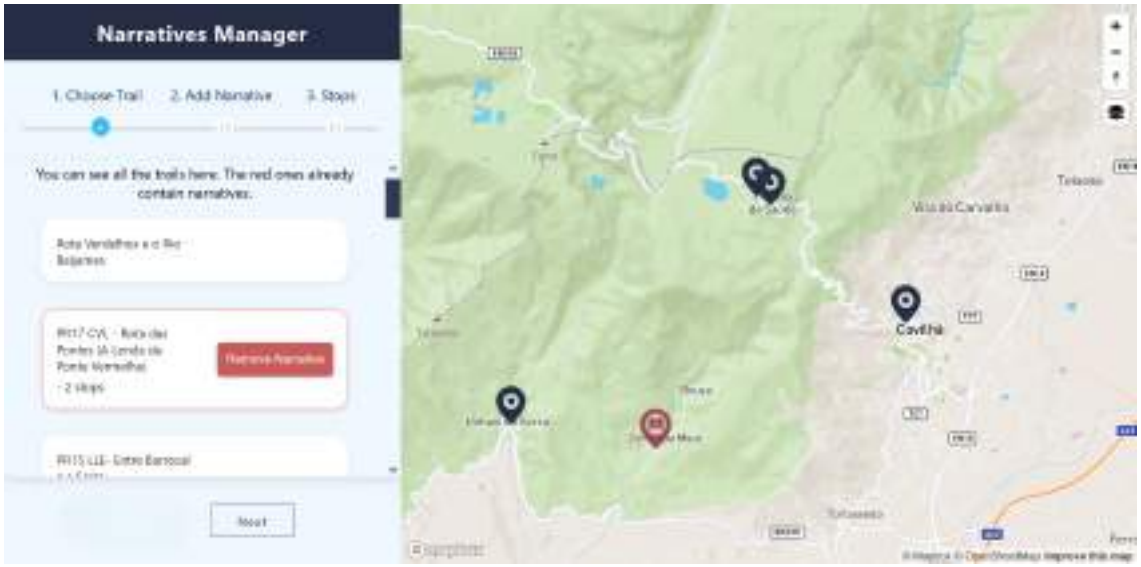


Figure 5.11: Initial state for the *Narratives Manager* - the back-office for the narratives back-end

On startup, the *Narratives Manager* fetches all available trails from the *Trails Server*, displaying them both as a list in the sidebar and as markers on the *Mapbox* map.

Subsequently, the manager is ready to receive information through a structured step-by-step logic: Initially, the user starts by choosing the trail, followed by the input of the narrative's details and, finally, selection of the stops. The process is described below:

Step 1 - Trail Selection or Narrative Removal With the map and sidebar now displaying selectable **trails** with and without **narratives**, users can select them via either component: by *clicking on a marker* or *selecting from the sidebar list*. This shows a preview of the trail's path as a *LineString* (Fig. 5.12). For trails that include a narrative, additional information is displayed, along with details about its stops along the *LineString*.

Via the sidebar, there is also an option to remove a trail's narrative. This results in a **DELETE** request being sent to the *Narratives Server* with the narrative's ID. The server then connects to the *PostgreSQL* database and begins a transaction, which starts by first deleting all stops associated with the narrative. If successful, it proceeds to delete the narrative itself, otherwise the transaction is rolled back to ensure data integrity. Once the narrative and its stops are successfully deleted, the transaction is committed and the database connection is closed. With a successful deletion, the client-side code reloads the page to reflect the changes, while an error prompts an alert to the user.

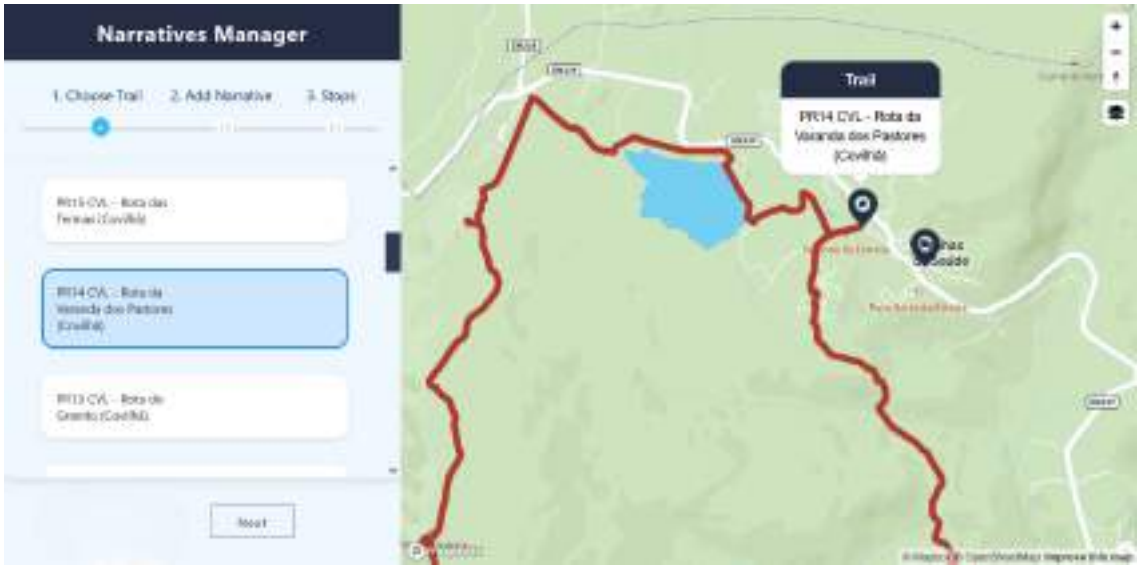


Figure 5.12: The back-office displaying a selected trail

Finally, clicking on the map during this step will unselect any chosen trail or narrative. However, while the user can select and unselect at their discretion, progression to the next step is contingent upon selecting a trail *without* a narrative - as trails cannot have more than one narrative.

Step 2 - Add Narrative Upon trail selection, the user will now be authorized to proceed to this step, where they can provide basic information about the narrative. As shown in figure 5.13, the required inputs include:

- **Title** for the narrative
- **Description** of up to 500 words giving an overview of the narrative
- **Category** from a dropdown of the five possible categories (detailed in the previous chapter)
- **Image** representative of the narrative

Other details required for the narrative object are either automatically calculated or referenced from the Trails database. For instance, the "*trailId*" is linked to the id of the selected trail object, while the "time" attribute is computed by combining the trail's estimated duration with additional time based on the number of stops (added in the next step).

Figure 5.13: Forms and information to input for the narrative during **Step 2** (left) and respective stops, in **Step 3** (right)

At this stage, users still retain the ability to change their selected trail, as their markers will stay visible on the map. The markers for the trails with narratives, however, will no longer be displayed.

Step 3 - Stops Upon reaching the third step, the ability to select different trails is disabled, with all markers except the current trail's being removed from the map. Additionally, the

functionality of clicking on the map shifts: whereas previously it would unselect a trail, it now adds a **stop** marker to the map. Each stop added on the map prompts the sidebar to display a corresponding form where the user can input relevant stop information (see Fig. 5.13). This behaviour of adding a stop can be seen in fig 5.14

Figure 5.14: Narratives Manager before and after adding stops to a narrative

Each narrative can have a minimum of 2 and a maximum of 10 stops, representing the key locations along the trail which will actually deliver the narrative. Stops have to be within 100 meters of the trail path and require the input of the following information:

- **Title**, which should be short;
- **Text** for the actual content of the stop. It allows for a large amount of words to account for audio or video transcripts;
- **Optional Image**;
- **Optional Video or Audio**.

The multimedia content entails a 50MB size limit, determined by the file upload restrictions on *Appwrite*.

When clicking on the stop marker, its input forms, or the "Go to Stop" button, the map automatically centers on the respective stop's coordinate. Conversely, when a stop is selected on the map, the sidebar also scrolls to the corresponding stop. Additionally, the option to remove stops is also provided, with the system automatically reordering the subsequent stops accordingly.

It should be noted that, similarly to the mobile app, each piece of information is stored in the *Redux* state, making it available in a global state for the submit process. As such, once all the necessary information for the narrative is filled out and validated, the "Submit" button becomes available to the user. Pressing it triggers a multi-step process that involves the insertion of both the narrative and its corresponding stops into the *Narrative Database*, while also uploading any associated multimedia files (images, audio, video) to *Appwrite*'s storage system. This process is illustrated in figure 5.15 and can be broken down into two main steps: submitting the narrative and submitting the stops.

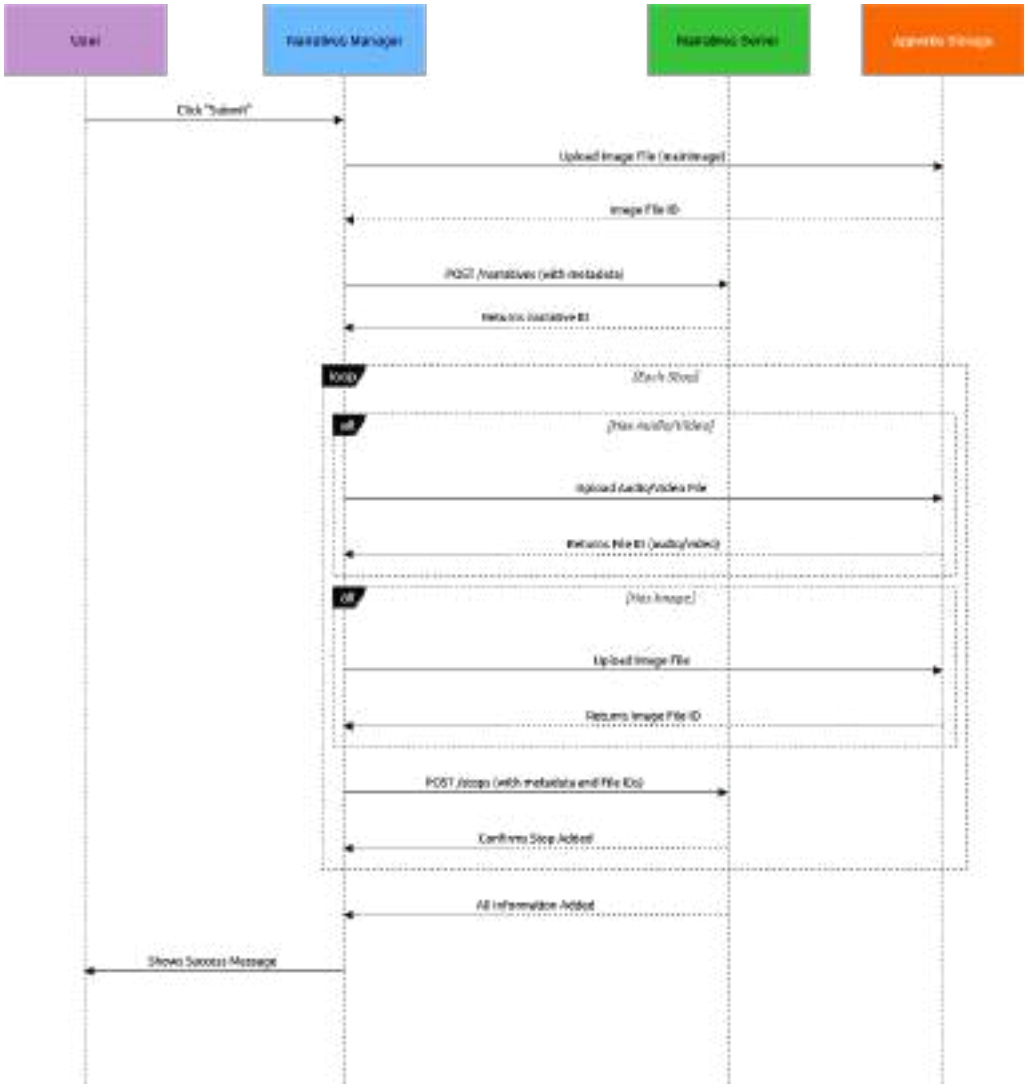


Figure 5.15: Flowchart illustrating the sequence of requests and responses during the narrative submission process

Submitting Narrative Upon clicking "Submit", this sends a **POST** request to the /narratives endpoint on the *Narratives Server*. The server expects a JSON payload containing metadata for the narrative, such as the title, description, associated trail ID, number of stops, and other relevant data. The response from this request returns a unique narrative ID, which is crucial for associating the stops with the corresponding narrative. If this step fails, the user is alerted, and the process is halted.

Simultaneously, the selected main image for the narrative is uploaded to *Appwrite*'s storage. This is done by sending the file to a specific *Appwrite* bucket dedicated to images. The image file's unique ID is included in the narrative metadata as part of the POST request. In case of any upload failure, the operation stops, and the user is notified.

Submitting Stops After the narrative has been successfully inserted and the main image uploaded, the next step is inserting each stop individually. The system loops

through the list of stops stored in the *Redux* state, and for each stop, it performs the following actions:

1. **Multimedia Upload** - If a stop includes audio, video, or an image, these files are uploaded to *Appwrite*. Based on the type (audio, video, or image), the file is placed in the appropriate *Appwrite* bucket. The IDs of these uploaded files are stored for later reference;

2. **Stop Submission** - A POST request is sent to the /stops endpoint on the *Narratives Server*. This request includes metadata such as the stop's title, description, coordinates, and stored references to the associated multimedia files (audio, video, image) uploaded earlier. The server responds, confirming whether the stop was successfully added to the database. In the case of an error, the process stops, with the admin being notified.

Finally, once all stops have been submitted, the user is alerted of the successful operation, and the app reloads after a brief timeout to reflect the changes. In the main page, the new narrative will now be visible, as reflected in figure 5.16

Figure 5.16: The newly added narrative in the *Narratives Manager*

5.2.2.1 User Flexibility and Feedback

Although the Narratives Manager operates with a step-by-step system, administrators can navigate freely between steps without losing progress. If an action does require removing progress (e.g. selecting a new trail when there are already stops selected for the current trail), the system will confirm this action with the user beforehand, ensuring no progress is unintentionally lost.

Figure 5.17: Map-related options available in each of the steps

For instance, the administrator has the flexibility to input details for the stops (**Step 3**) or provide basic information about the narrative (**Step 2**) in any order they wish, or they can re-select trails at will without losing the content written in **Step 2**. Table 5.17 highlights some the map options available in each step.

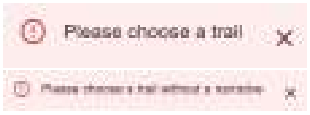
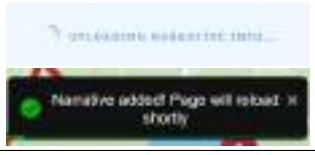
Feedback	Explanation	Examples
Trail not chosen	User tried to proceed to the second step (add a narrative) without choosing a trail, or having chosen a trail which already has a narrative	
File too large	User tried to upload a file larger than 50MB	
Stops Already Selected	Warning message that appears when stops have already been selected for a new narrative but the user is returning to previous steps to select a new trail	
Invalid Information	Various verifications associated with the input in the narrative and stop forms, and which prevent the user from submitting the narrative	
Submit Feedback	Loading feedback and confirmation that the narrative was added	

Table 5.6: Examples of feedback mechanisms in the *Narratives Manager*

Finally, it is important to note that feedback mechanisms play a crucial role in guiding users through the process, requesting confirmation in the necessary cases and prompting

them with appropriate error message. Table 5.6 shows some examples of these feedback mechanisms within the system.

5.3 Discussion

When compared to alternatives detailed in chapter 3, the goal of this project was to cater to a more diverse user base by providing detailed trail data, accessibility information and interactive narratives under a unified platform with a strong emphasis on UX.

To that end, this chapter outlined the development process, undertaken under an iterative design. The feature evolution in the aforementioned sections and the decision-making process regarding which types of data to include was not arbitrary; rather, it was guided by continuous user feedback and requests throughout the development phase.

Additionally, we provided an in-depth analysis of the narrative's database and corresponding back-office system, designed to streamline the management of narrative content and optimize administrative workflows.

Significant credit must once again be attributed to A. Tavira [88], whose parallel thesis played a pivotal role in storing much of the geographical data for the trails, which is hosted on the *Trails Server* and *Database*, along with the accessibility data.

Additionally, the actual gathering of trail data and respective accessibility and narrative data implies an effort from people in general to physically survey trails, gathering critical information such as signage, terrain types, and surface conditions, all according to the guidelines detailed in the document of Annex I.

This multidisciplinary collaboration highlights the collaborative nature of investing on a platform such as this, emphasizing that the accurate depiction of trail characteristics and accessibility is an outcome of not just technological infrastructure, but also user and field-based research.

6

Evaluation

This chapter presents the usability evaluations conducted across three distinct phases of testing, designed to assess and improve the mobile application's functionality and user experience. These evaluations were carried out with different groups of users, with some participants returning in later phases.

Whereas Chapter 5 focused on how the platform's functionalities were developed and subsequently evolved, this chapter aims to outline the testing methodology, present the findings from each phase, and analyse the overall evolution of usability ratings through user feedback and quantitative measurements such as the SUS scores. A summary of the key differences between each phase is detailed in Table 6.

Phase	**Number of Participants**	**Main Objective**
Phase 1	16	Initial testing of the mobile platform's first batch of implemented features, in order to ascertain usability and new improvements;
Phase 2	6 (all repeated from Phase 1)	Testing of *only* the second large batch of functionalities, with users already familiar with the application who could immediately test the new features;
Phase 3	21 (8 repeated from previous Phases)	Final version of the platform, with only minor features added and with the aim of testing the improvements made on the platform.

Table 6.1: Summary of each testing phase

For each phase, user feedback was the driving force for adjustments, improvements, and even redesigns of key features. Users were encouraged and given the space to give their recommendations and feedback, which contributed to refining the application, adding new functionalities, and addressing several bugs and issues. For each phase in the sections below, a table summarizing its the feedback is presented. Additionally, relevant appendices - E, F, G, H, I, J - also provide additional information for this chapter.

6.1 Methodology and Testing Reports

To evaluate the platform's usability, structured testing sessions were conducted where participants were asked to complete a set of predefined **tasks**, followed by a post-task **questionnaire**.

For this project, three testing phases were carried out, where each phase involved the users completing tasks based on the platform's use cases - usage scenarios for the platform. Following task completion, participants were asked to fill out the questionnaires present in Appendices G, H and I, for each phase respectively. In all phases except Phase 2, this also included a SUS form (Appendix J). Nearly all tests were conducted in person using the users' respective *Android* devices or, for those who did not have one, a provided Android smartphone.

While the first and second phases focused on distinct and non-overlapping use cases (as each of those phases was designed to test different features), the third phase consolidated all previous use cases into a comprehensive test round.

For each phase detailed next, a corresponding report detailing its respective use cases and testing tasks is displayed in Appendix F. These documents also contain the user feedback collected during task completion and the results from the SUS evaluations. Finally, it should be noted that, as all tests were conducted in Portuguese, much of the content in the following sections and appendices has been translated for this paper.

6.2 First Phase

The first phase of testing involved 16 participants who were new to the app. The group was characterized by being predominantly younger and with varying levels of experience with similar applications, as figure 6.1 attests.

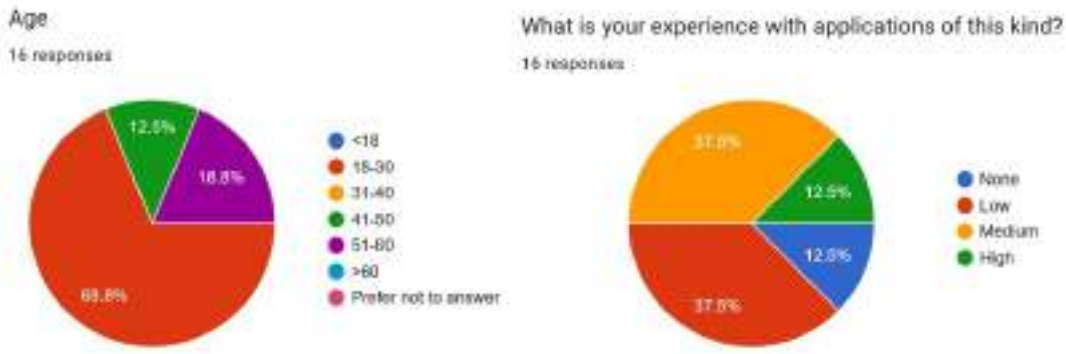


Figure 6.1: Age and Experience Distribution for the 1st Phase of Testing

After completing tasks based on the application's use cases (Appendix F), the participants filled the questionnaire seen in Appendix G, providing both qualitative suggestions and quantitative ratings on how intuitive the features were, using a 1-5 scale. They also

filled the SUS questionnaire (Appendix J), which had been translated into Portuguese using the EU Portuguese version by Martins et al. [54].

The features introduced and their respective feedback can be seen in table 6.2.

Functionality	**User Feedback**
Map Interaction	-
Distinguishing between trail markers and narrative markers	Confusion between markers; Suggested clearer differentiation beyond colour coding
Seeing trail path/information on the map	Not all users realized the markers on the map were clickable
Searching for a trail	Requested more advanced filtering options; Encountered issues with search bar functionality
Accessing trail and narrative information	Participants did not intuitively pull up the bottom sheet for trail/narrative details
Accessing trail difficulty and terrain type information	Suggestion to also show difficulty while navigating trail
Accessing accessibility information	-
Accessing weather information	Weather was in "Accessibility" tab, but users expected it to be in "Details" tab
Using the altitude graph	Confusion due to missing x-axis labels; participants did not click on the graph
3D visualization	Requested ability to switch between different layers
Navigation	Confusion over which direction to take in circular trails; requested difficulty information during navigation; complaints about screen turning off automatically
Narrative Navigation	Many people did not notice the "Unlock" option when reaching a certain narrative stop due to distractions ; complaints about application closing and losing progress, generally unintuitive
Video/audio interaction	Slower load times with worse connectivity; lack of clear feedback on multimedia buffering; requests for full-screen videos

Table 6.2: Functionalities introduced in the first phase, and respective feedback

It is also important to note that not all tests were conducted in the same location, which required the creation of trails in the participants' different addresses when preparing navigation-related tasks. Similarly, custom narratives were developed for each location to test narrative navigation features. Overall, out of the 16 participants, 9 tested navigation.

All the feedback in this phase laid the groundwork for understanding the application's baseline usability (or lack thereof - as the SUS score was averaged at 77) at this point (Fig. 6.2). This data would be later compared to the third phase.

Participant	Age	Experience w/ Similar App	SUS Score
1	18-30	Low	90
2	18-30	High	75
3	18-30	Low	82.5
4	18-30	Medium	75
5	51-60	High	87.5
6	18-30	Low	87.5
7	51-60	Medium	90
8	51-60	Medium	67.5
9	18-30	None	72.5
10	18-30	Low	92.5
11	18-30	Medium	72.5
12	41-50	Medium	67.5
13	41-50	Low	77.5
14	18-30	Medium	85
15	18-30	None	70
16	18-30	Low	82.5
Average			77.25
Std. Deviation			8.58

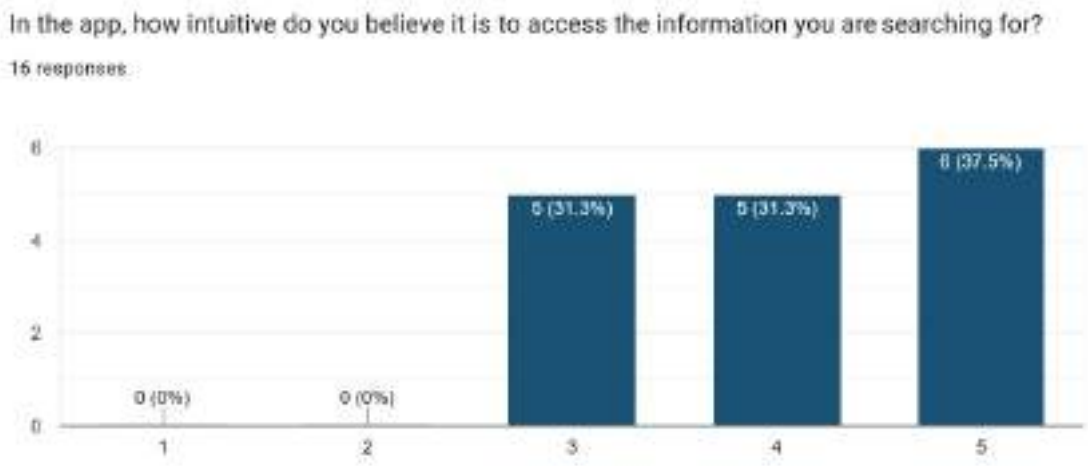


Figure 6.2: SUS ratings for Phase 1 of testing, and general intuitiveness perceptions

6.3 Second Phase

The second phase of testing was a smaller, more focused iteration compared to the first and third phases, serving as an intermediary step between the two. Similarly to the other two phases, users completed tasks based on use cases (Appendix F), filling a questionnaire upon completion (as seen in Appendix H).

In this phase, a smaller group of six participants — all of whom had participated in the first phase — were recruited to test only the *new features* added since the initial testing phase. This group was intentionally chosen for their prior familiarity with the application,

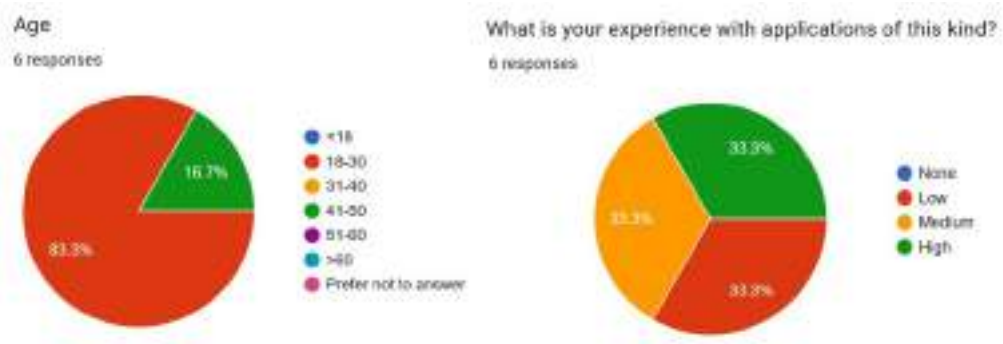


Figure 6.3: Age and Experience Distributions for Phase 2 of Testing

allowing them to bypass the learning curve associated with the app and focus directly on assessing the newly implemented functionalities (seen in Table 6.3). The overall aim was to examine only these new features, and their integration into the pre-existing system. Consequently, although feedback from the preceding testing phase had already been incorporated into the application at this point, no evaluation was done of the features tested in the first phase. Instead, those (and other improvements) were deferred for Phase 3, which allowed more comprehensive testing of every feature of the application.

Functionality	**User Feedback**
Points of Interest	Some categories' names were unclear
Trail Filtering	Smaller phones made filter sliders harder to use ; some issues with the interaction between the Search Bar and the Filtering system
Narrative Categories	-
Adding and Managing Favourites	-
Adding and Managing Downloads	Unclear how to download a narrative
Offline Functionality	-
Navigation: see trail information (difficulty, altitude, user speed)	-
Navigation: change navigation to an alternate intersecting trail	Absence of a loading indicator when switching to an intersecting trail left users unsure if the new trail was being loaded
User Progress Tracking	-

Table 6.3: Functionalities introduced in the second phase, and respective feedback

Once again, extensive feedback and the general perception of usability in this phase (Fig. 6.4) informed the continuous development of the platform, and the features introduced in this phase were equally re-tested again in the final testing phase.

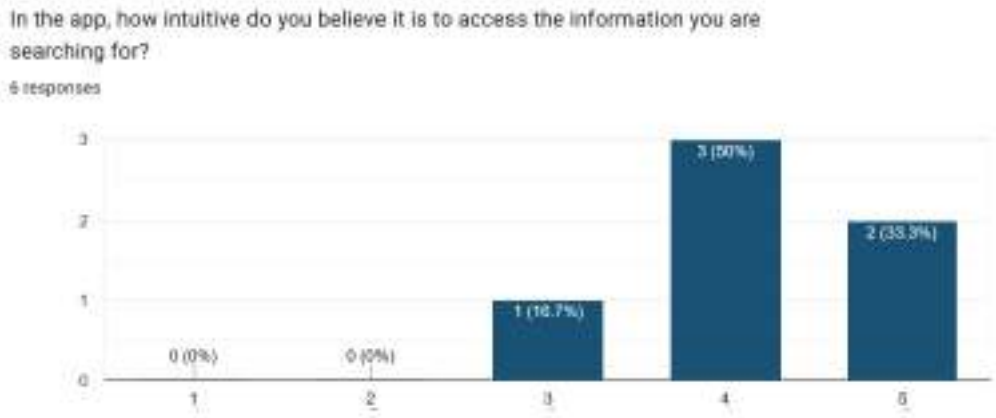


Figure 6.4: General Intuitiveness Perceptions for Phase 2 of testing

6.4 Third Phase

The third and final phase of testing was the most extensive, encompassing a significantly larger and more comprehensive group of participants compared to the earlier phases. It involved twenty-one (21) users, representing a broader age demographic and a mix of both new and returning participants: of these 21, eight had participated in previous phases, with five of them having been involved in *all three* phases of testing.

Notably, three of these five were interviewees in the initial empathy map exercises, with their ongoing feedback and contributions being further explored in a subsequent section.

The greater age and experience distribution for this phase (Fig. 6.5), as well as the inclusion of both experienced users and first-time participants, allowed for a more thorough assessment of the platform's usability across different user groups.

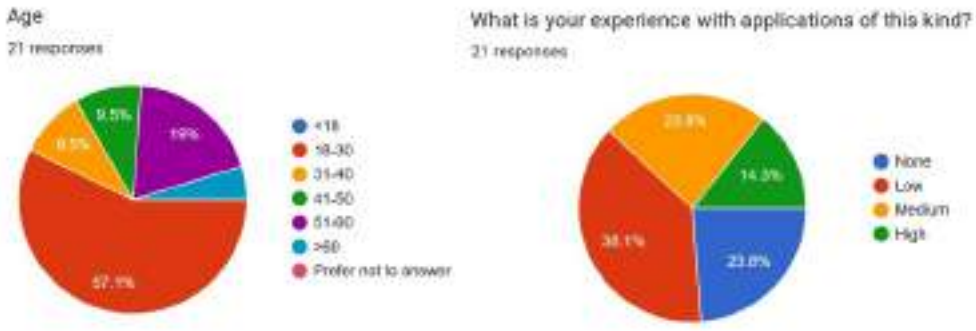


Figure 6.5: Age and Experience Distribution for the final phase of testing

The primary objective of this phase was to test the entire application with minimal new functionality introduced; to serve as a final evaluation of the system's usability as a whole. As such, only 2 new small additional features were introduced, as laid out in table 6.4.

Once again, testing of the navigation feature required the creation of several custom

narratives and trails to accommodate participants located in various geographical regions. In total, approximately 10 distinct narratives were developed for the tests, each incorporating at least one video and audio component. In total, out of the 21 participants, 16 were able to test navigation, alongside the other tasks specified in Appendix F.

Afterwards, the questionnaire (Appendix I) and SUS form (Appendix J) were filled. A later section will show how this data was later compared with the results in the previous phases.

Functionality	**User Feedback**
Changing App Language	Most users instinctively navigated to the "You" tab to change the language, rather than the "Map" tab
Get Directions to Trail	-

Table 6.4: Functionalities introduced in the third phase, and respective feedback

Two main caveats should be noted about this phase of testing, in spite of its comprehensive nature:

- **Familiarity breeds content** - Given that a few participants had been involved in multiple phases of testing, it is important to consider the effect of prior experience on their feedback. Familiarity with the app's interface and features may have led these participants to feel more comfortable with the system [30], which could influence their perceptions of usability compared to first-time users;

- **Spanish Language Testing** - While the platform features Spanish language support, none of the participants opted to use the application in Spanish during testing. As a result, verification of the Spanish language functionality was conducted externally, through feedback obtained from non-native Spanish speakers who were not participants in the formal testing. This means that the absence of in-depth testing by participants limits the conclusions that can be drawn about its overall usability.

Finally, the results of this final phase demonstrated significant progress in terms of feature development and overall system usability compared to previous phases. The iterative process, driven by continuous user feedback, allowed for refinements that better aligned the product with user needs. As such, the final SUS score for the platform was evaluated at **91.90**, with a standard deviation of **6.63**, indicating a high level of user satisfaction [4] and perceived ease of use (Fig. 6.6).

6.4.1 SUS

From a high-level perspective, the SUS average of **91.90** reflects a system with good usability and, as Figure 6.7 shows, it surpasses the minimum threshold for a system with "Good" usability, as defined by A. Bangor et al. [4].

Participant	Age	Experience Level	Previous Testing Phases	SUS Score
1	18-30	Low	All Phases	100
2	18-30	High	All Phases	97.5
3	18-30	Low	All Phases	85
4	18-30	Medium	All Phases	90
5	51-60	High	All Phases	100
6	18-30	Low	1 Phase	87.5
7	51-60	Medium	1 Phase	92.5
8	51-60	Medium	1 Phase	95
9	41-50	None	-	87.5
10	18-30	Medium	-	100
11	18-30	Low	-	77.5
12	18-30	Medium	-	90
13	18-30	Low	-	95
14	41-50	None	-	90
15	31-40	None	-	80
16	18-30	Low	-	95
17	18-30	Low	-	97.5
18	51-60	High	-	97.5
19	18-30	Low	-	100
20	>60	None	-	82.5
21	31-40	Low	-	90
Average				91.90
Std. Deviation				6.63

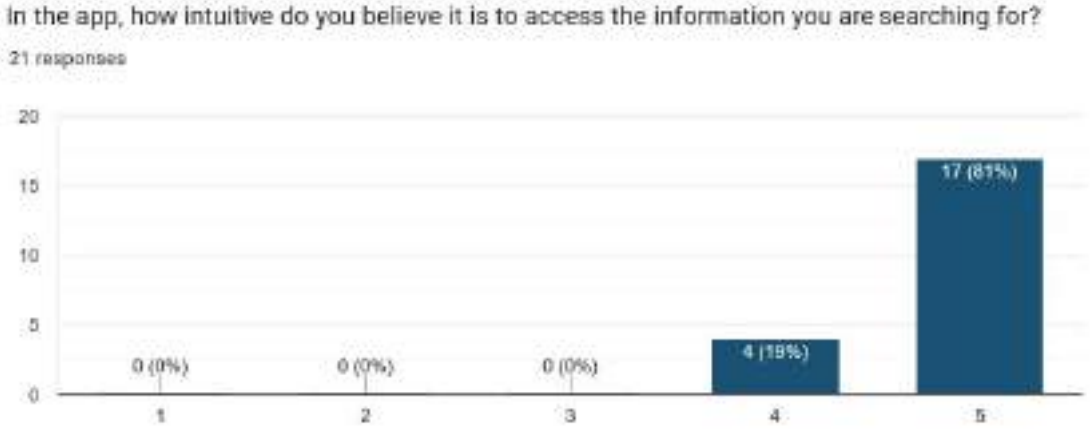


Figure 6.6: General Intuitiveness Perceptions for Phase 3 of testing, and the respective SUS ratings

However, it may be of interest to analyse the SUS individual ratings from a more multi-dimensional perspective and see how certain clear trends emerged.

For example, as seen in Fig. 6.8, question 3 of the SUS - "I thought the system was easy to use" - consistently received high scores, indicating that users found the platform straightforward and intuitive. Similarly, question 5 - "I found the system to be inconsistent" - received low scores, reinforcing the idea that users perceived the various functionalities as well-integrated and cohesive.

On the other hand, *learnability* might be more compromised, as question 7 - "I would

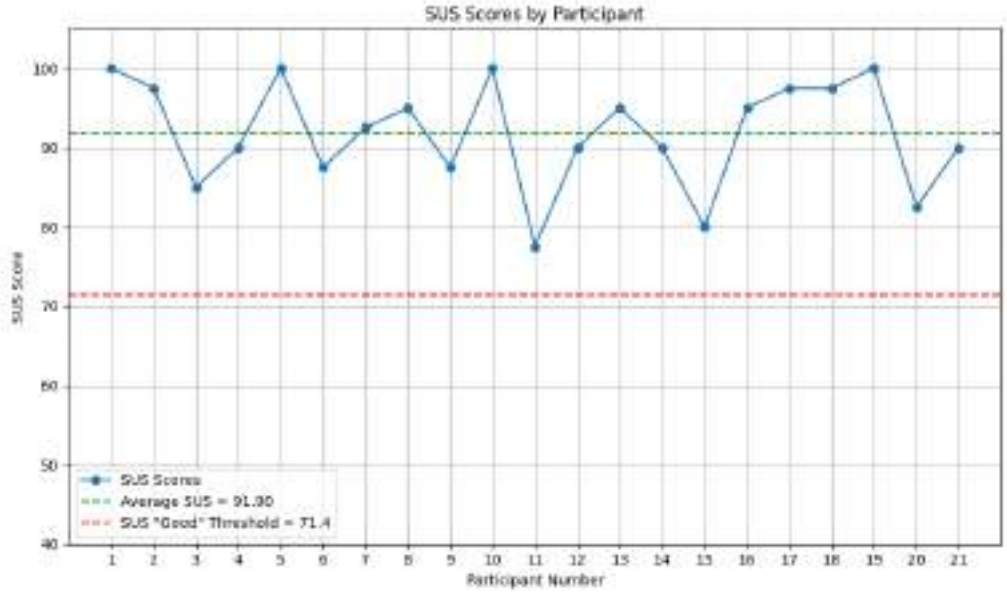


Figure 6.7: SUS Scores by participant, with average and minimum value threshold

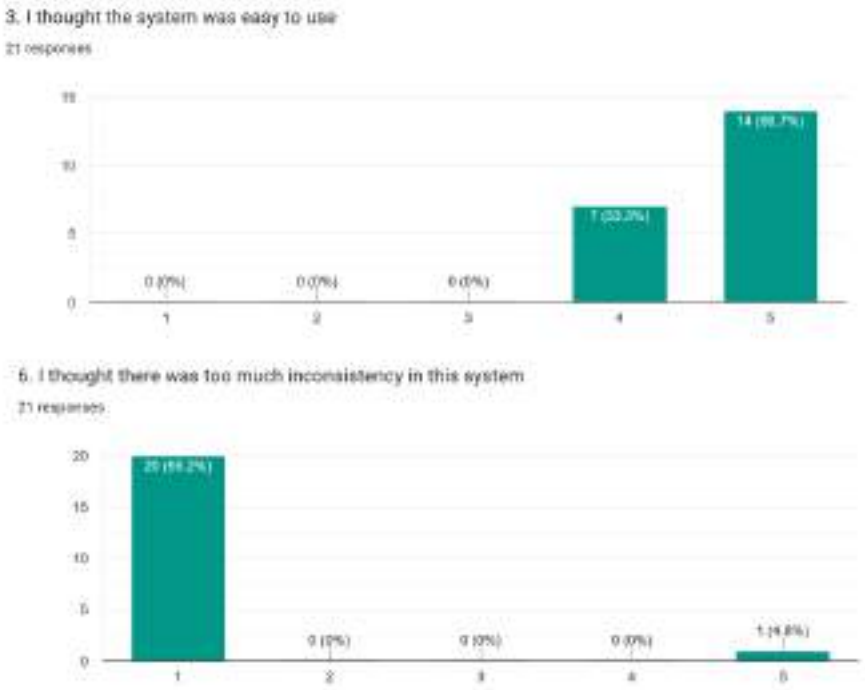


Figure 6.8: User answers from 1 (Strongly Disagree) to 5 (Strongly Agree) for questions 3 and 5 in SUS

imagine that most people would learn to use this system very quickly" - yielded a more varied response distribution (Fig. 6.9). This hints at potential reservations about the ease at which other demographics might learn to use the system.

Lastly, a correlation analysis was conducted to explore the relationship between SUS scores and user experience levels. Although no clear correlation was observed between age and SUS ratings, the users' familiarity with similar applications appeared to have a

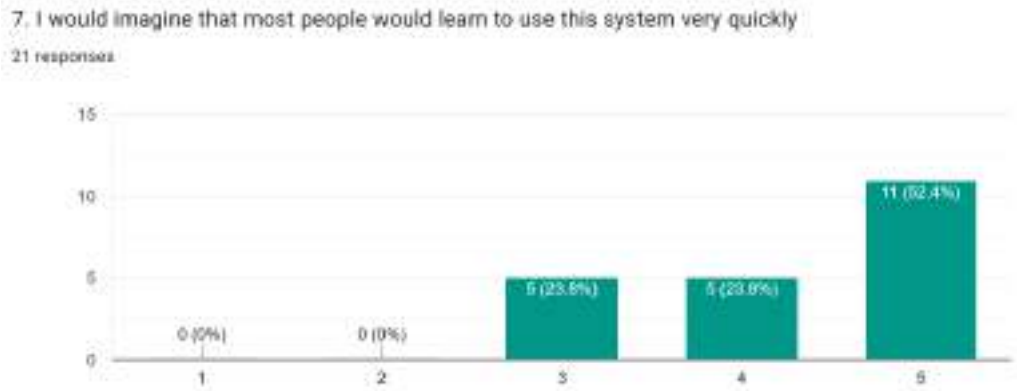


Figure 6.9: User answers from 1 (Strongly Disagree) to 5 (Strongly Agree) for question 7 of the SUS

slight positive correlation with higher SUS scores. Participants with "Medium" and "High" experience levels tended to rate the system more favourably, while those with "None" or "Low" experience exhibited a wider range of scores, with some falling lower, around 80. This trend is reflected in Fig. 6.10. Finally, while accessibility concerns were considered for another analysis, the sample size of participants with mobility impairments was too small (two) to draw any definitive conclusions. Both participants rated the platform highly, but were also involved in all testing phases and had an active role in shaping the platform's development in regards to accessibility. As such, the sample was not considered representative enough to allow for wider statements about users with mobility-impairment issues using the platform.

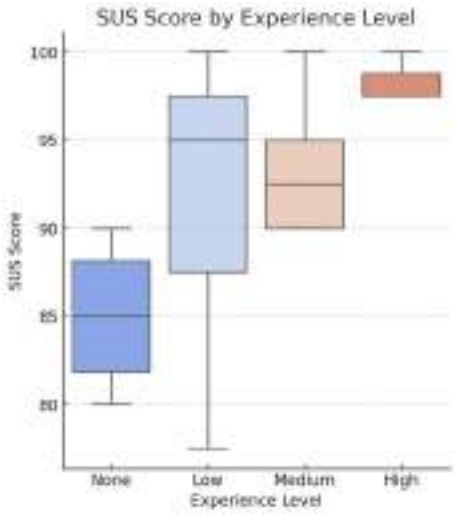


Figure 6.10: Correlation between SUS ratings and participant's experience level with trails applications

6.5 Usability Evolution

The iterative development process employed in this thesis allowed for a continuous evolution of the application's features: with testing phases contributing to an evolving understanding of how users interacted with the platform, subsequent updates addressed key issues and implemented adjustments based on user feedback.

As a result, the usability ratings of the platform evolved accordingly, reflecting the impact of user feedback and iterative adjustments.

When comparing usability ratings across the phases, a noticeable increase is observed, driven by changes implemented in response to user input: whereas the application's overall usability was rated at **77** in the first phase, this value was raised 15 points up to the final value of **92** in the final testing phase. Additionally, the user's overall perception of the system's usability increased, as Figure 6.11 shows.

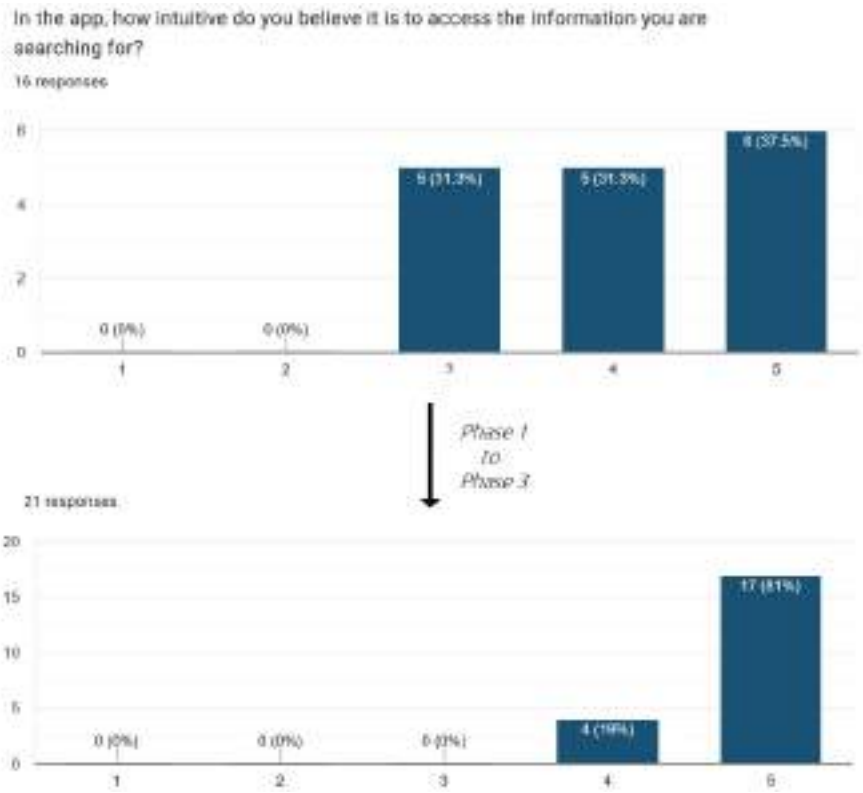


Figure 6.11: Comparison between user's perceptions of the intuitiveness of the platform in the first (top) and last (bottom) phases of testing

From a more aesthetic standpoint, user perceptions of the application's design also improved between the first and last testing phases (Fig. 6.12).

Finally, many of the platform's features underwent substantial development throughout the course of this project, with user's usability ratings of each of those features evolving accordingly. As such, Appendix E details the **progression of every functionality** introduced in the first and second testing phase. This includes, for each feature, a comparative

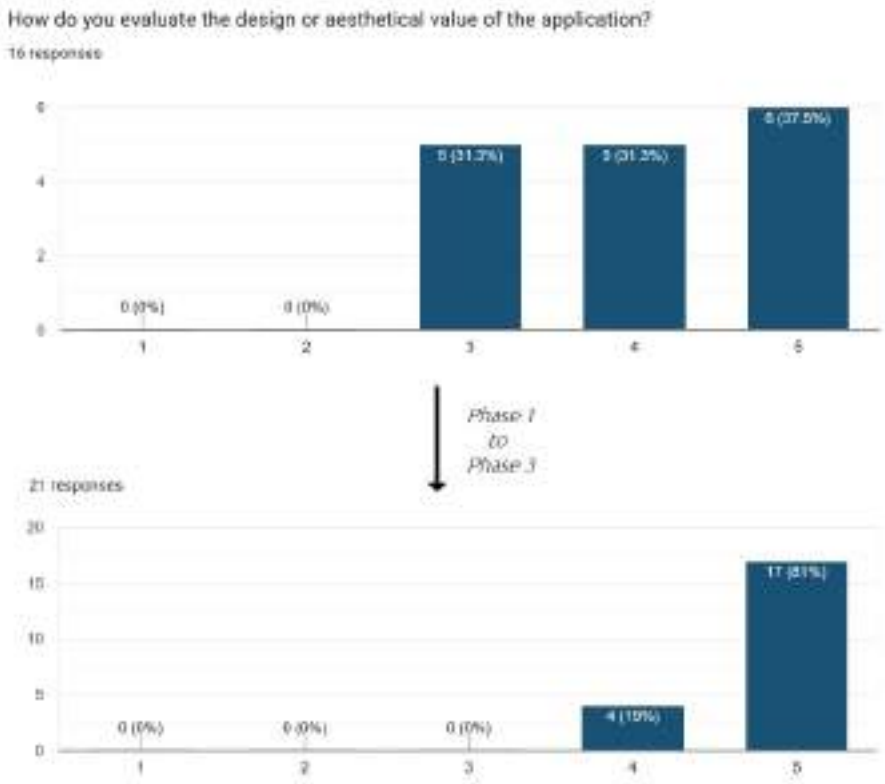


Figure 6.12: Comparison between user's perceptions of the design of the platform in the first (top) and last (bottom) phases of testing

analysis of user ratings at the time of feature introduction versus their perceptions in the final version of the platform.

6.6 Empathy Map Retrospective

The Empathy Map interviews conducted in the early stages of the project played a critical role in shaping the direction of development. Given the project's iterative nature, it was only logical to include its interviewees in the testing process to see how well their needs were met by the final version of the application.

As such, 3 out of the 4 participants in the Empathy Maps interviews were present in all 3 testing phases: **Cristina**, **Lucas**, and **Tatiana**, with the following retrospective analysis assessing the evolution of their experiences and feedback throughout development:

Cristina As an ultra-trail runner, Cristina's needs were more technical, with a focus on extensive trail details and POI for navigation during her competitions. She also expressed a desire for a unified platform to avoid relying on multiple applications.

From the outset, Cristina demonstrated a higher level of satisfaction compared to other participants, awarding the platform a SUS score of **87.5** in the first phase. Her familiarity with similar applications enabled her to navigate the platform more easily, although she

identified several issues, particularly with the search and filtering systems. Despite these challenges, Cristina appreciated the platform's comprehensive trail data and provided extensive feedback aimed at improving narrative navigation.

By the final phase of testing, Cristina's feedback had largely been incorporated, particularly in relation to the narrative navigation, and she noted that the platform had evolved into a robust tool that provided nearly all of the information she sought. She was particularly content with the trail being divided into sections with varying difficulty and terrain type information, and was one of the few participants who awarded a SUS score of **100** in the final testing phase.

However, one of her specific wants — integrating a calendarization feature for ultra-trail competitions — remained unmet. Implementing this feature would have introduced a significant layer of complexity to the project, making it unfeasible within the current scope.

Lucas As a casual hiker, Lucas valued navigation tools and environmental narratives but had earlier concerns about getting lost and the difficulty of finding comprehensive information in one place. He was particularly keen on features that would provide some sort of gamification, such as progress tracking.

During the first phase, Lucas encountered usability issues, particularly with navigation within the application, which led to confusion when trying to access trail and narrative information. These challenges were reflected in his initial SUS score of **75**, as he noted that the platform, while promising, needed substantial improvement in terms of user experience and quality-of-life features

By the second and third phases of testing, however, Lucas reported significant improvements, being particularly appreciative of the progress tracking feature (which had been directly influenced by his input during the Empathy Map interviews). This, coupled with a more functional navigational component and his enjoyment of the narratives, saw the rise of his initial SUS score from **75** up to **97.5**.

Tatiana Last but not least, Tatiana was a key voice in shaping the accessibility features of the platform. As a wheelchair user and outdoor enthusiast, her concerns revolved around the lack of accessible trails and the absence of detailed information regarding terrain type and other accessibility considerations. In her initial interview, she described how the effort required to plan accessible hikes often outweighed the enjoyment, and she hoped that the platform could alleviate some of that burden by offering clear, reliable data on accessible trails.

In the first phase, Tatiana pointed out that, while the application showed promise, there were still gaps in the accessibility information provided - she requested additional information be added, most notably related to trail difficulty, and her SUS score was marked at **70**.

By the final phase, Tatiana's concerns had largely been addressed. Significant improvements were made, including the addition of terrain and difficulty details, allowing her to better assess the suitability of trails for wheelchair use. Additionally, she found the platform much more intuitive to navigate due to all its smaller improvements.

In the end, Tatiana's final SUS score was **90**, with her contributions to this project having been instrumental in ensuring that accessibility considerations remained a focus of the design process

6.7 Discussion

In this chapter, we explored how the iterative development process employed in this project was used to refine the platform's usability and ensure that it addressed the diverse needs of its various types of users.

Phase 1 served as the foundation for identifying the platform's core strengths and weaknesses. Initial testing provided users with a chance to explore basic functionalities, and their feedback revealed critical areas requiring attention, with an initial SUS score (77) highlighting how significant improvements were necessary to meet user expectations.

In the smaller-scale *Phase 2*, new features were introduced to a returning participant base, who tested only those new features and provided feedback on how they could be improved.

By the time *Phase 3* testing was conducted, with a larger and more diverse participant pool, the platform had matured significantly as a result from the user feedback from previous phases. The higher SUS score (92) achieved underscored the platform's progression and how the final product had incorporated most user's feedback.

We also mentioned how three empathy map interviewees played a crucial role in all testing phases, shedding light on specific needs - such as accessibility, advanced trail details, and general ease-of-use for casual hikers. Overall, this empathy map framework was particularly helpful in driving user-centric design, with the interviewees also serving as representative figures for larger user populations and ensuring that the platform's design catered to a broad spectrum of needs.

Overall, starting with user research and then embodying user feedback throughout the entirety of development allowed the platform to evolve in a way that directly responded to user concerns and preferences. As a result, the final mobile platform ended up delivering a solution that aimed to cater to a wide range of trail users, including casual hikers, competitive runners, hiking enthusiasts, uninterested parties, and individuals with accessibility needs.

7

Conclusion and Future Work

In this final chapter, the final conclusions derived from this project are presented, alongside the possible future developments in store for the mobile platform.

7.1 Conclusion

When starting this thesis, the aim was to develop a platform that not only served as a repository of standardized hiking data, but which also recognized and solved the gaps within existing hiking platforms - namely inclusivity, comprehensive trail data, and user engagement.

From the outset, it was clear that the project's success would be contingent on how well it met the needs of diverse user bases, ranging from casual hikers to seasoned athletes, individuals with no interest in hiking, and those with accessibility challenges. As such, early user research - conducted via the empathy maps - enabled the establishment of a representative sample of user types, which helped identify the specific requirements for each group and informed the platform's core design features.

For avid and casual hikers, the platform delivered extensive, standardized trail data, addressing the need for detailed and accurate information. The inclusion of functionalities like search and filtering mechanisms, navigation tools, progress tracking and offline functionality - among many others iteratively developed based on user feedback - contributed to a detailed and reliable solution in terms of trail data.

On the other hand, the integration of multimedia-rich interactive narratives was a crucial aspect integrated into the platform, with a positive reception. While these narratives served to attract individuals who might otherwise find hiking uninteresting and compel them to explore the trails, it also doubled as an educational tool for all users to engage with trails from a more cultural, historical, or environmental perspective.

Finally, accessibility considerations were tackled by incorporating detailed information, such as trail difficulty levels and terrain types divided by section, as well as accessibility-specific information. It is important to note that this data proved valuable not only to those with specific mobility needs but also to the wider user base. Even if some accessibility

details were not directly applicable to able-bodied participants, their inclusion in the platform helped foster greater awareness about the challenges faced by people with disabilities in regards to hiking. Many test participants reported never having considered these issues or knowing about tools like Joëlette chairs, recognizing the importance of inclusive design in outdoor activities. This awareness-raising aspect of the platform became an unexpected but meaningful outcome of the project.

Finally, it cannot be understated how the completion of this thesis was deeply rooted in collaborative efforts and a strong user-centric approach. From the contributions of the *Universidade da Beira Interior* (UBI) and the collaboration with A. Tavira [88], to the invaluable feedback from the empathy map interviewees and participants in all testing phases, this project was a labor of collaboration and it is the author's hope that it demonstrated how a platform shaped by real-world user needs and continuous feedback leads to a more inclusive, user-friendly and practical solution for all types of users.

7.2 Future Work

Although this project successfully achieved its core objectives, there are several areas that offer significant potential for improvement and future development.

First, while the platform provided comprehensive trail data, performance optimization was not a primary focus during development. One of the main elements causing performance issues was the elevation graph - which was optimized to some extent - but the trail pages still experience slight delays when loading. An alternative to improve performance could involve implementing more *progressive loading*, with content being loaded incrementally rather than all at once.

Additionally, several features suggested by users during the testing phases could not be implemented within the scope of this project. Among the most notable omissions were social and community features, as well as information about ultra-trail competitions, which had been specifically requested during the empathy map interviews. However, all these elements would have to be included within the context of good UX and usability, at the risk of developing an overtly complex system. Feedback from the third testing phase indicated that users were already navigating a complex system, though they found it manageable, so future development would need to focus on maintaining usability while gradually introducing new functionalities.

In terms of narratives, the platform's potential is optimal for the exploration of other interactive elements, such as augmented reality (AR) features. In addition, eventual collaborations with local cultural institutions could serve as a way of raising awareness about the country's cultural and historical heritage, while also highlighting the environmental significance of its trails. More extensive testing is also needed to evaluate the long-term impact of these narratives: specifically, longer evaluation processes could help determine whether the presence of interactive narratives increases sustained interest in hiking over time.

Finally, one of the areas which has the most potential for improvement is the realm of accessibility. While the mobile platform provides the information already mentioned, there was not so much of a focus on the accessibility of the platform *itself*. Beyond offering language customization, the application could be improved further to include different accessibility options, such as *screen reader compatibility*, *text-to-speech options*, or even *voice commands*. A promising future direction within the context of what was already developed would be a personalisation system for the mobile platform. Users experience trail difficulty differently, and by tailoring suggestions based on factors like age, physical ability, and personal preferences, the app could significantly enhance the user experience. The databases built for the narratives and trails already include the foundational infrastructure for managing user profiles, which will be expanded in a future dissertation to support these personalization and accessibility features.

Finally, expanding the platform's compatibility to other ecosystems would significantly broaden its user base. Given that the current solution was developed with cross-platform technologies, the next logical step would be to test and optimize the app for *iOS*, and develop a web version of the platform.

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A

Portuguese Trails

Figure A.1: Portuguese Trails page when attempting to search for trails in Algarve

Figure A.2: Page for *Vereda do Areeiro*, a trail

Figure A.3: Search page showing there are no results for the search 'Areeiro'

Figure A.4: Map for a Trail in *Portuguese Trails*, showing the trail path but not any of the selected points of interest

B

Empathy Maps

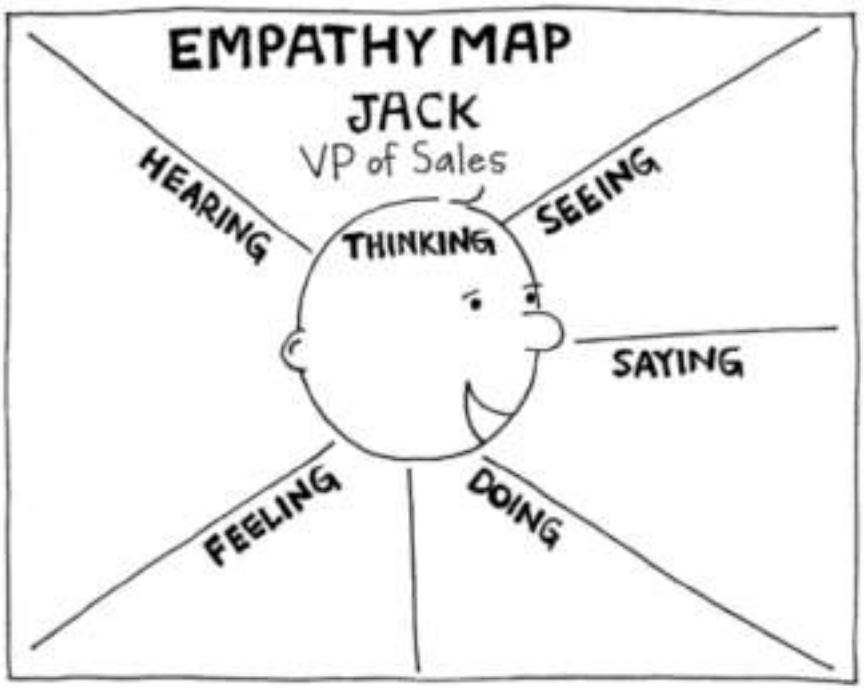

Figure B.1: Original Empathy Map Template by *XPLAN* (adapted from [31])

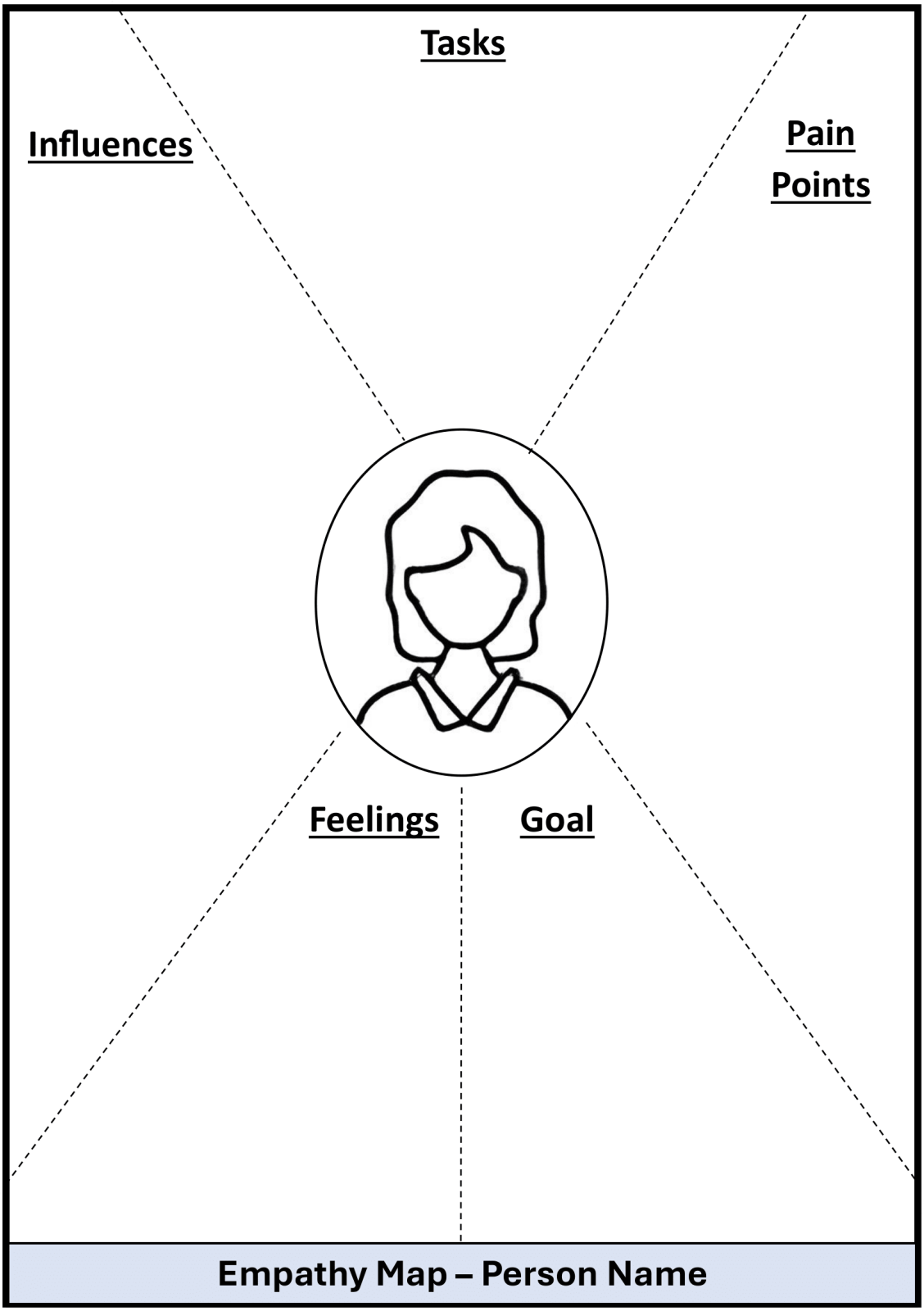

Figure B.2: Adapted Empathy Map Template

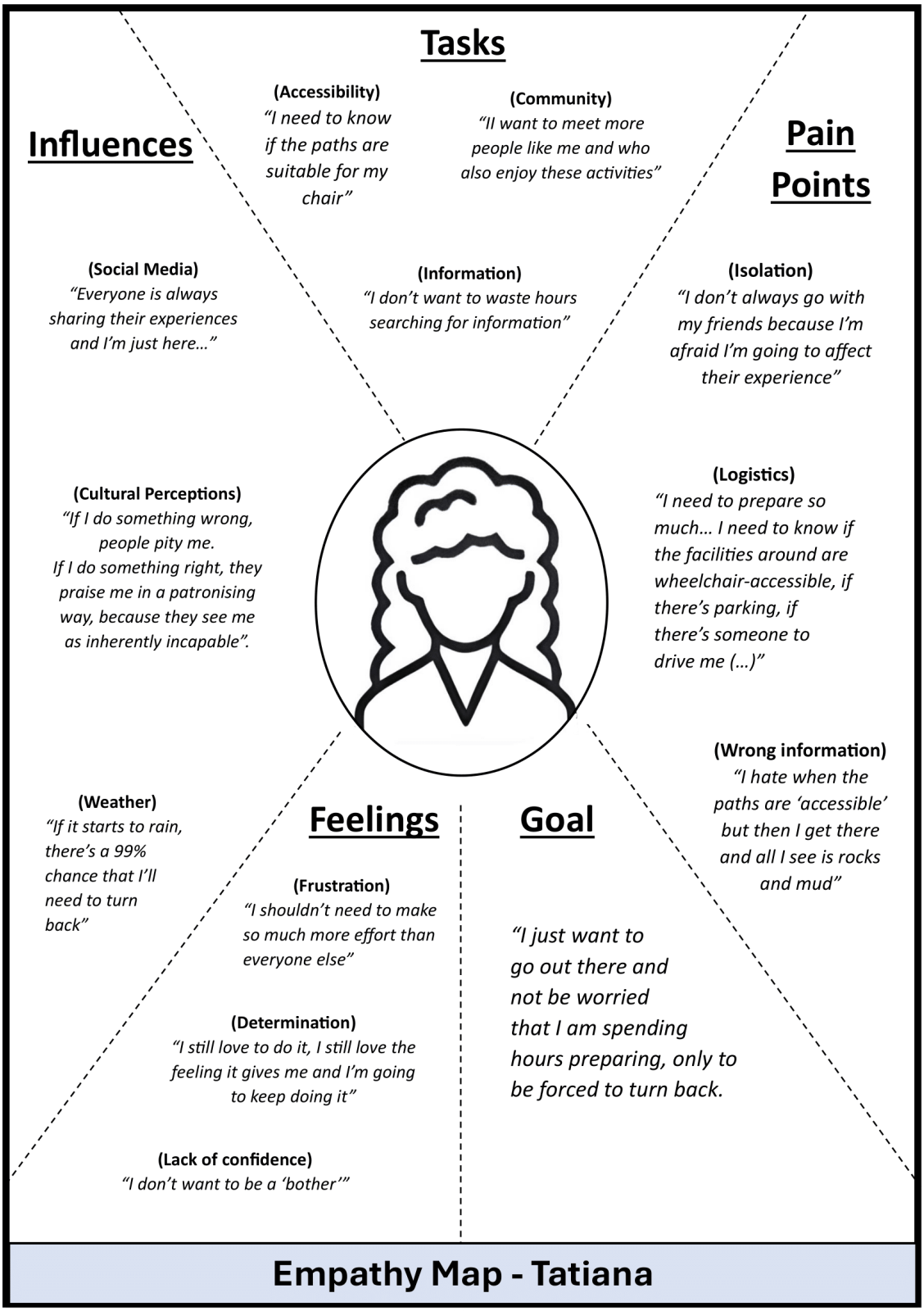

Figure B.3: Tatiana enjoys hiking as a hobby and uses a wheelchair

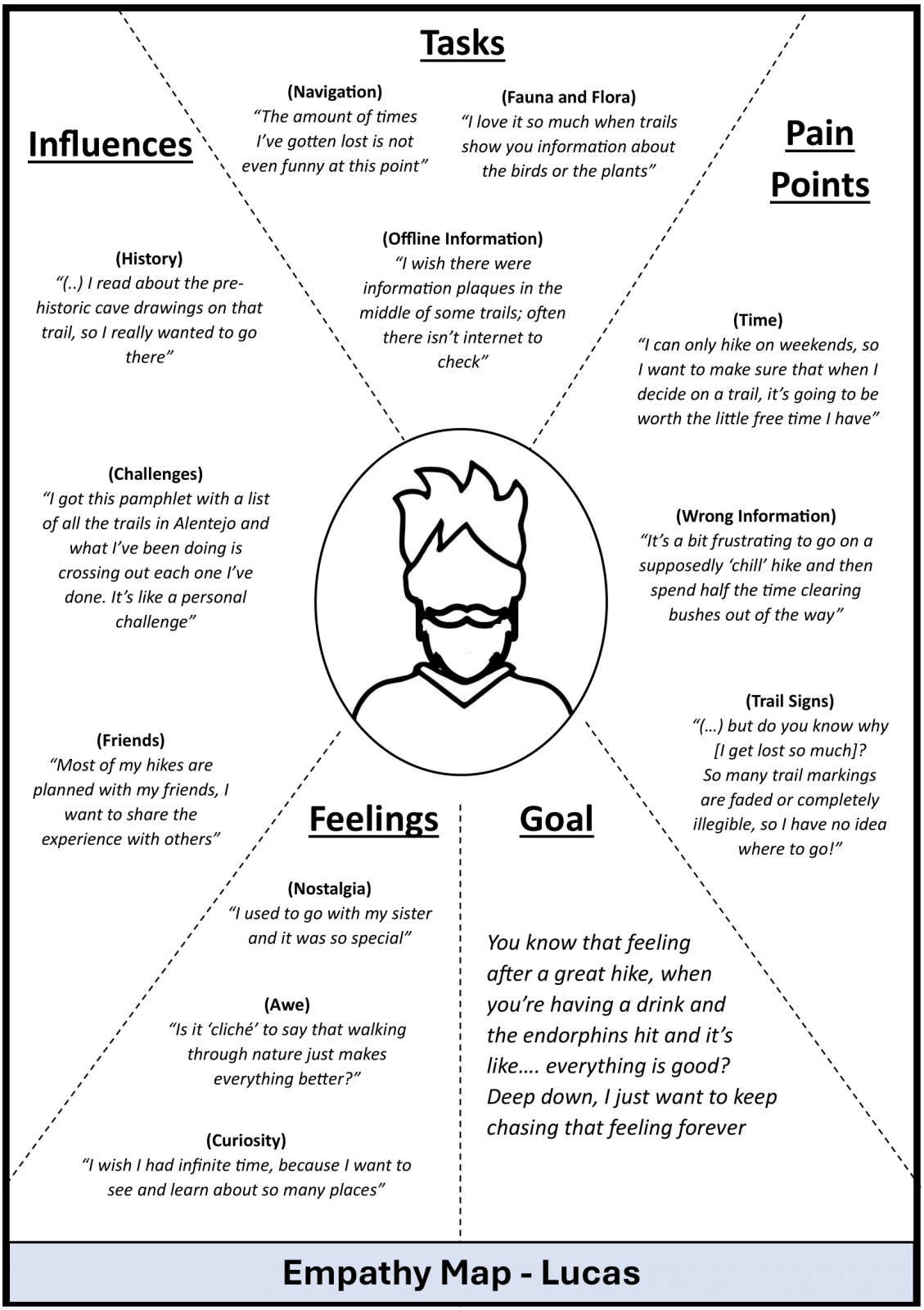

Figure B.4: Lucas enjoys hiking as a hobby

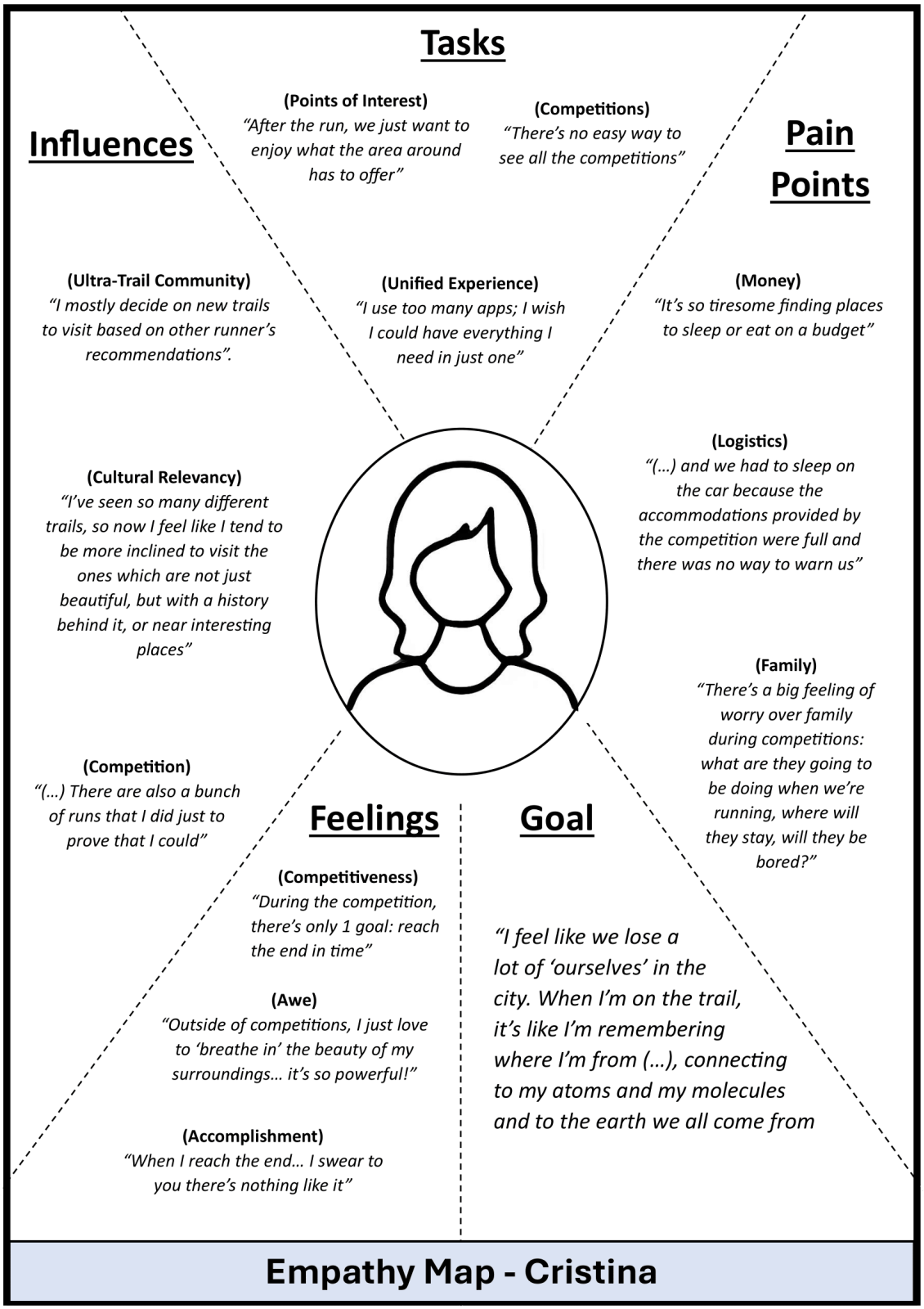

Figure B.5: Cristina is an Ultra-Trail runner

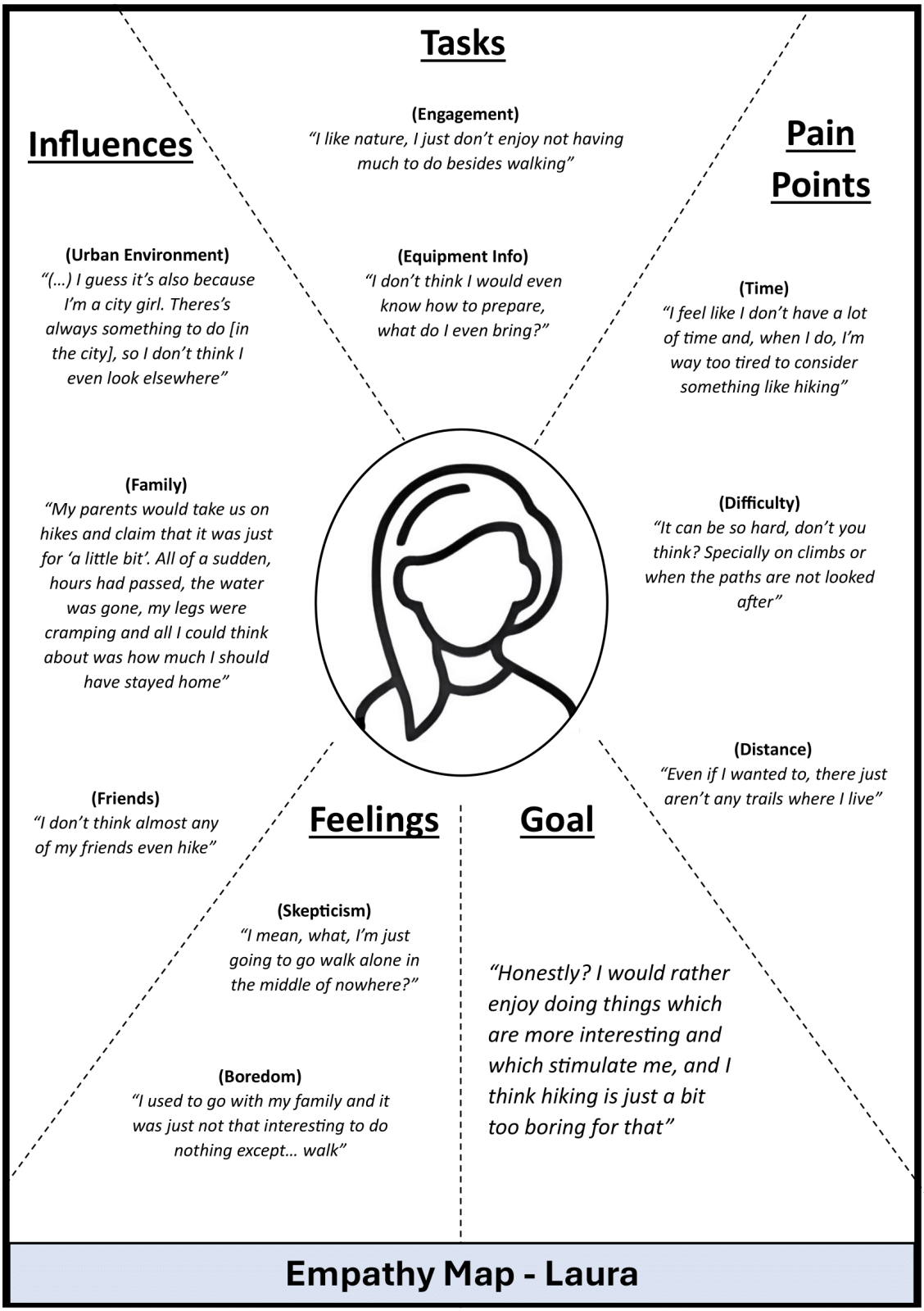

Figure B.6: Laura has no interest in hiking

C

Visual Prototype

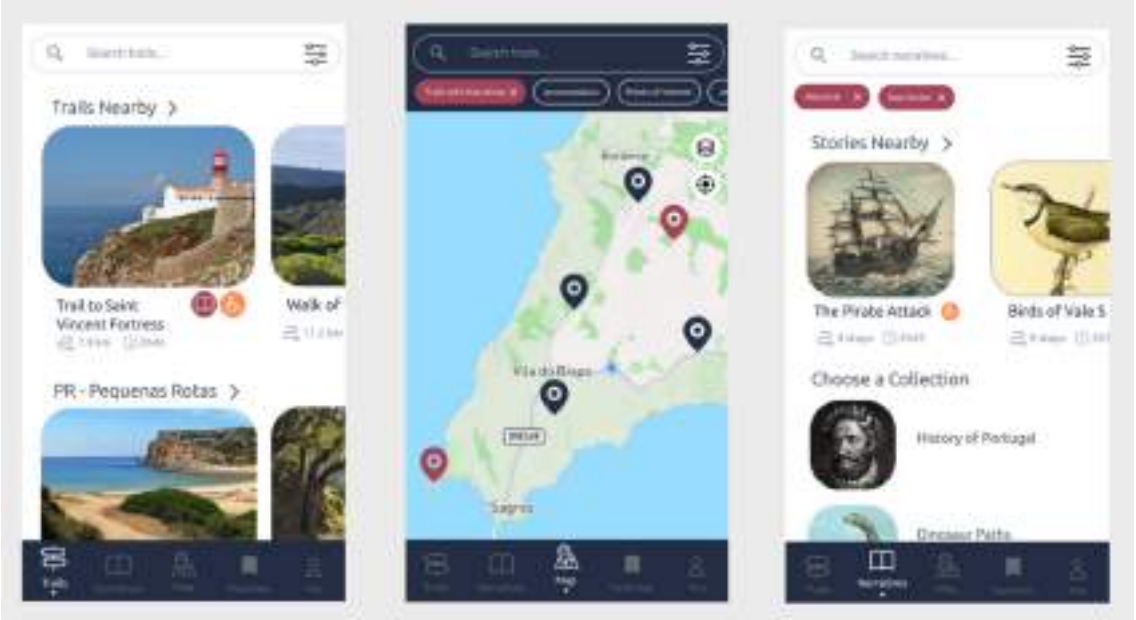

Figure C.1: Initial pages for the *Trails*, *Map* and *Narratives* tabs

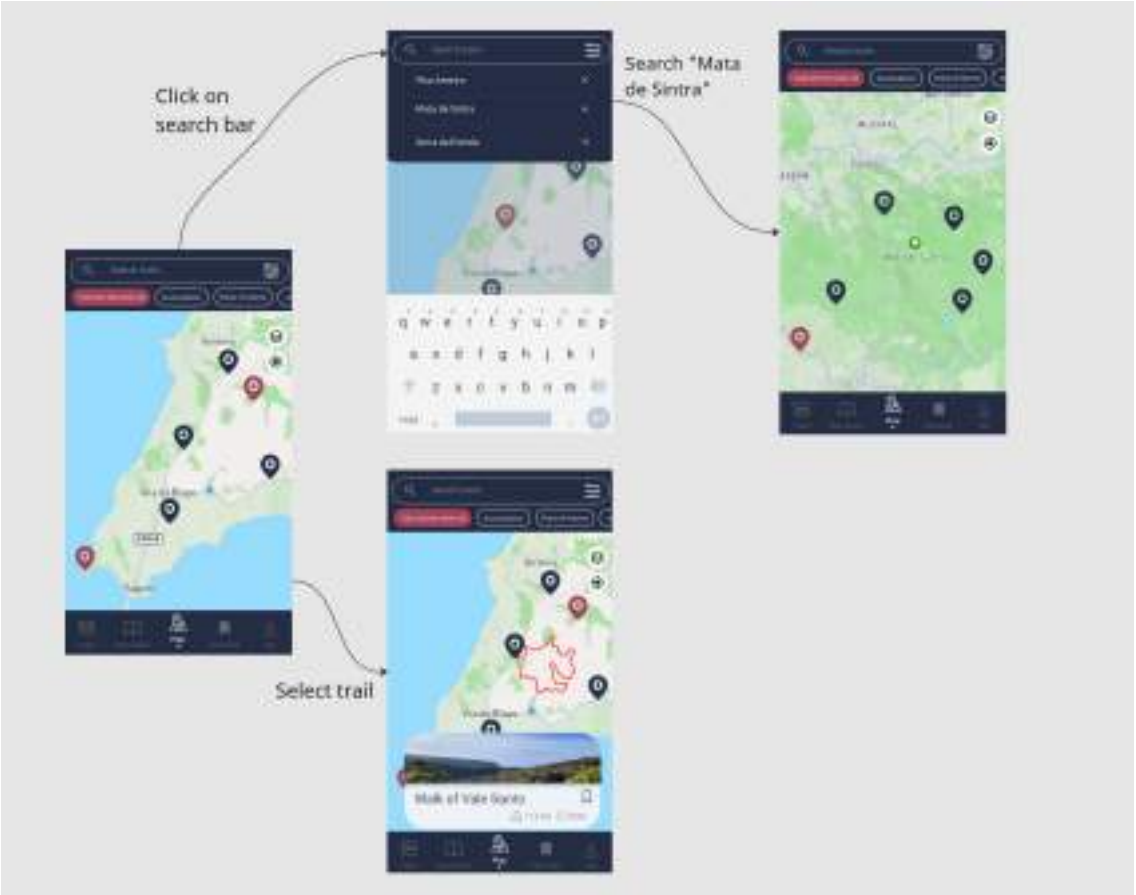

Figure C.2: Interaction flow for the *Map* tab

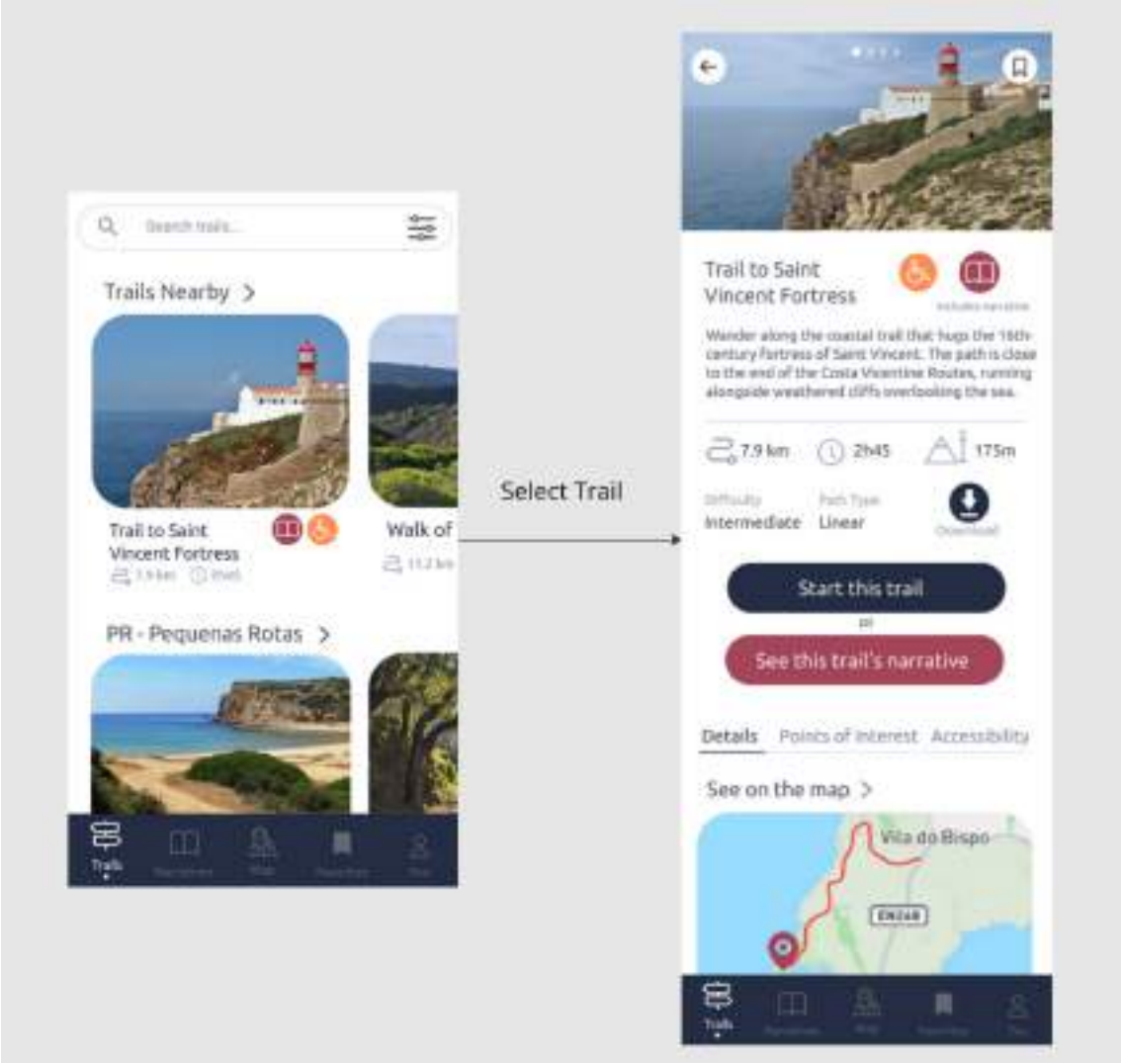

Figure C.3: Interaction flow for the *Trail* tab

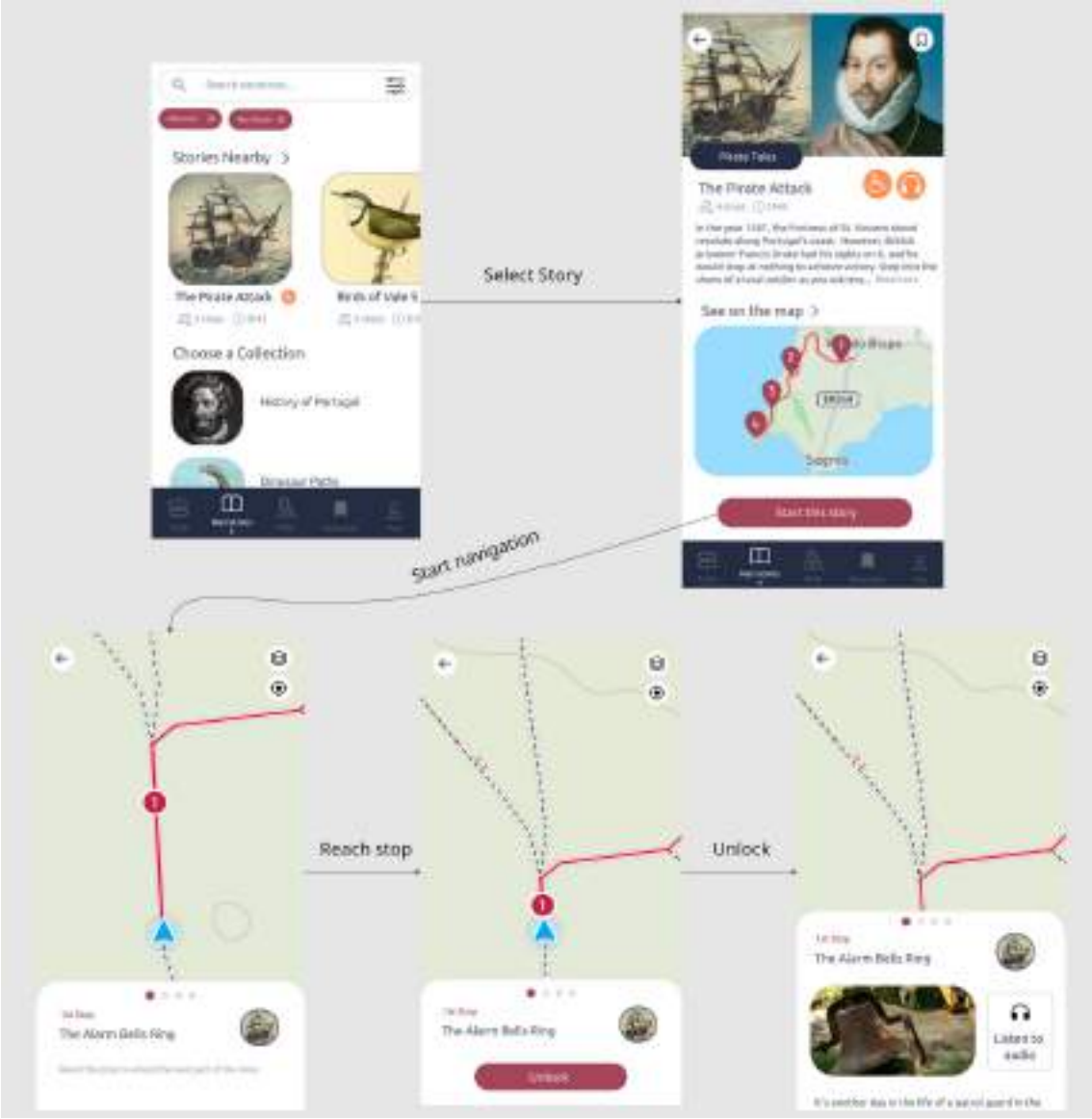

Figure C.4: Interaction flow for the *Narratives* tab, including simulation of navigation

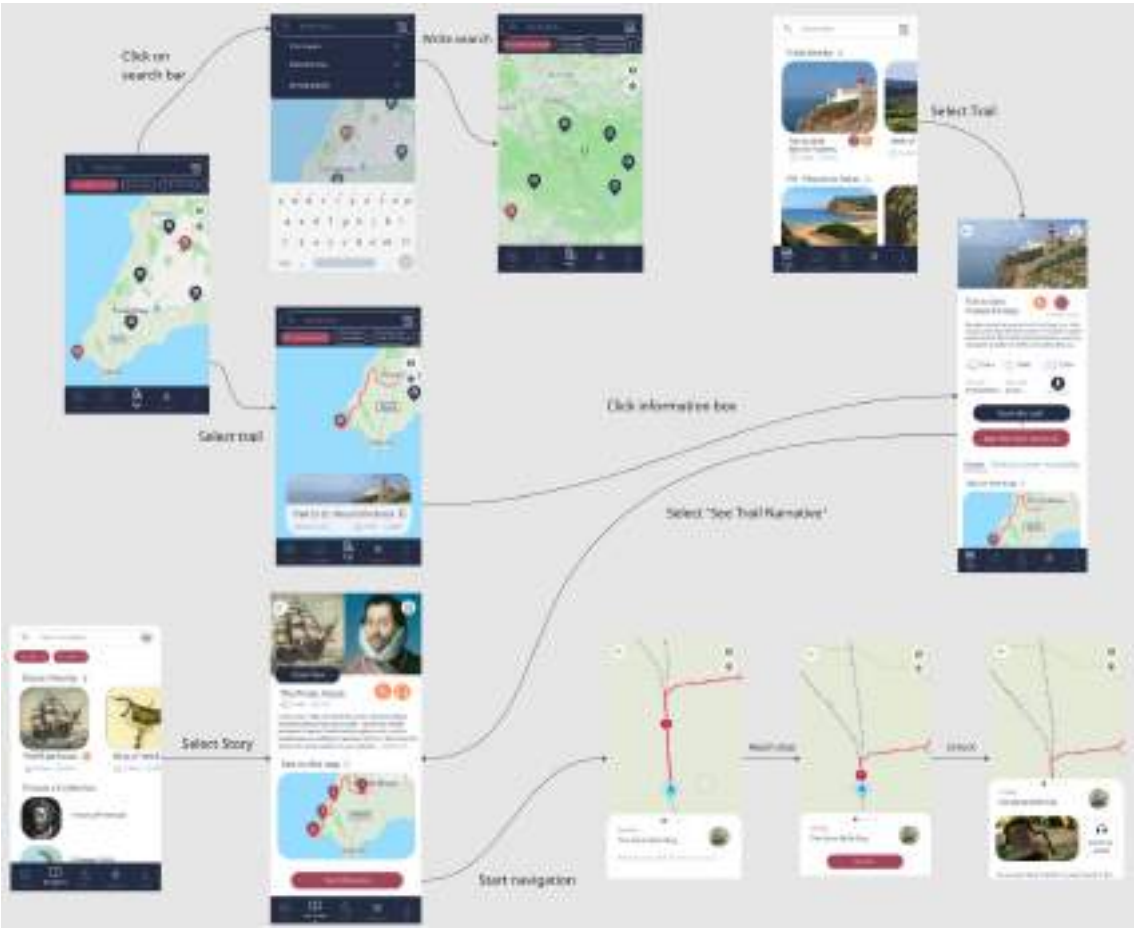

Figure C.5: Interaction flow between the three main tabs of the prototype

D

Mobile Platform - Tell me a Trail

Figure D.1: Design for the logo of the platform

D.1 Navigation Flow

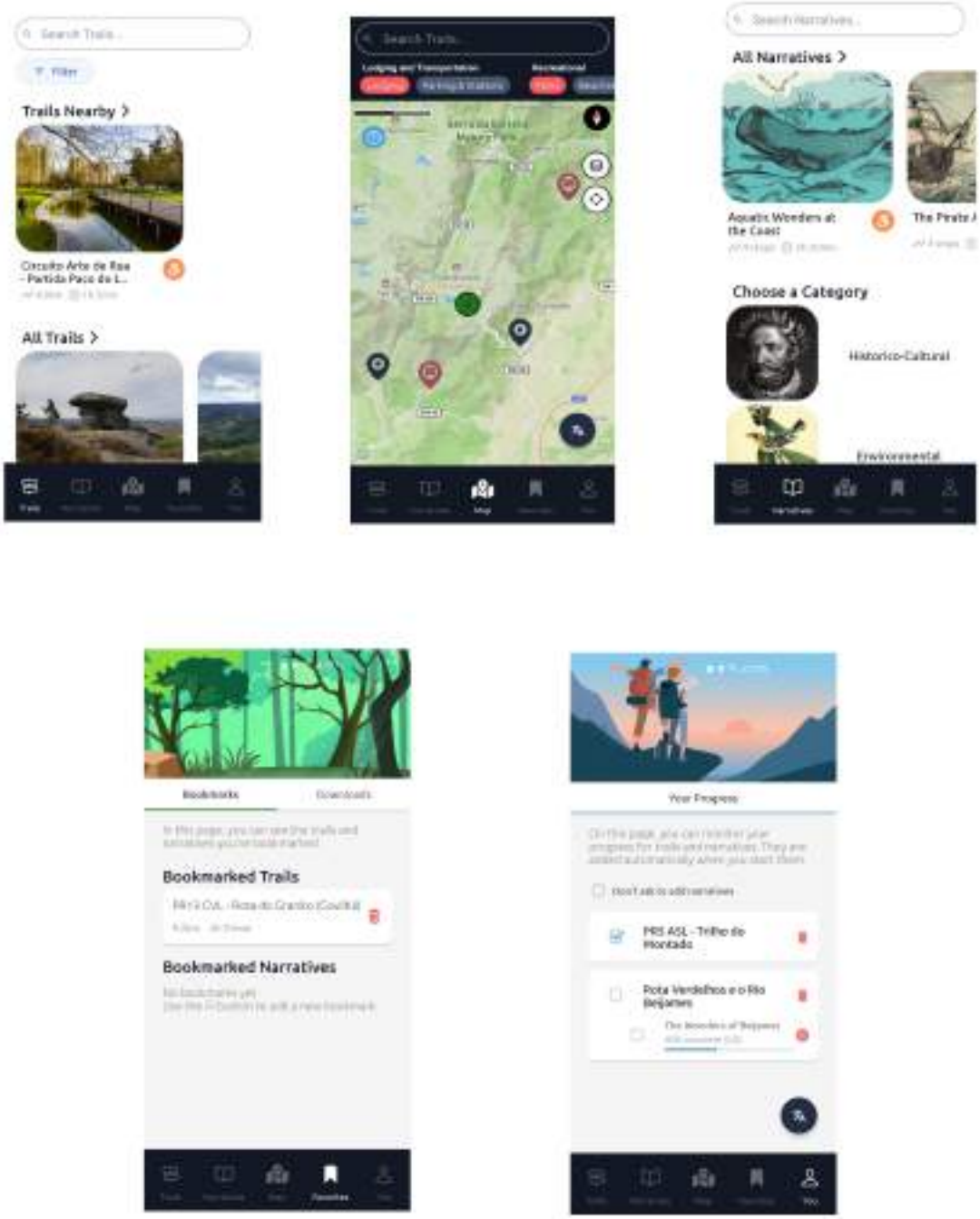

Figure D.2: The main screens of the app - Trails, Map, Narratives, Favorites and You

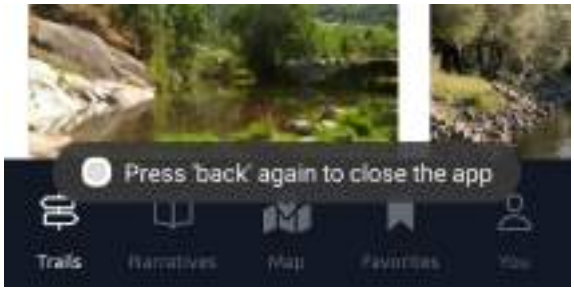

Figure D.3: *Toast* message warning users before they exit the application

D.2 Map

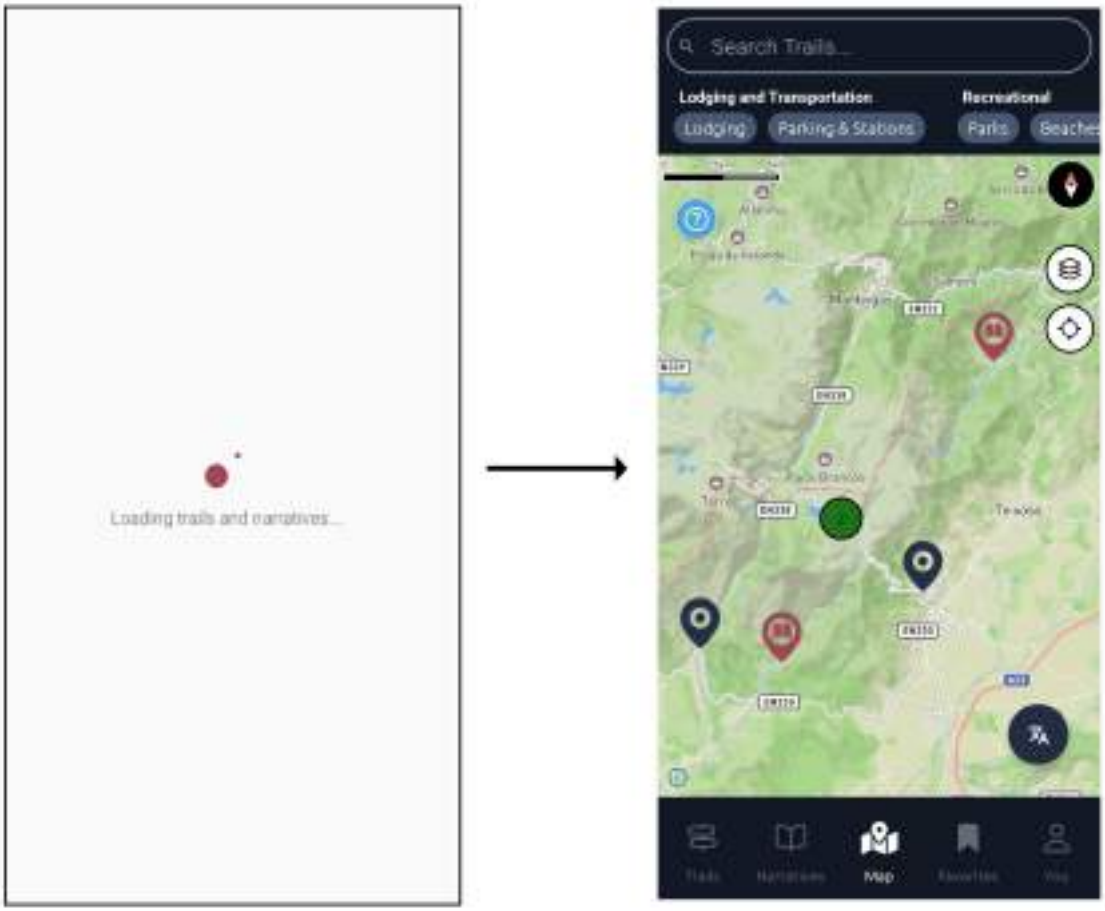

Figure D.4: Initial loading and subsequent default tab: Map

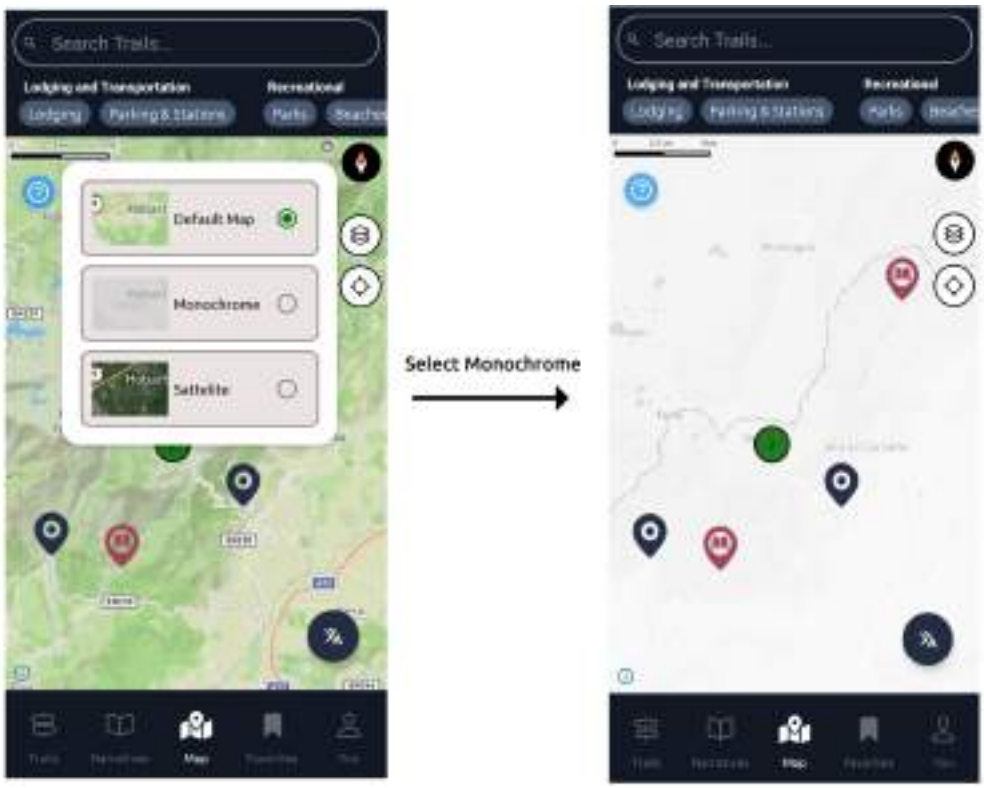

Figure D.5: Example of layer selection on the map

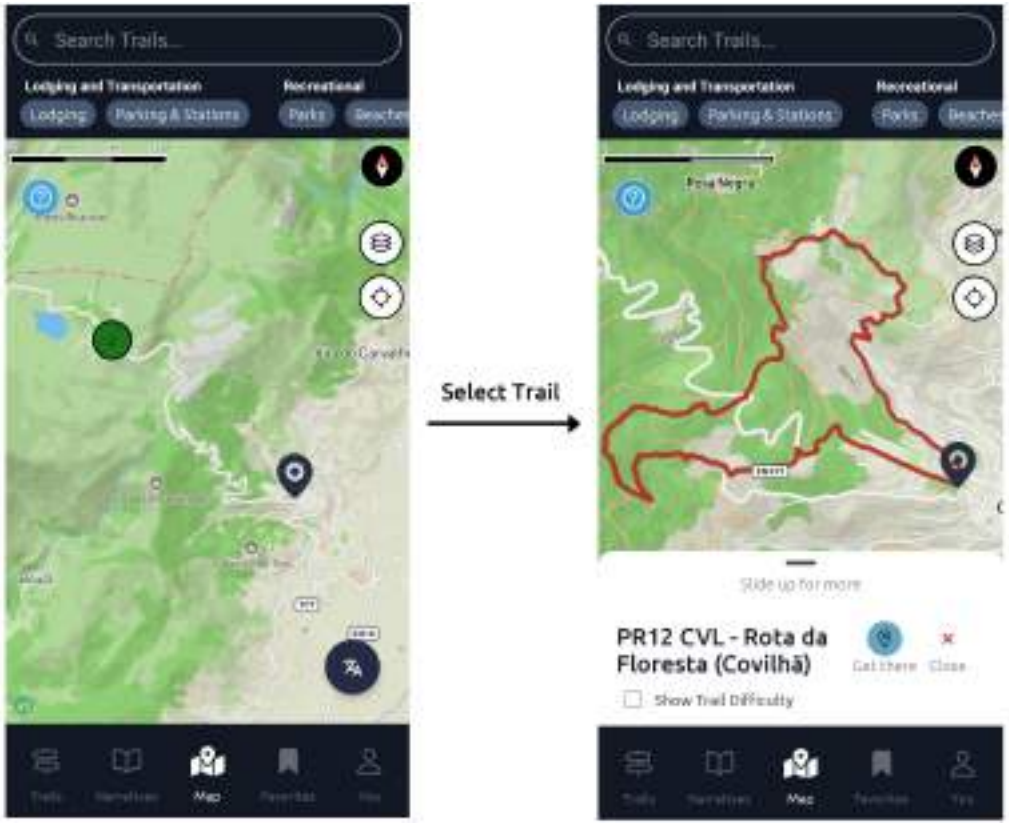

Figure D.6: Selection of a trail on the map, displaying and zooming into the trail path and opening the bottom sheet with information

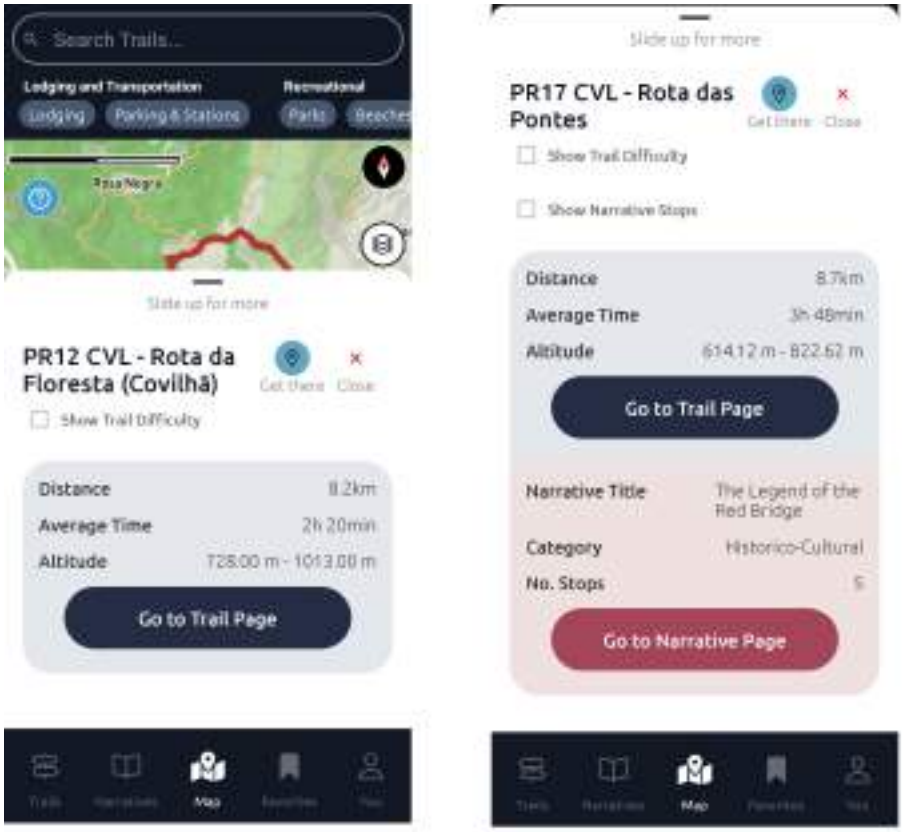

Figure D.7: Information in the bottom sheet for a trail without (left) and with a narrative (right)

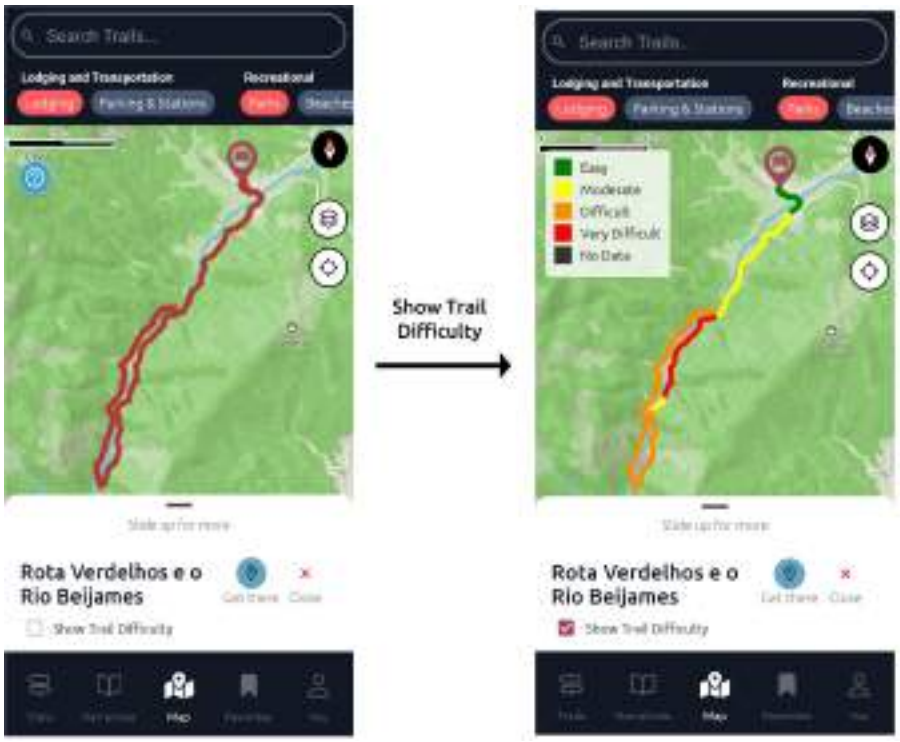

Figure D.8: Showing the difficulty sections for a trail, along with the respective legend

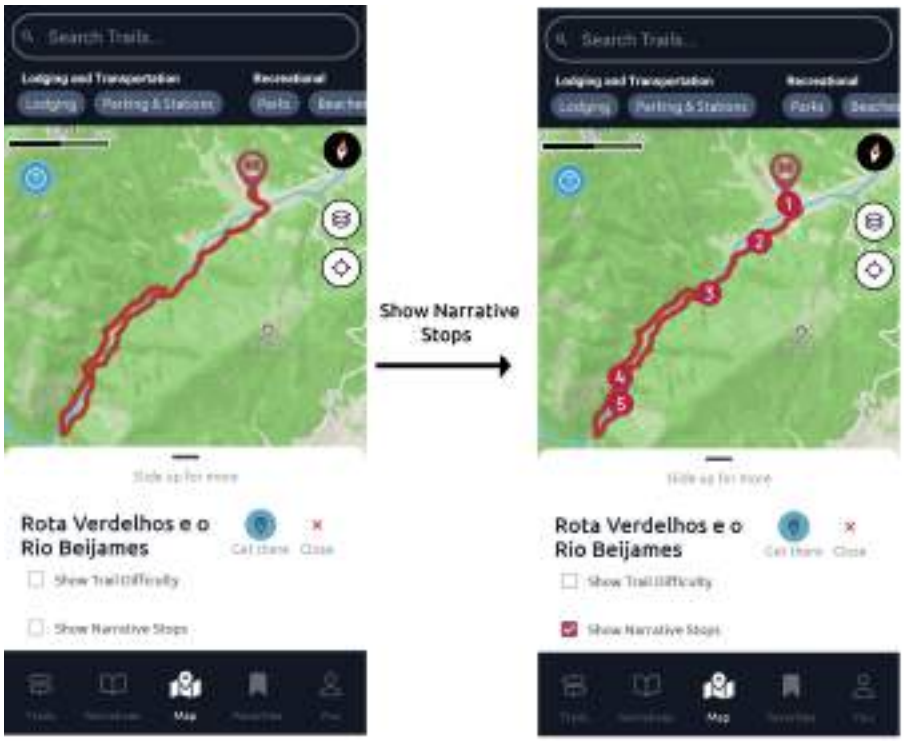

Figure D.9: Showing the stops for a narrative in the map

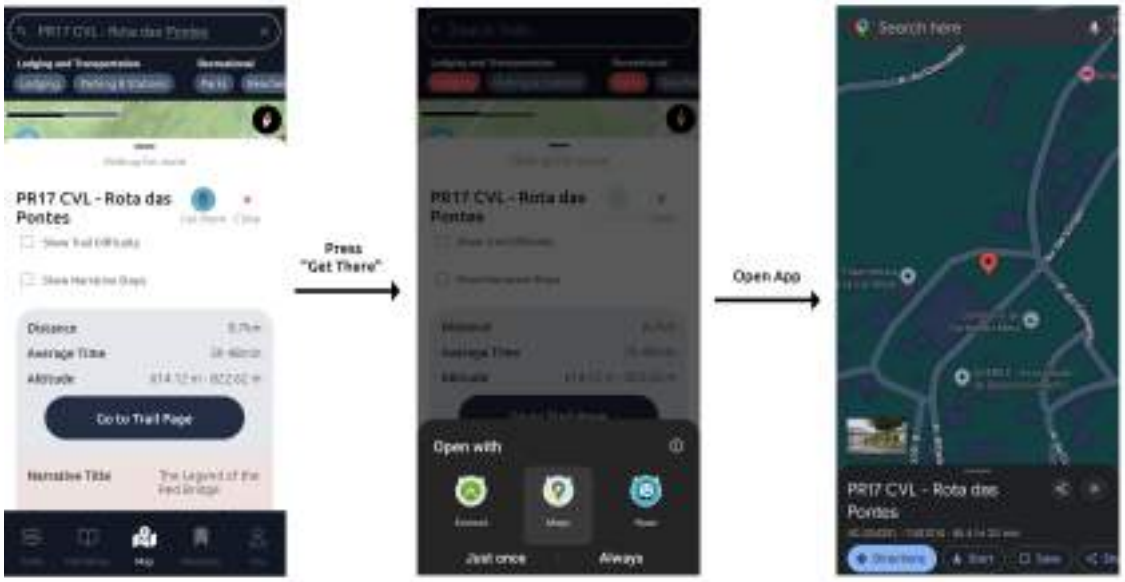

Figure D.10: Showing directions to trail: clicking the button redirects to another application in the user's device, which will give directions to the trail's start point

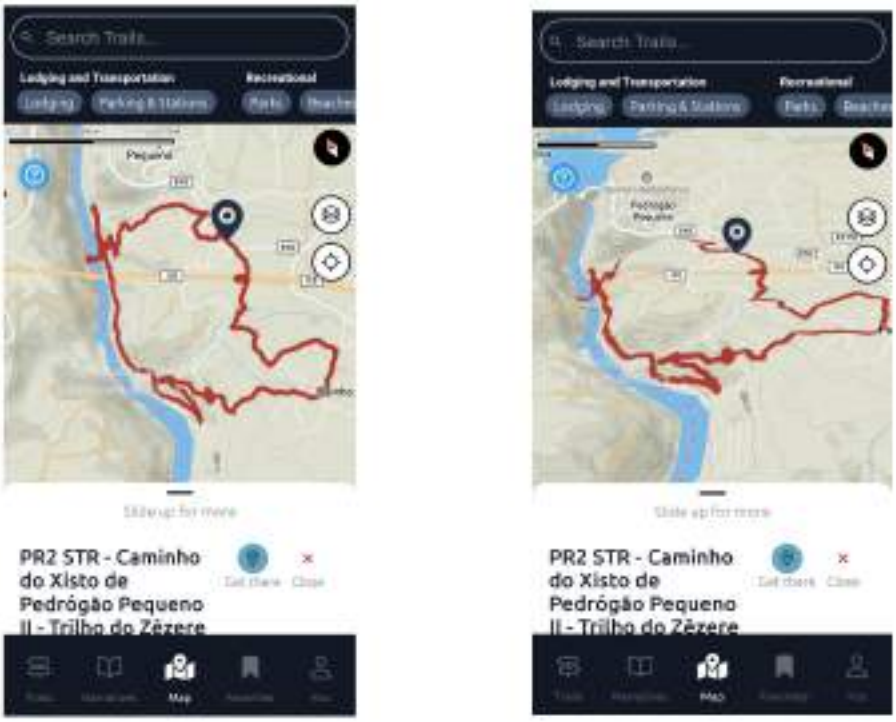

Figure D.11: Selected trail in a typically 2D view (left) and with the map pitched, showing a 3D view (right)

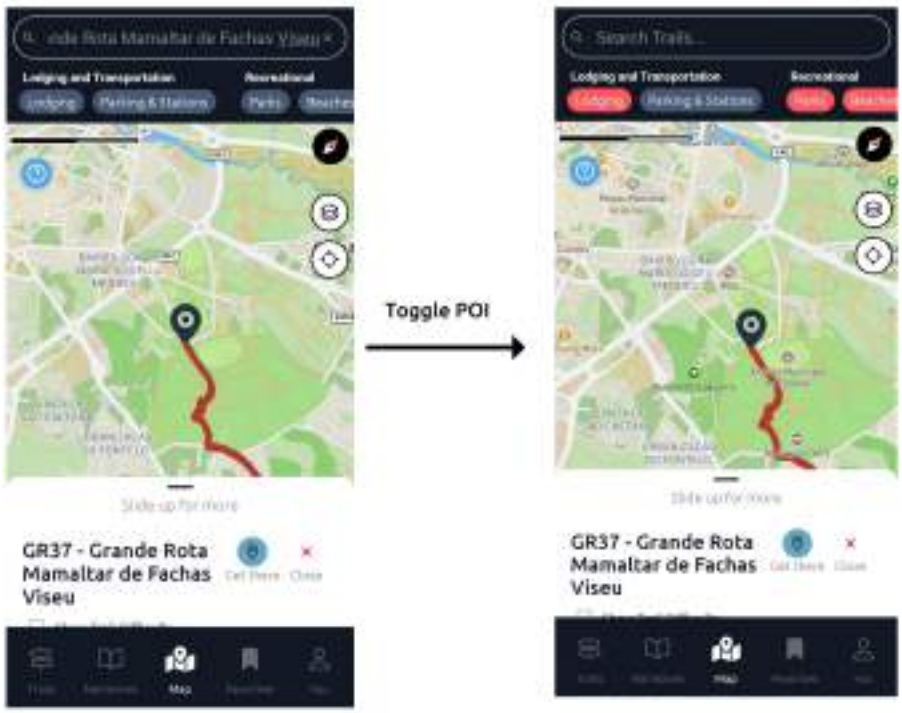

Figure D.12: Map view of area around a trail before (left) and after (right) toggling various *Points of Interest*, such as Lodging, Parks and Landmarks

D.3 Trails Tab

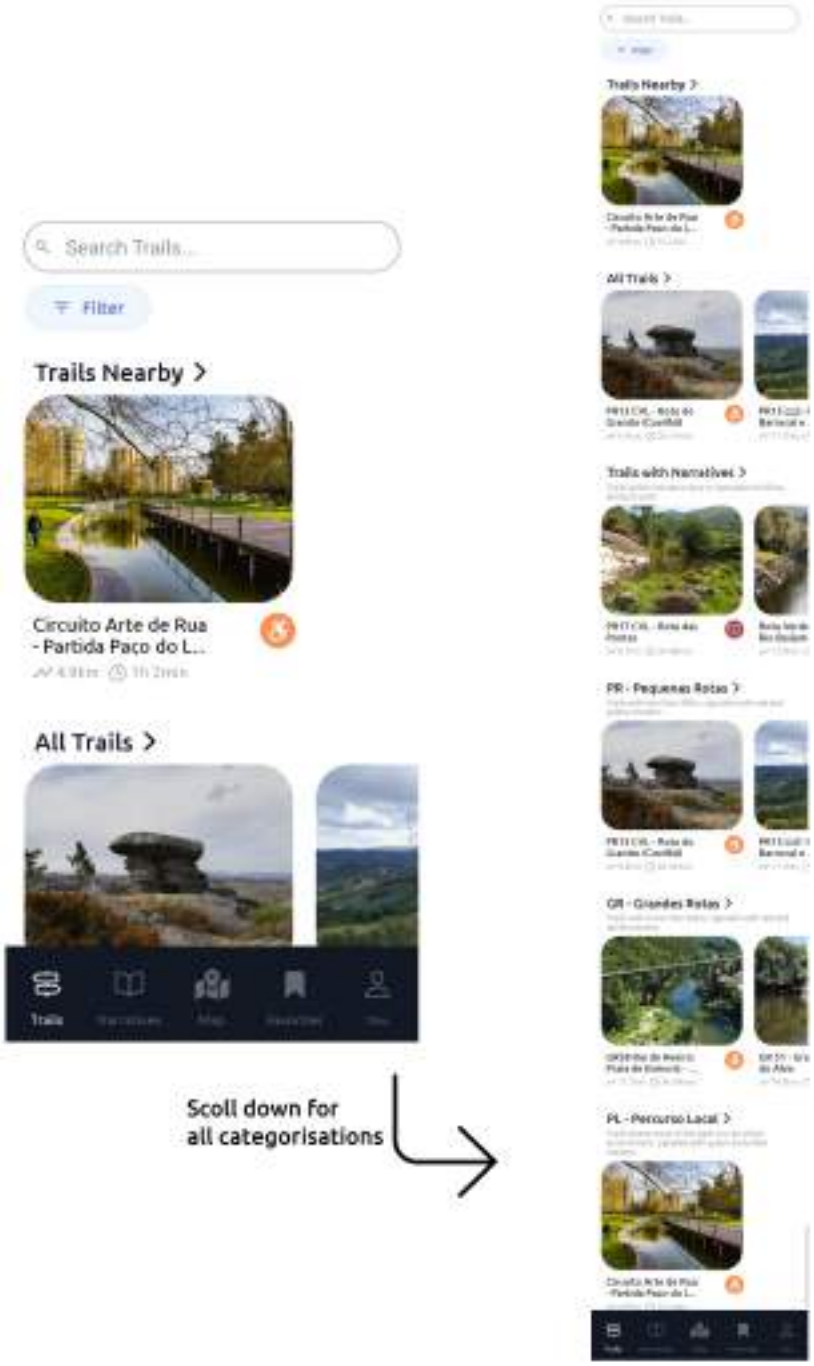

Figure D.13: Trails tab

Figure D.14: List of Trails as a result of pressing the title of the scrolling cards

D.3.1 Trail Details

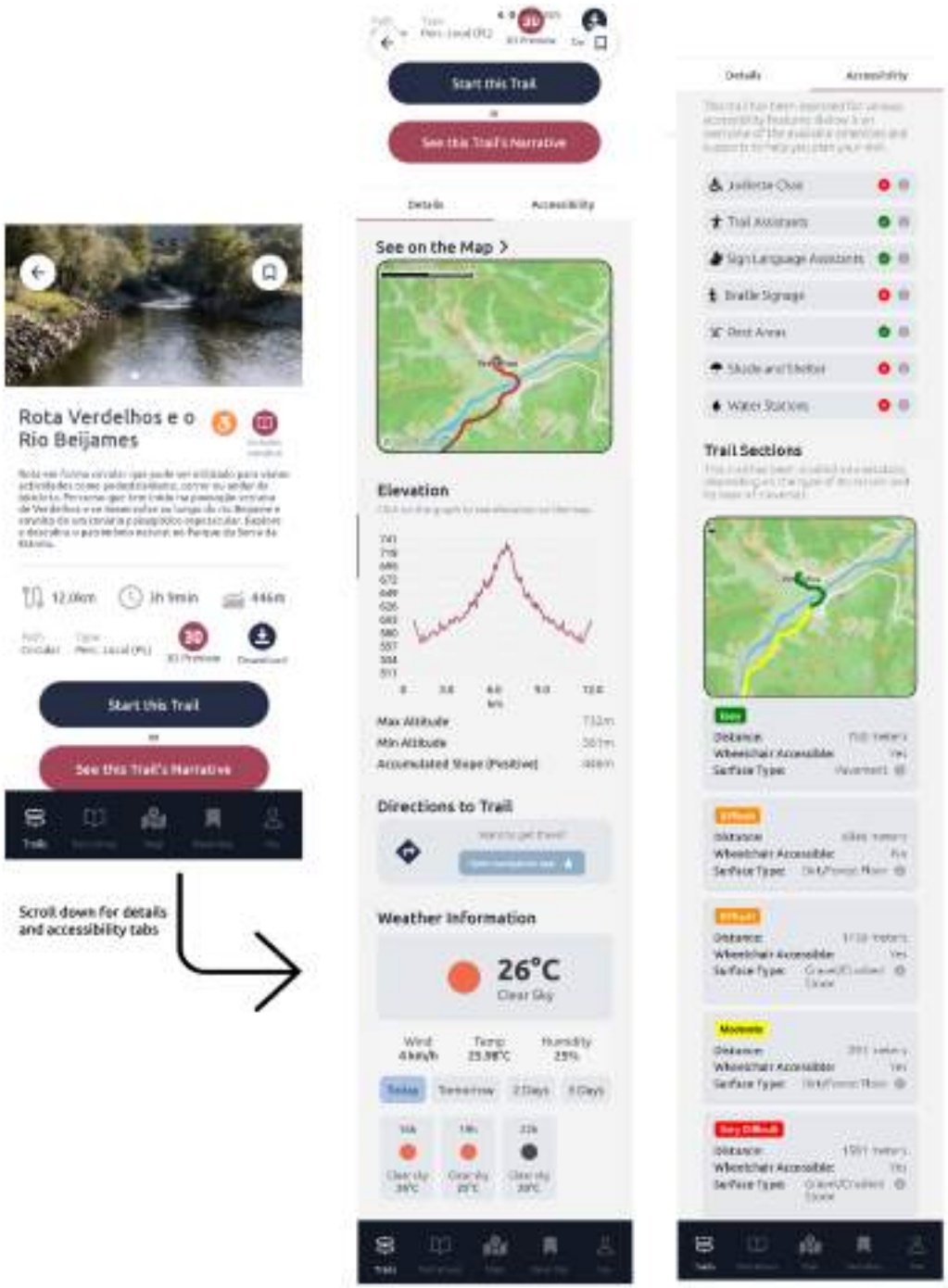

Figure D.15: Trails Details page, with respective sub-tabs - **Details** and **Accessibility**

D.3.1.1 3D Visualization

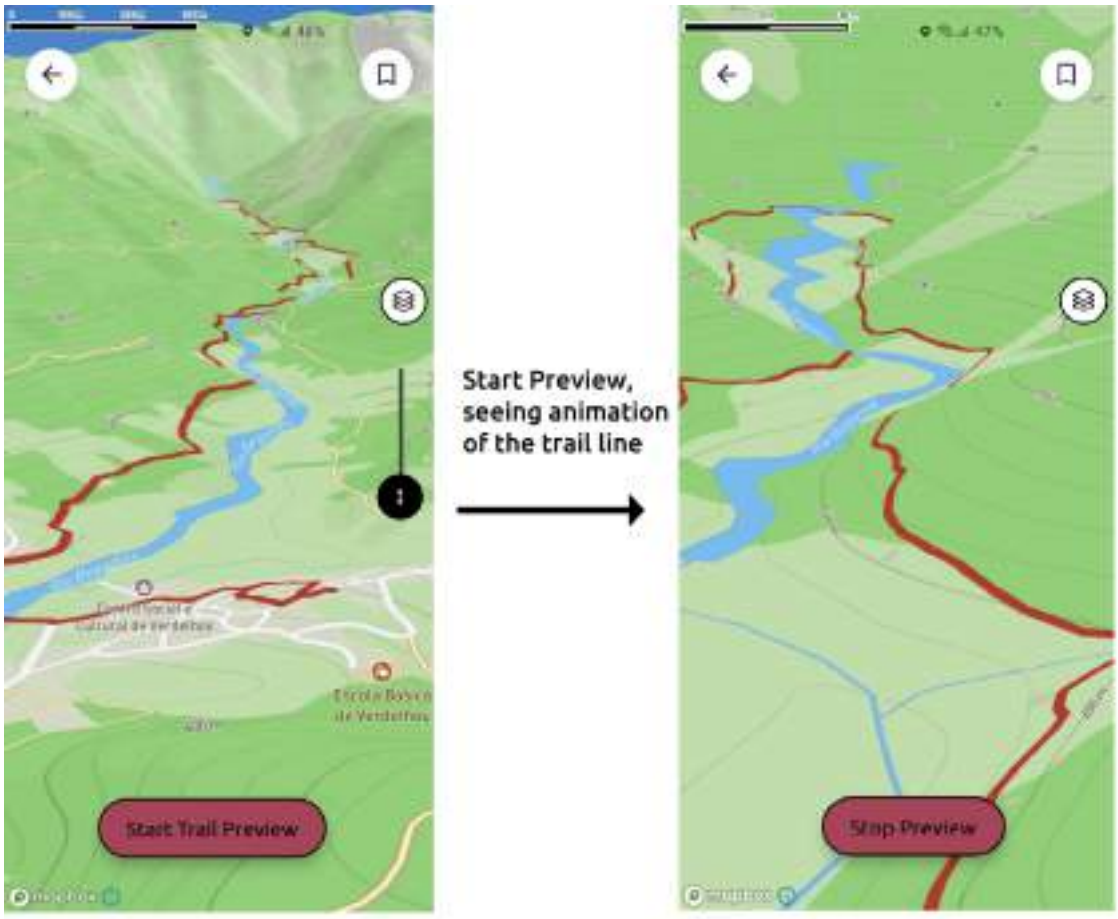

Figure D.16: 3D Preview Page. Pressing the "Start Preview" will initiate an animation following the trail's linestring

D.3.1.2 Minimap and Elevation

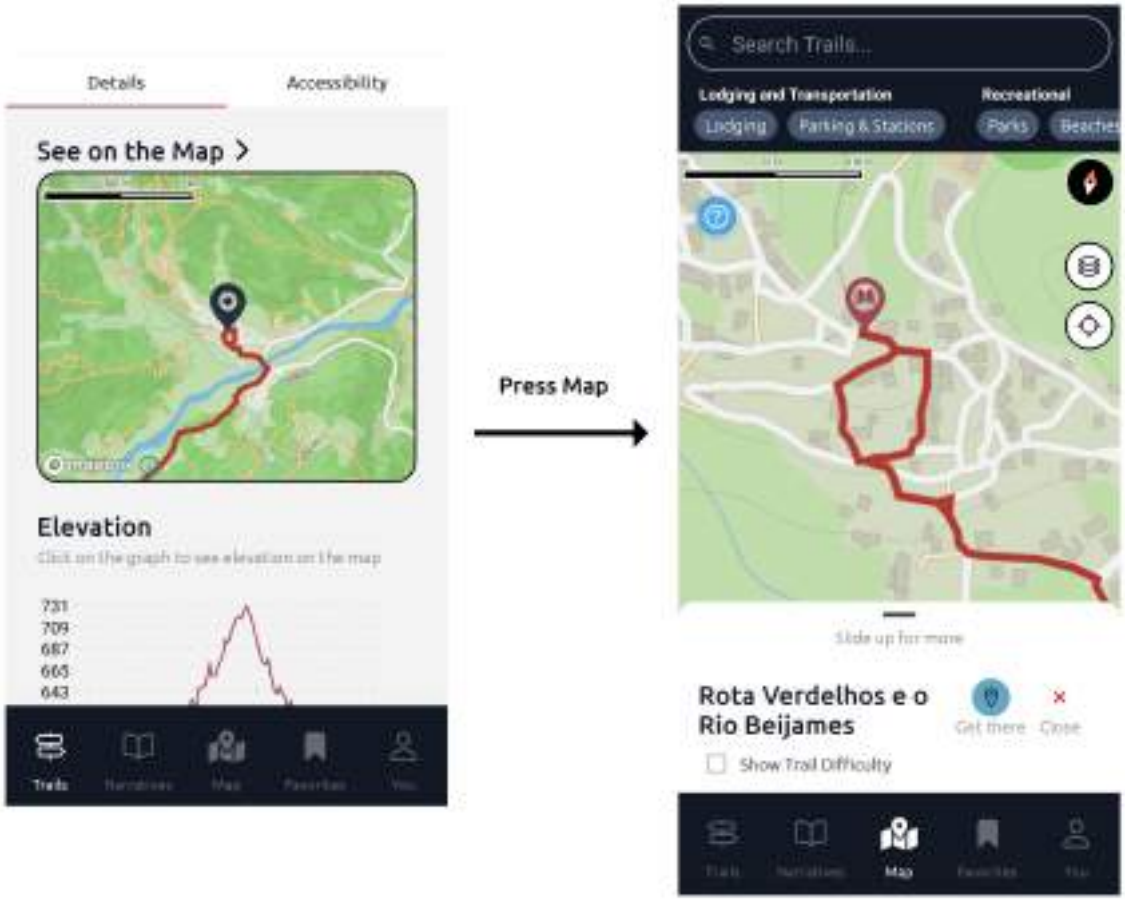

Figure D.17: Mini-map in the details sub-tab. Pressing it will show the trail on the **Map** tab

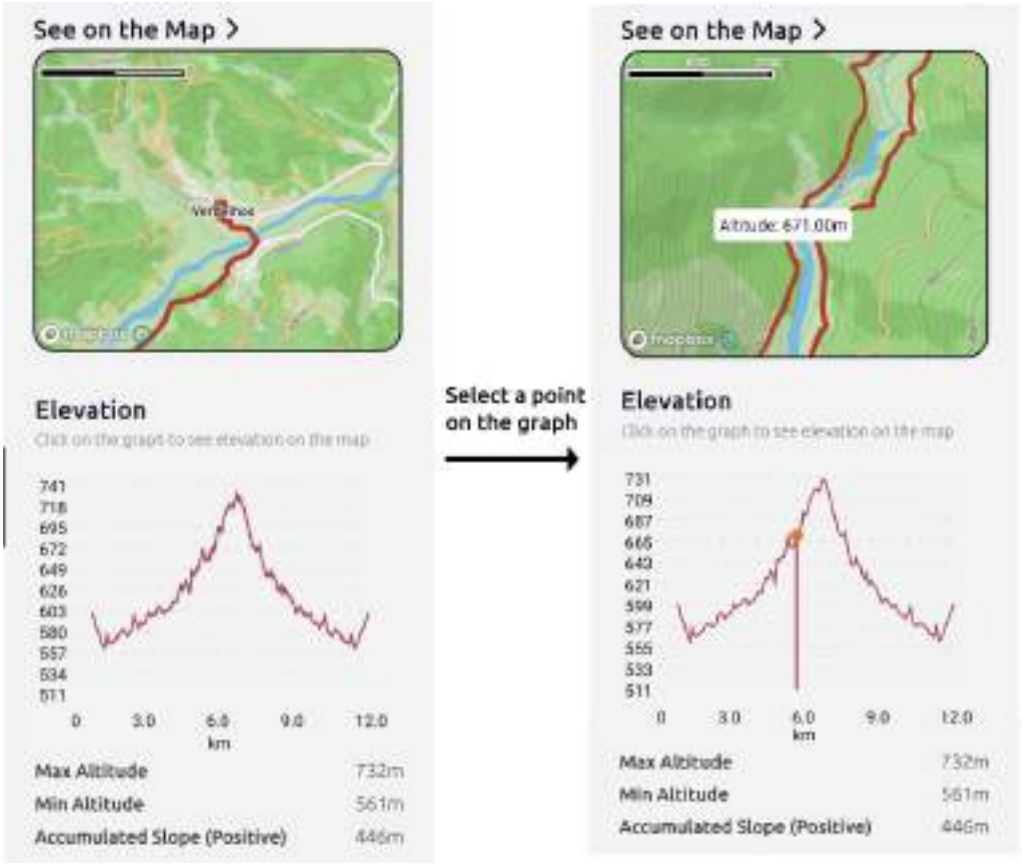

Figure D.18: Interaction between the elevation graph and the Mini-map: pressing the graph will show the respective coordinates for that altitude on the Mini-map

D.3.1.3 Directions Information

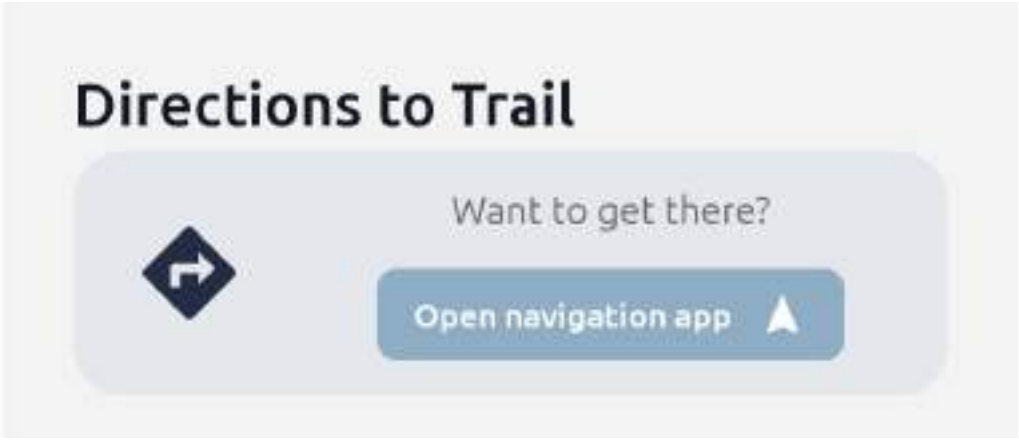

Figure D.19: Button which redirects to another application which navigates to the trail's starting point

D.3.1.4 Weather

Figure D.20: Weather component

D.3.2 Accessibility

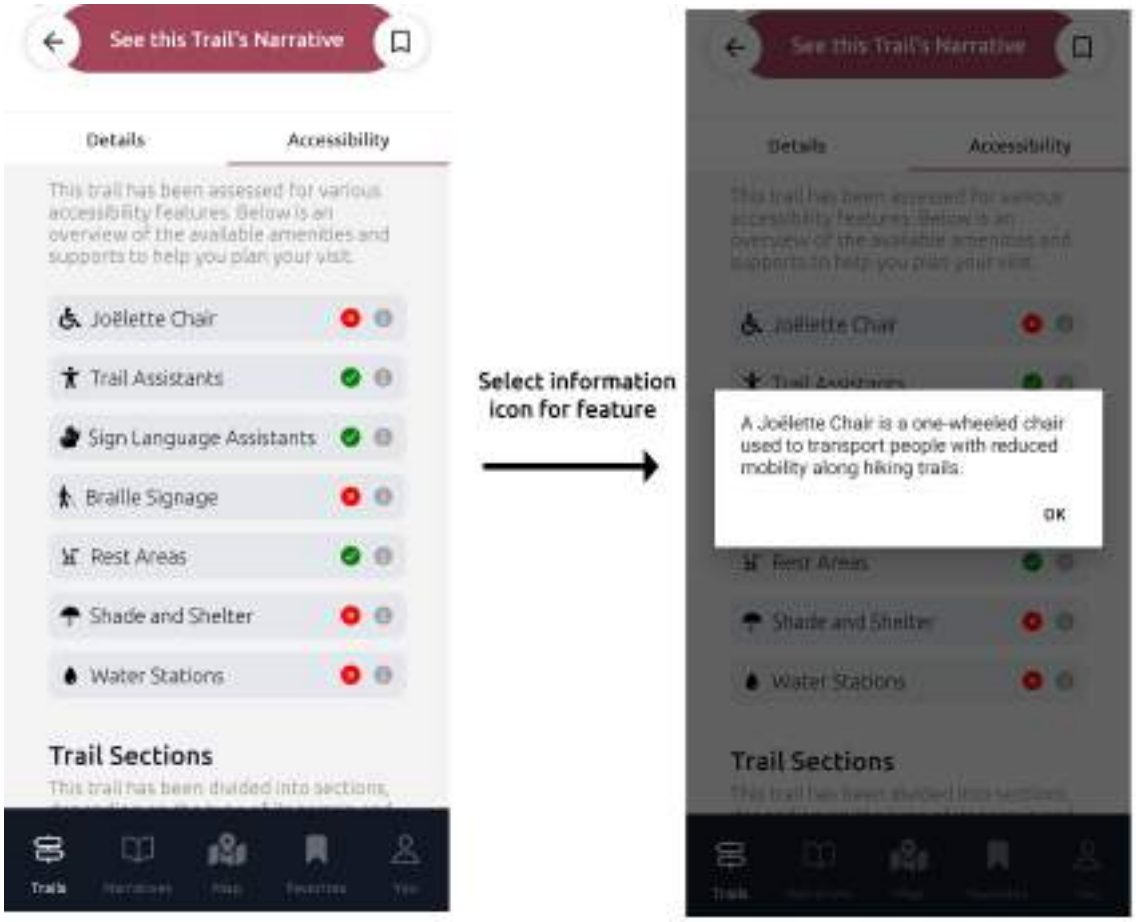

Figure D.21: Accessibility features displayed on the accessibility tab of the page for trail details

Figure D.22: Interaction flow of the information on the sections of difficulty the trail is separated in, including an information popup for the terrain types

D.4 Narratives Tab

Figure D.23: Narratives tab

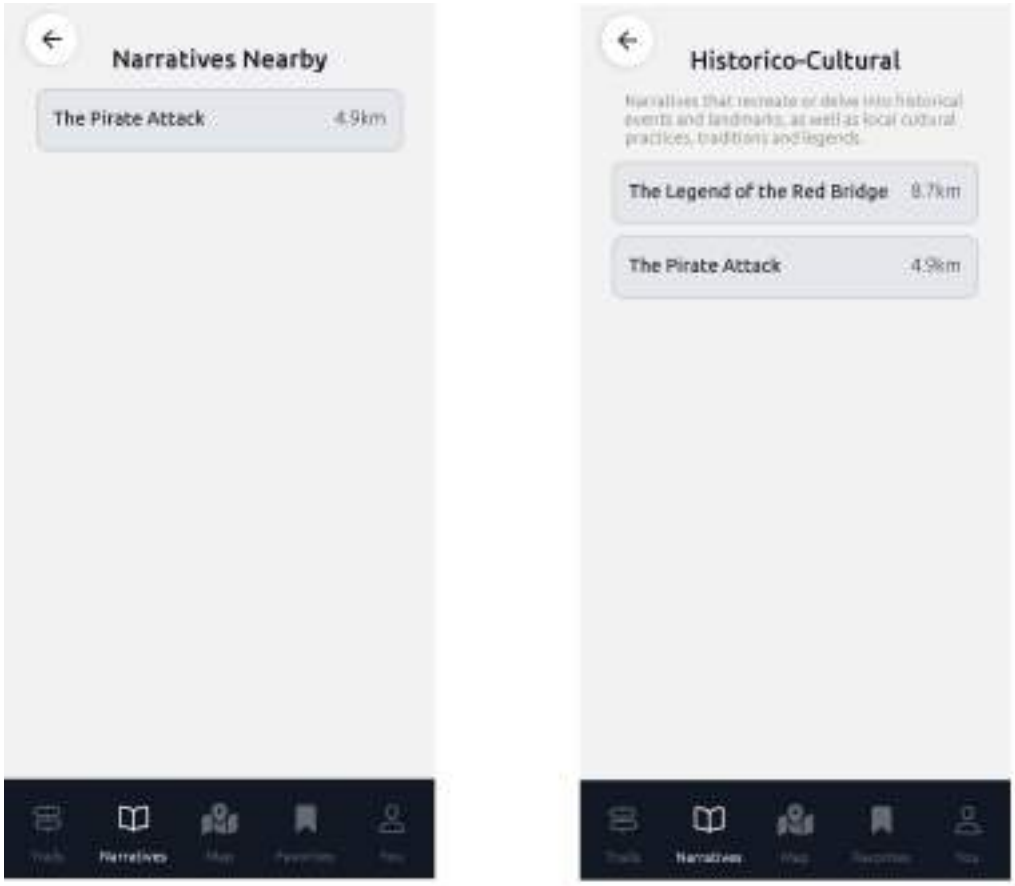

Figure D.24: List of narratives when pressing above scrollable cards (left) and when selecting a category (right)

D.4.1 Narrative Details

Figure D.25: Page for details of a specific narrative

D.5 Search and Filtering

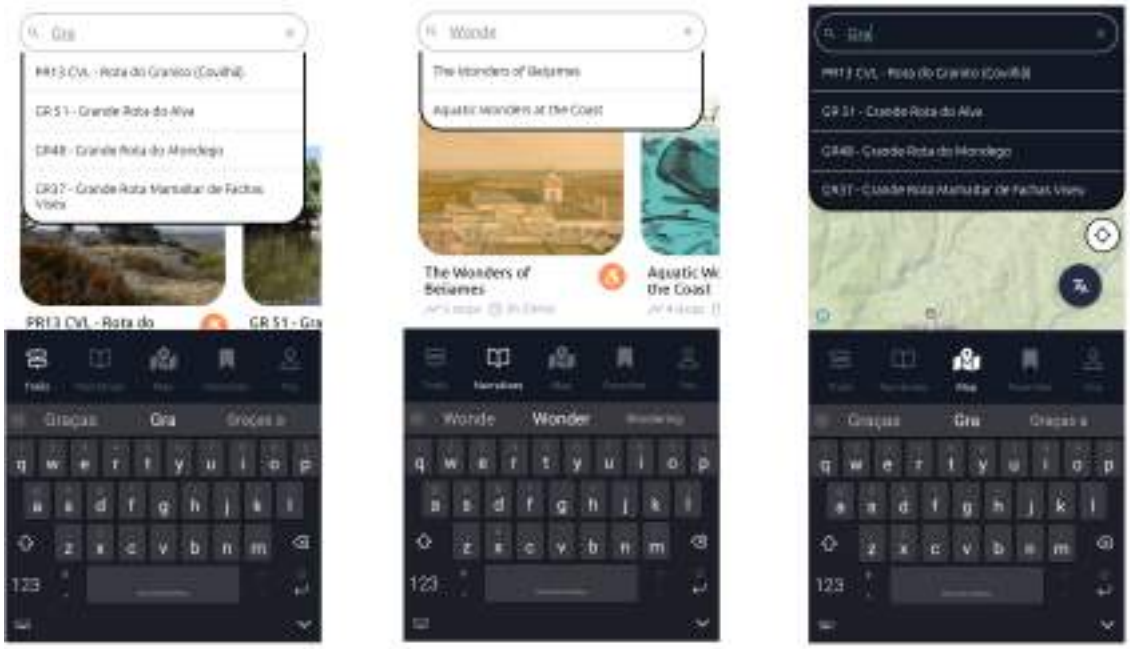

Figure D.26: Search bar functionality in the trails, narratives and map pages

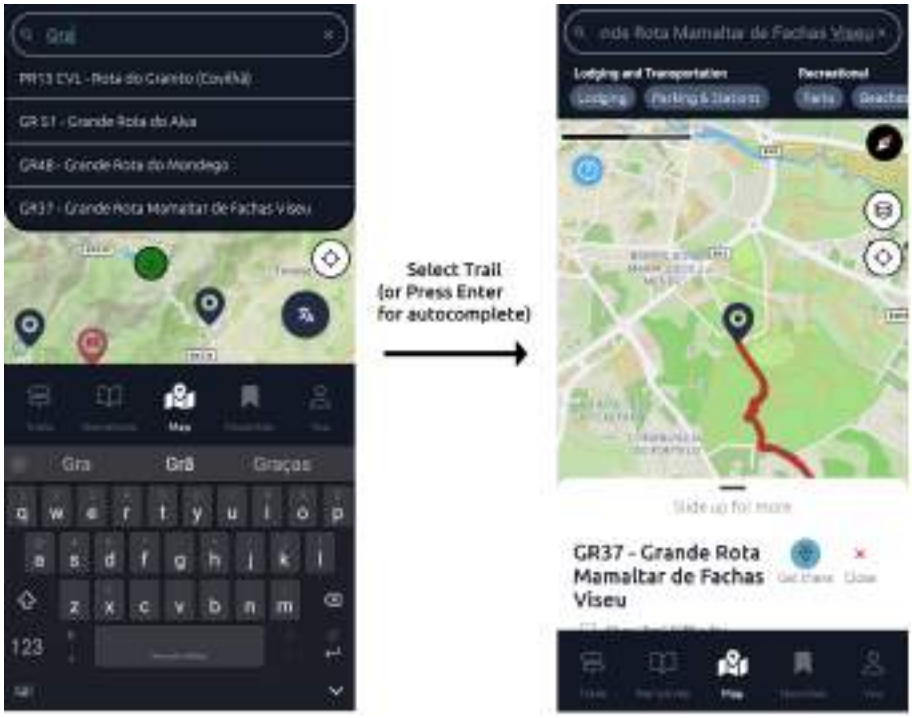

Figure D.27: Search functionality on the map, centering and zooming on the selected trail

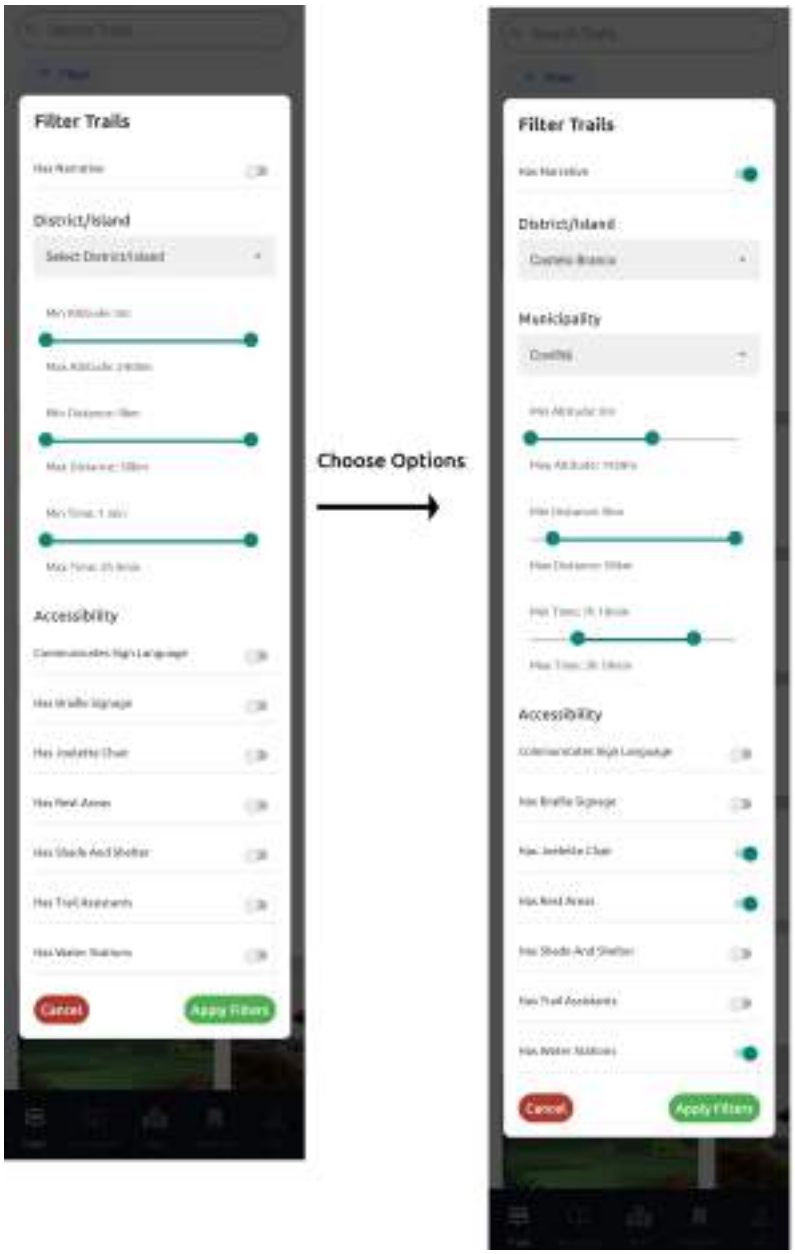

Figure D.28: Filtering modal

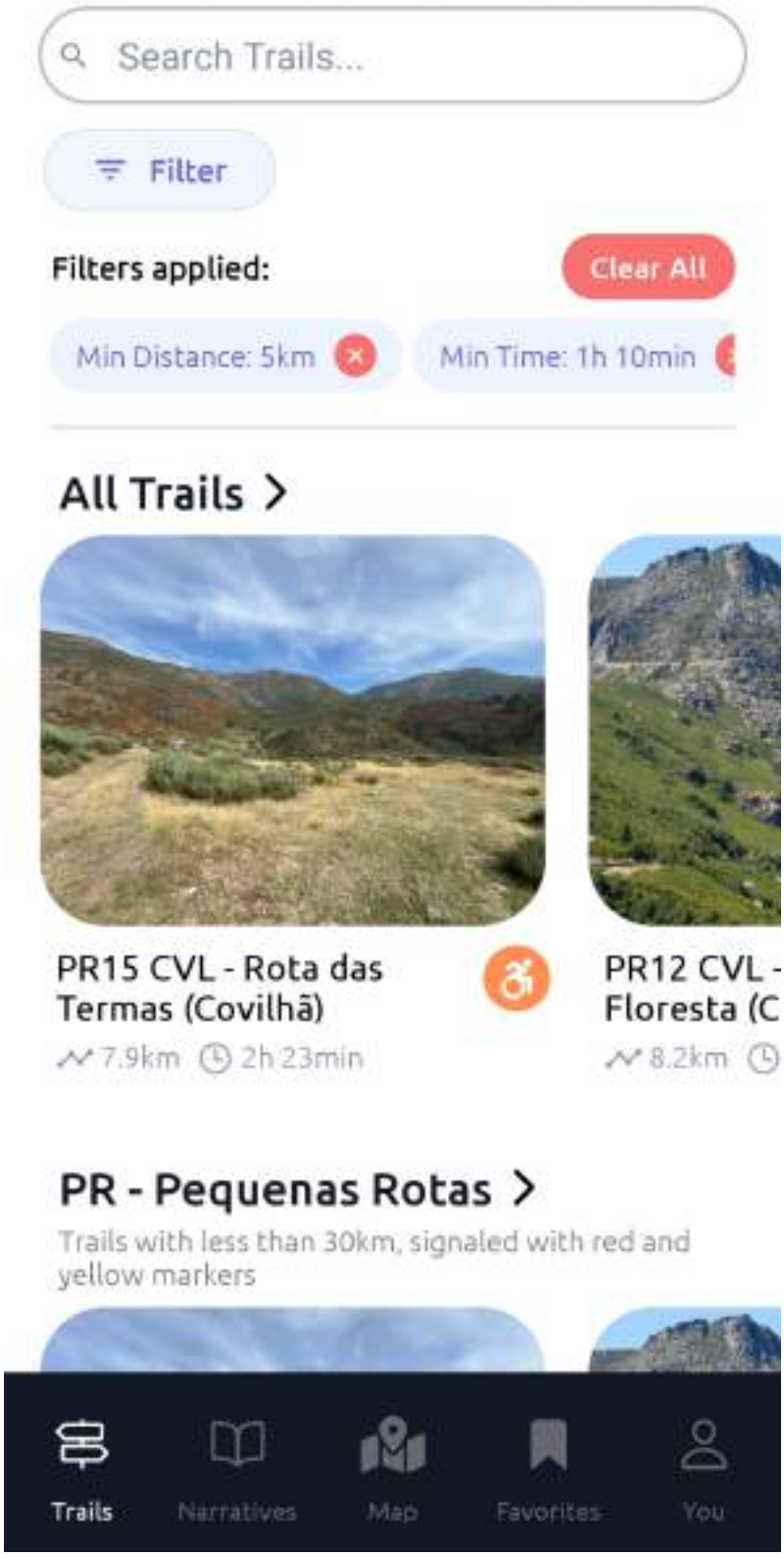

Figure D.29: Result from applying filters in the trails tab

D.6 Navigation

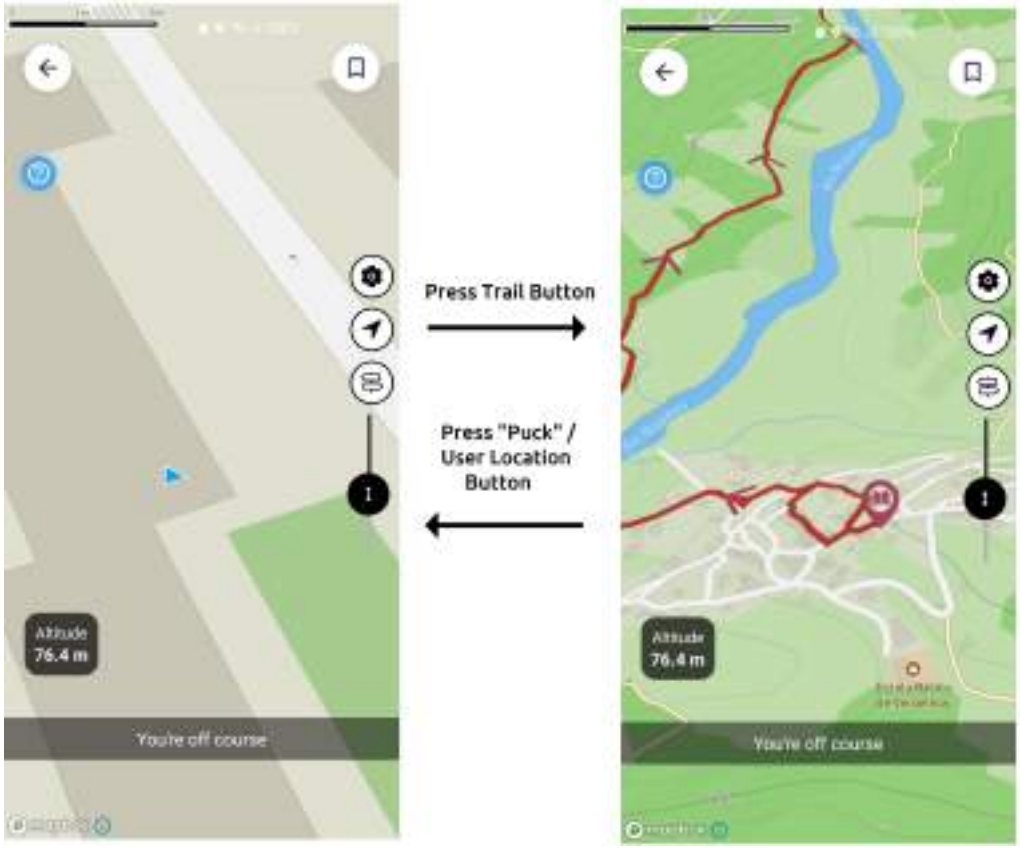

Figure D.30: Navigation Screen, and the resulting action from pressing two of the buttons on the right side

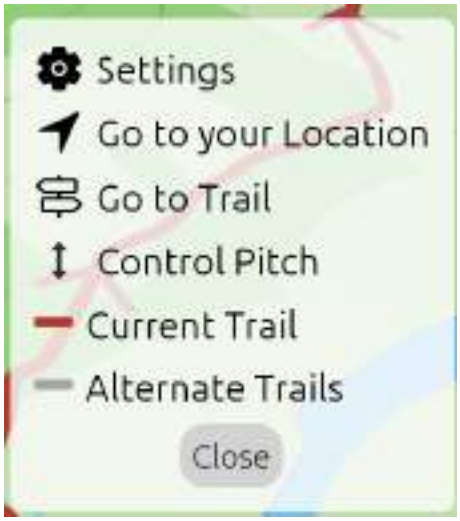

Figure D.31: Help Legend in the Navigation screen

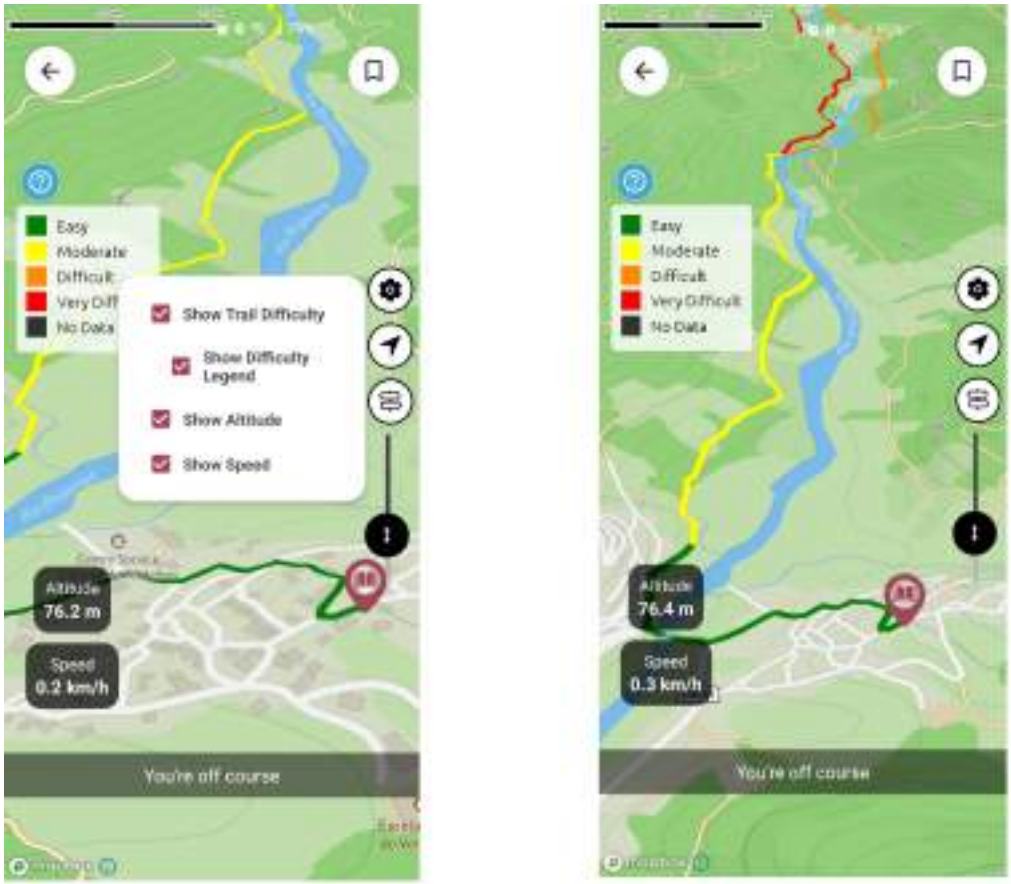

Figure D.32: Settings options in the Navigation Screen, enabling the option to show speed, altitude and the different trail sections classified by difficulty

D.6.1 Intersecting Trails

Figure D.33: Selecting an alternate trail to switch to during navigation

D.6.2 Narrative Navigation

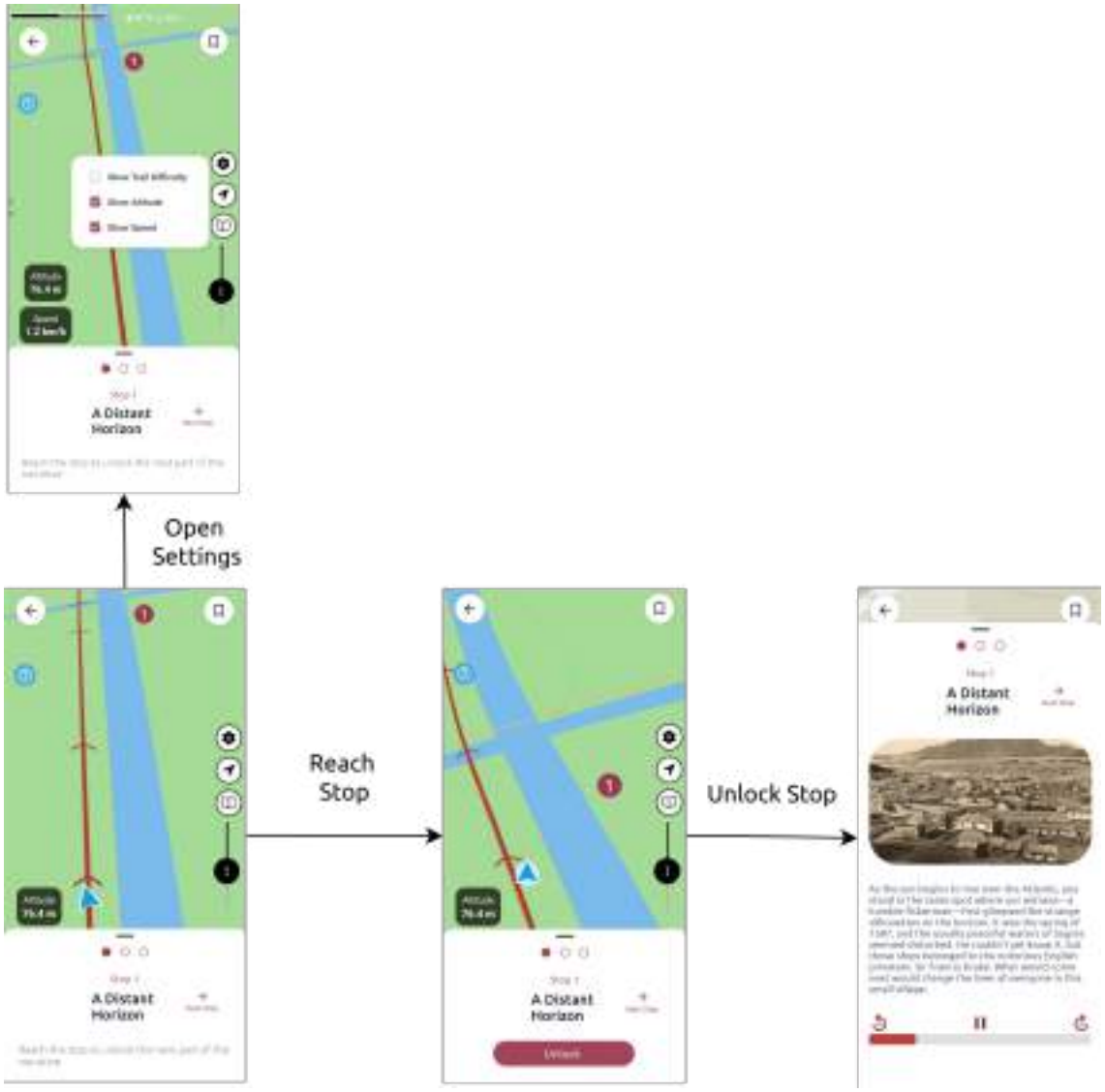

Figure D.34: Flow of navigation for a narrative

Figure D.35: Audio and Video Players for the application

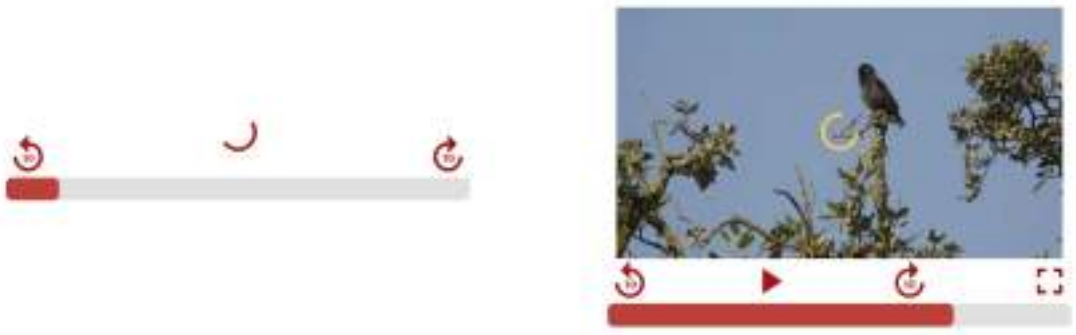

Figure D.36: Loading indicators for multimedia players while buffering

D.7 Favourites Tab

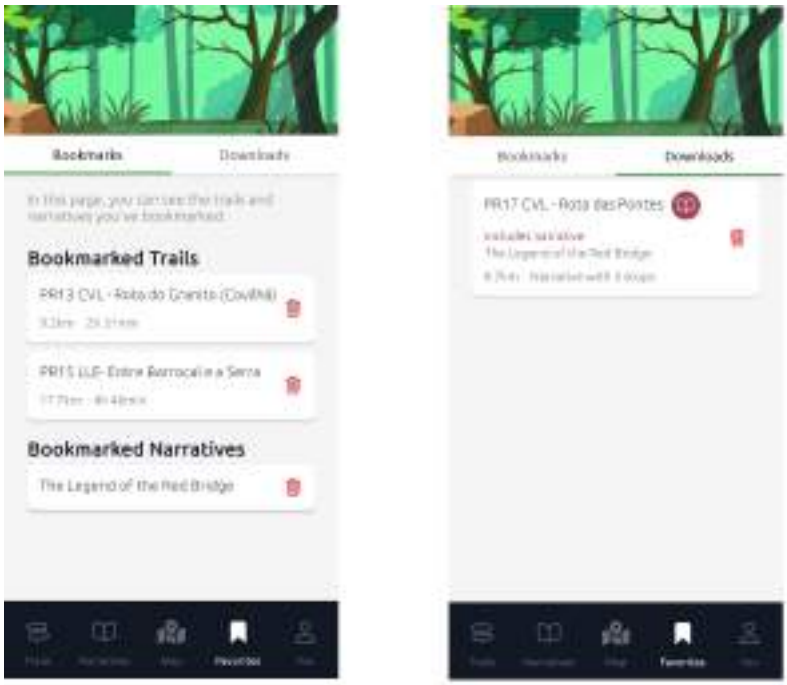

Figure D.37: Favourites Tab, showing the bookmarks (left) and downloads (right) tabs

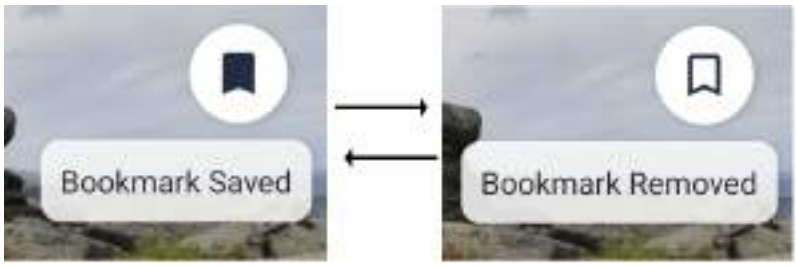

Figure D.38: Process of adding or removing a bookmark/favourite, via the trail or narrative pages

D.8 User Progress

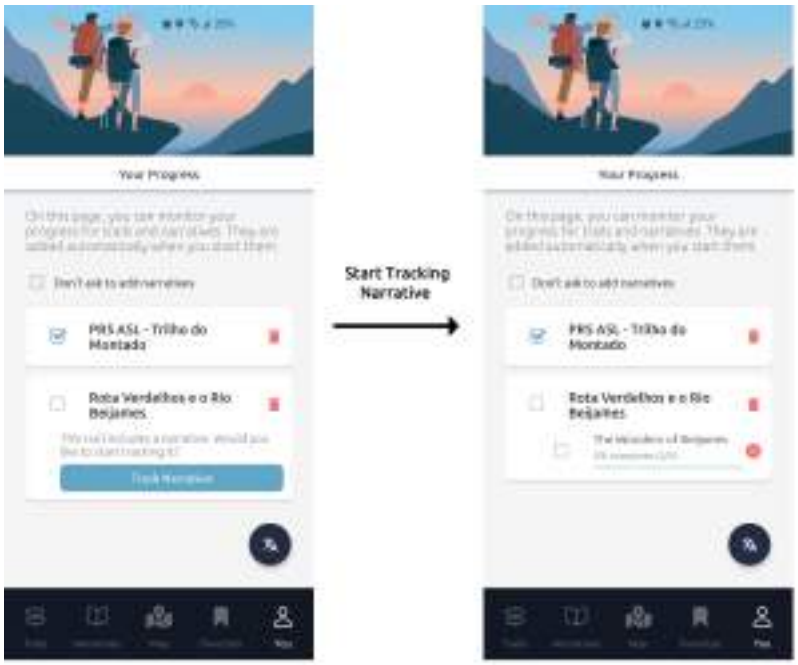

Figure D.39: User Progress tab, showing the option of starting to track a trail's narrative

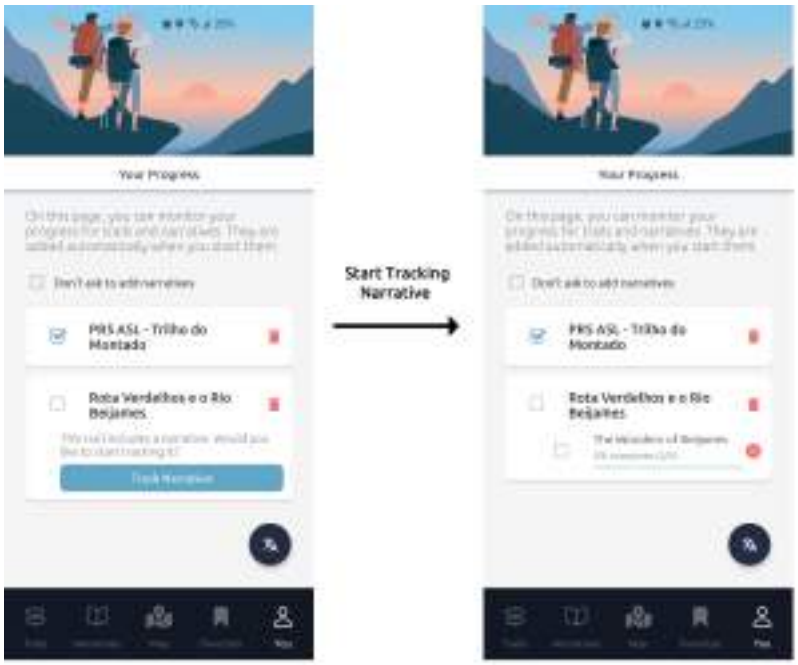

Figure D.40: Different levels of progression for a narrative in the User Progress Tab

D.9 Offline Functionality

Figure D.41: Example of flow for trail download, allowing for the download to run in the background

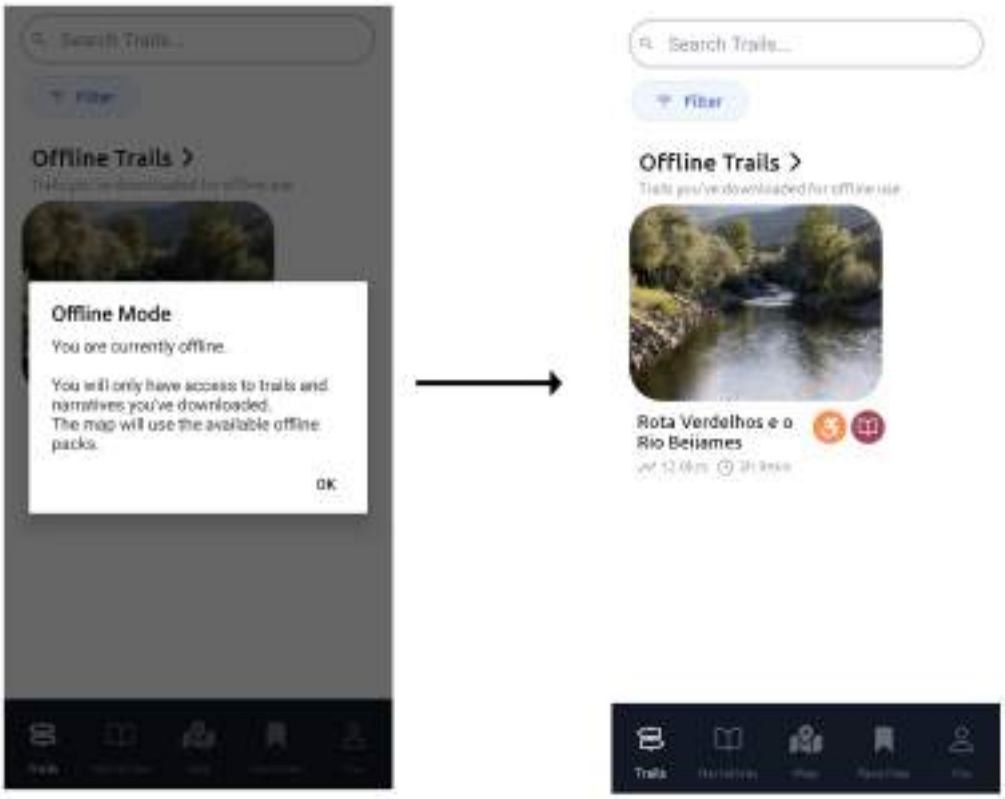

Figure D.42: Application behaviour when internet connectivity is severed

D.10 Localization

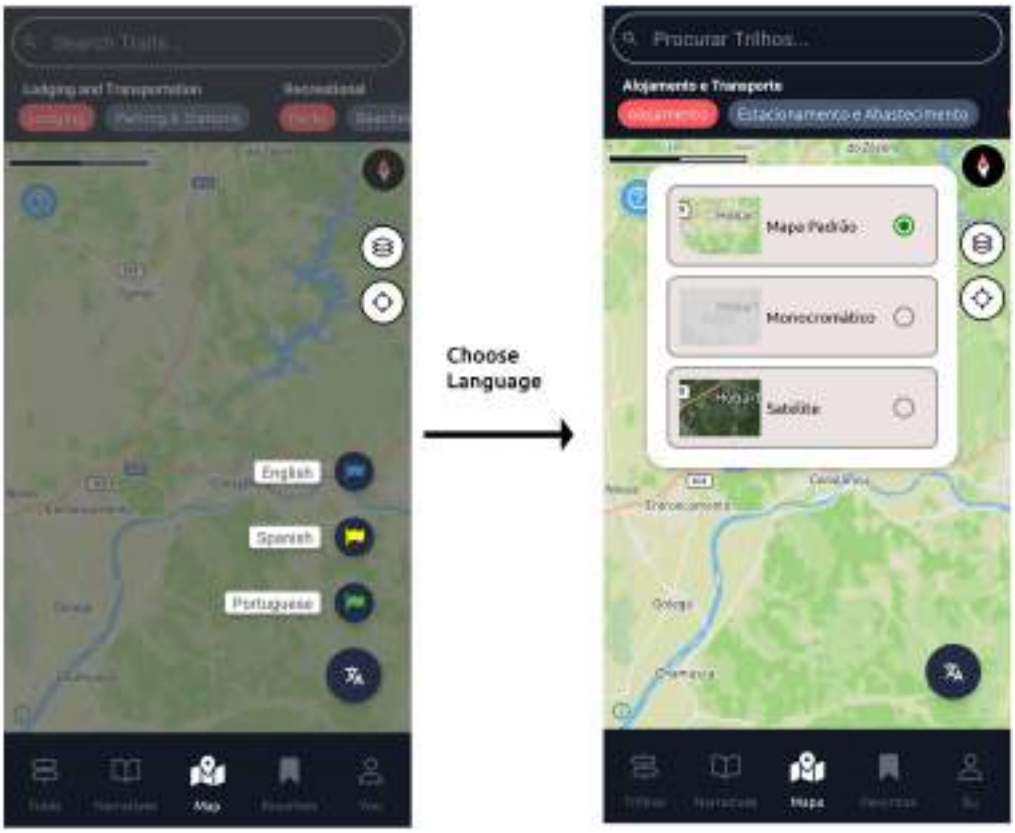

Figure D.43: Example of language change in the platform, from English to Portuguese

E

User Feedback Evolution for Features

Each of the following images show the evolution of user perceptions regarding the intuitiveness of the labeled feature, from its initial introduction (Phase 1 or 2) to the final testing phase (Phase 3).

The legends reflect a rating scale from 1 (Not Intuitive) to 5 (Very Intuitive) for the question: "How intuitive was this task for you?"

E.1 Features Introduced in Phase 1

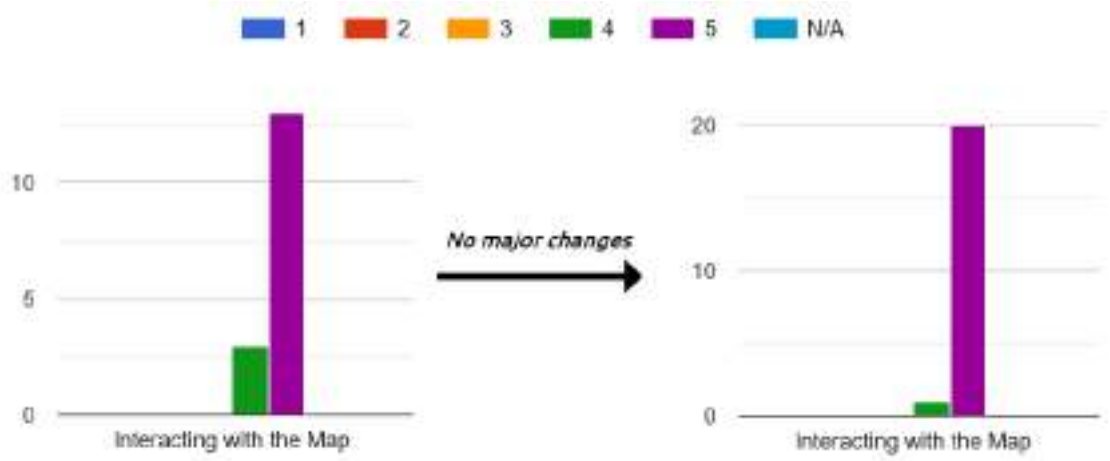

Figure E.1: Map Interaction

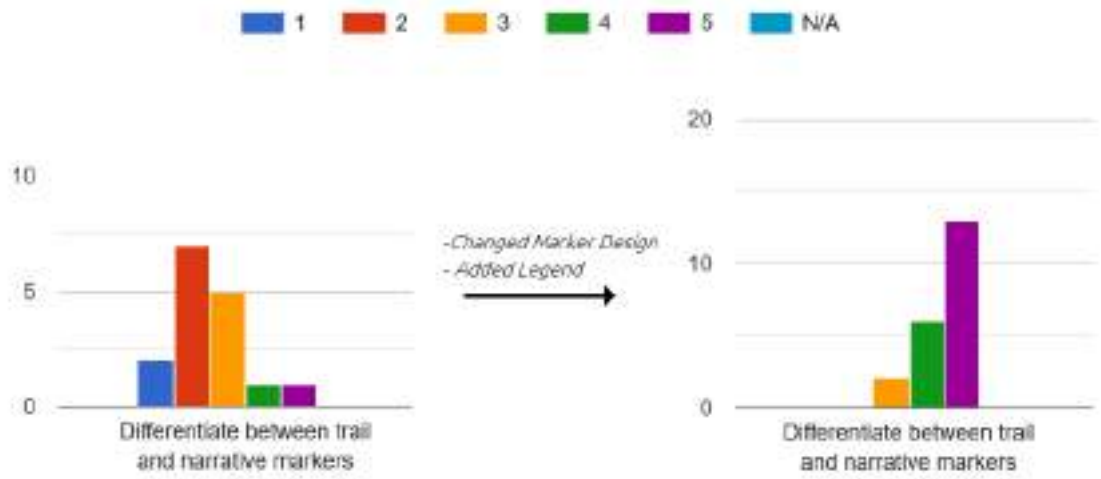

Figure E.2: Marker Differentiation

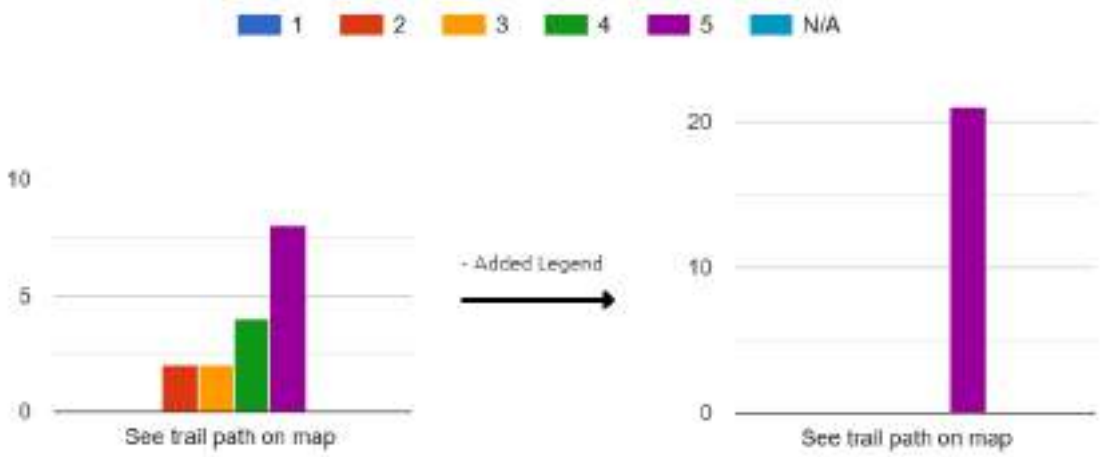

Figure E.3: Seeing trail on map

Figure E.4: Search Functionality

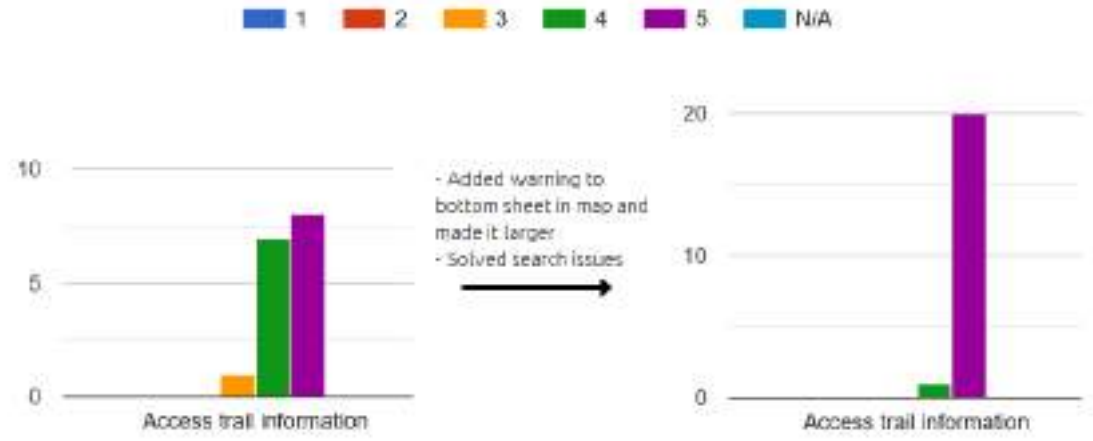

Figure E.5: Accessing Trail Information

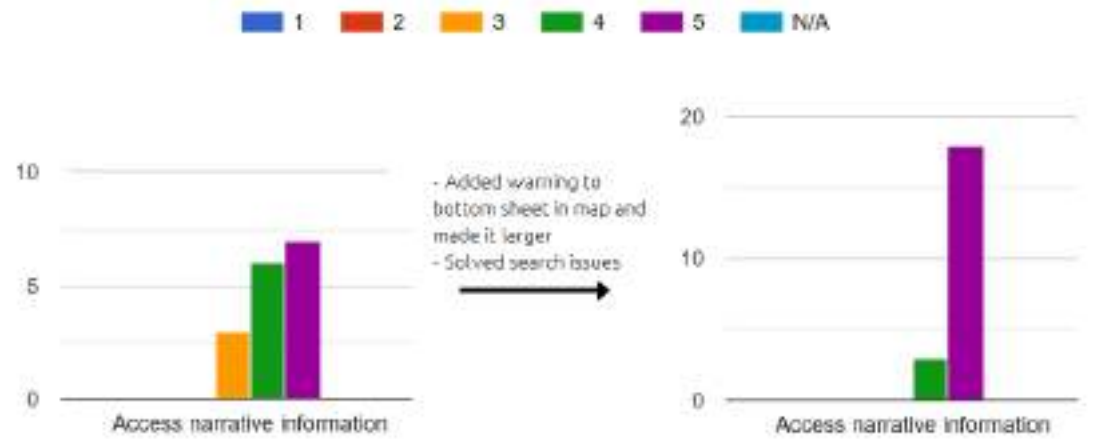

Figure E.6: Accessing Narrative Information

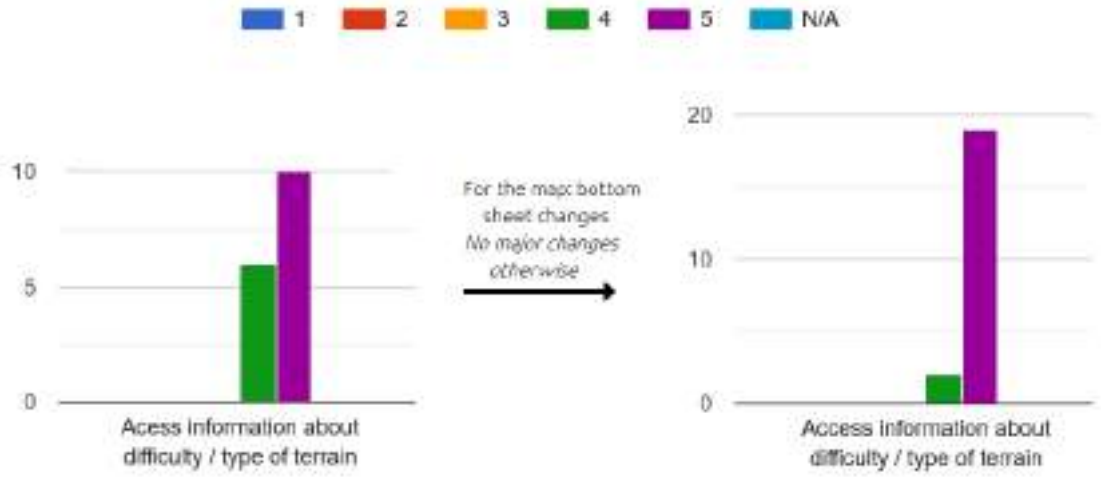

Figure E.7: Accessing Difficulty and Terrain Type Information

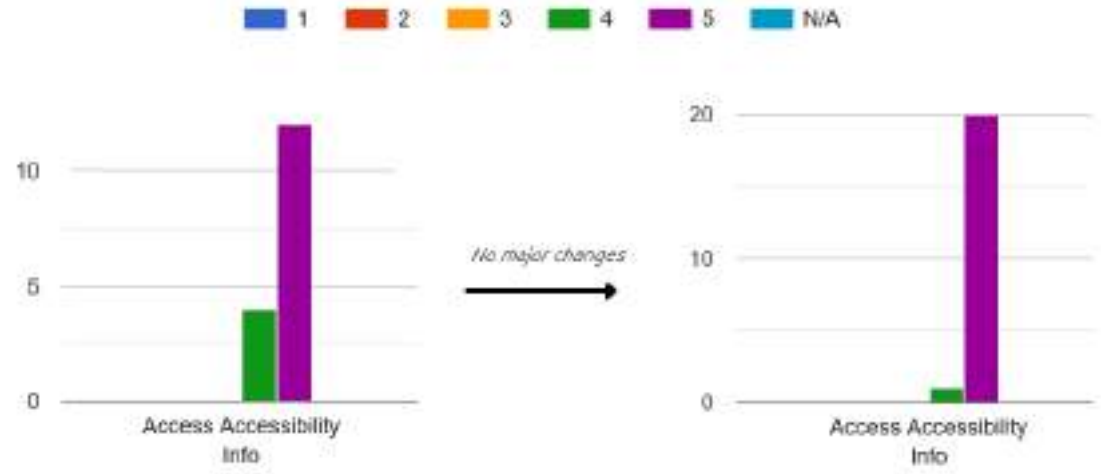

Figure E.8: Accessing Accessibility Information

Figure E.9: Accessing Weather Information

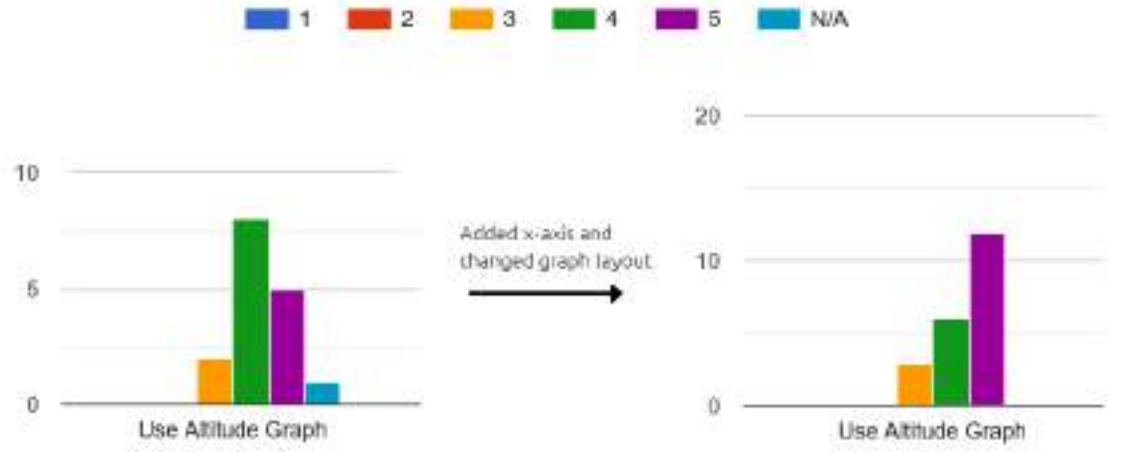

Figure E.10: Handling Elevation Graph

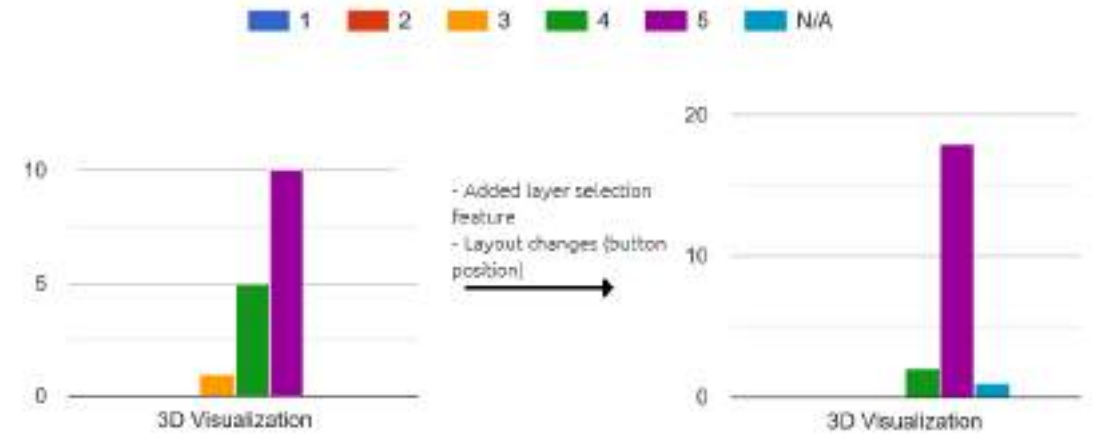

Figure E.11: 3D Visualization

Figure E.12: Trail Navigation

Figure E.13: Narrative Navigation

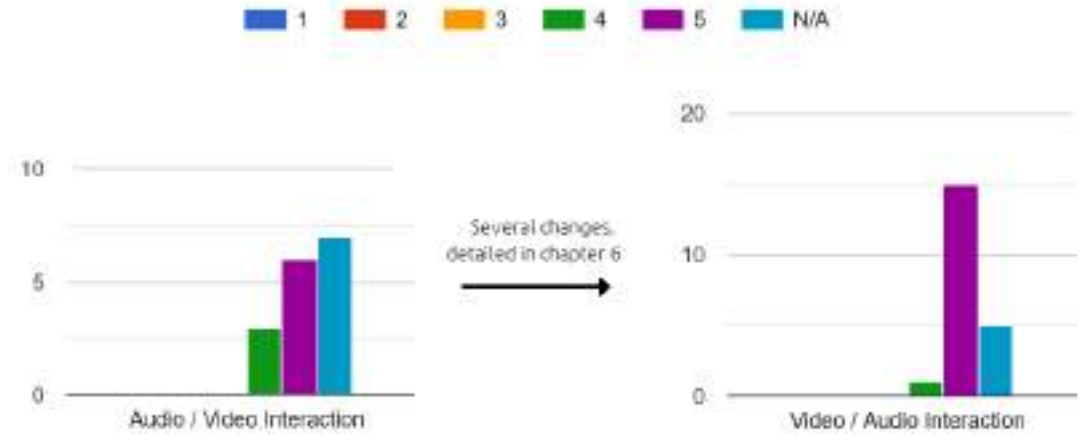

Figure E.14: Multimedia Interaction during Narrative Navigation

E.2 Features Introduced in Phase 2

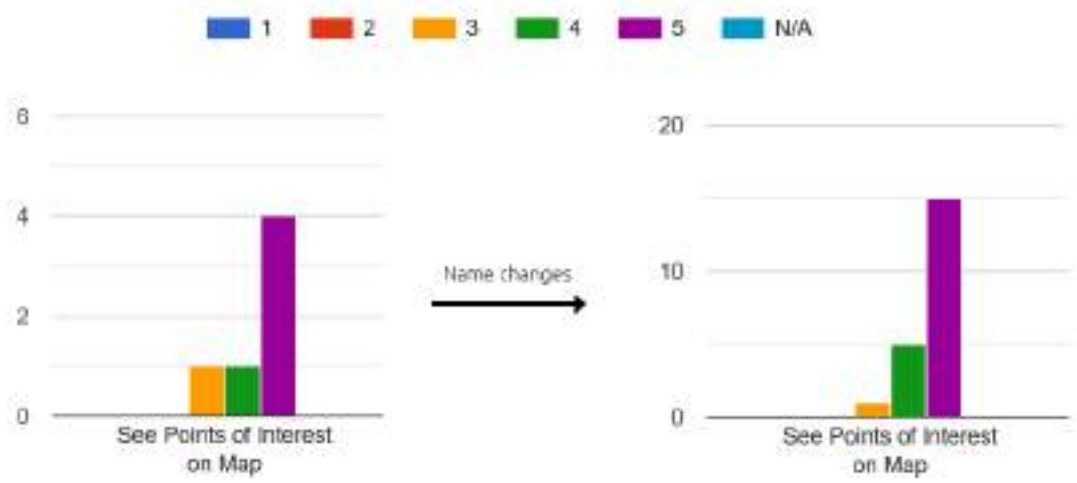

Figure E.15: Points of Interest

Figure E.16: Filtering

Figure E.17: Favourites

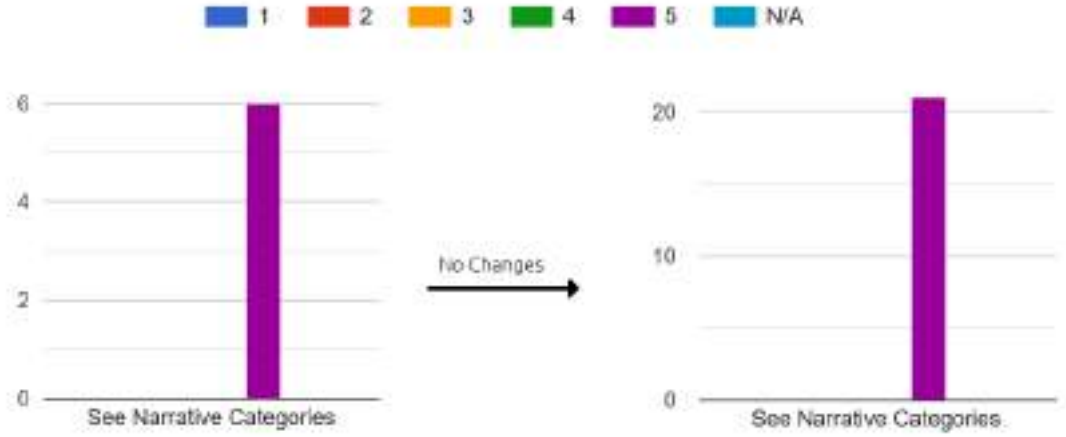

Figure E.18: Narrative Categorisation

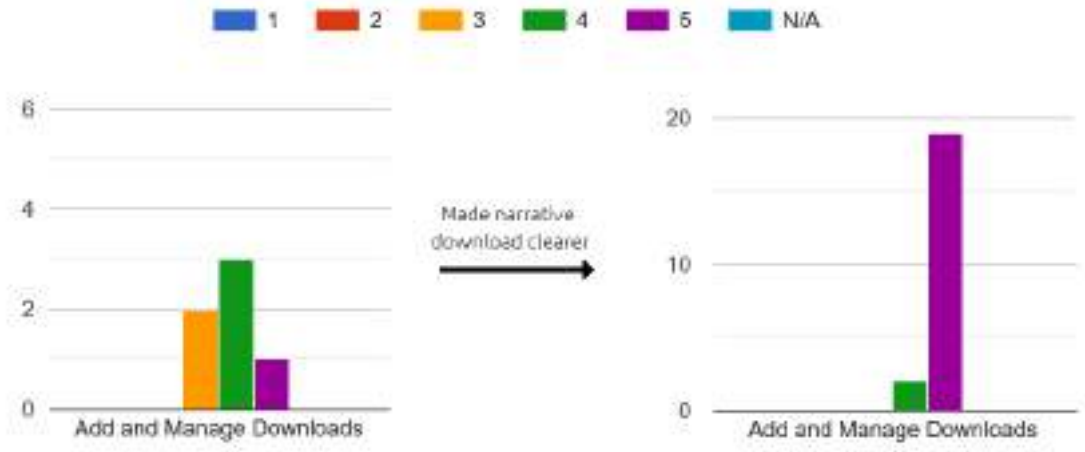

Figure E.19: Downloads

Figure E.20: Offline Functionality

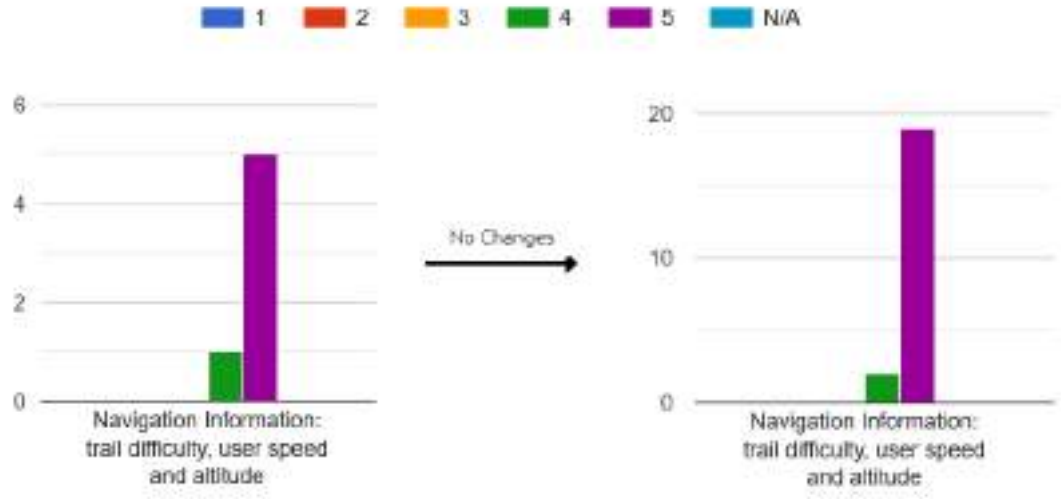

Figure E.21: Navigation Settings

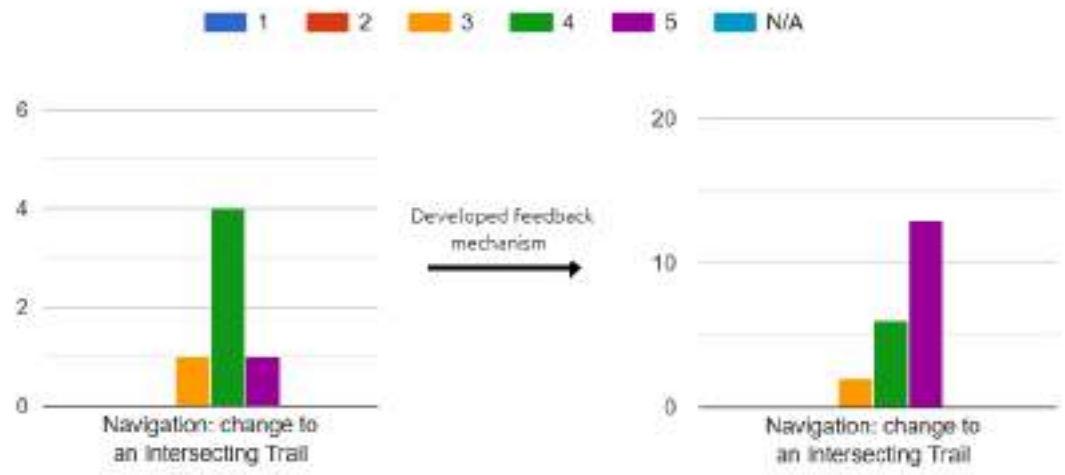

Figure E.22: Intersecting Trails

F

Use Cases, Tasks and Testing Reports

Usability Testing Report - Phase 1

Kiara Ventura

The usability testing for Phase 1 was conducted with 16 users, each of whom filled out a System Usability Scale (SUS) questionnaire and provided additional feedback through a follow-up form. The goal was to evaluate the application's functionality and ease of use across multiple use cases, focusing on navigation, information retrieval, and interaction with the map, trails and narratives.

1 Use Cases

The following use cases were designed to assess various functionalities of the trails app, ensuring that users could effectively navigate the app and access relevant trail and narrative information.

1. Users can easily maneuver through map controls and layers.
2. Users can navigate through tabs and understand the content presented in each one.
3. Users can differentiate between trail and narrative markers without needing prior clarification.
4. Users can view basic information about a trail.
5. Users can search for a trail and check its difficulty level.
6. Users can view elevation information for a trail.
7. Users can understand and interpret the trail's elevation graph.
8. Users can switch between different trails easily.
9. Users can view accessibility information about a trail.
10. Users can view the trail in 3D and preview its path.

11. Users can easily locate a trail on the map from the trail's details page.
12. Users can view weather forecast information for a trail.
13. For different trail sections, users can view terrain type and difficulty.
14. Users can find narratives associated with a particular trail and view the relevant information.
15. Users can navigate a trail.
16. Users can navigate a narrative, unlocking stops that include text, images, audio, or video content.
17. Users can fast-forward, rewind, pause, and resume audio or video content in narratives.

2 User Tasks

The following tasks were assigned to the users during the usability testing phase. The comments noted reflect the user feedback and time expended on the task.

1. Set the map to the "Satellite" layer, zoom out until the entire country is visible, then switch back to the base layer and center the map on your current location.
2. Find out how many trails are categorized as "Grandes Rotas" and how many narratives are available overall.
3. Check the distance of a trail without a narrative, and then check the distance of a trail with a narrative.
    - **Issue:** When using the map, difficulty differentiating between trail and narrative markers
    - **Issue:** No initiative to press the markers
    - **Issue:** Users often got stuck not realizing that the bottom sheet with trail information could be pulled up
4. Use the map to find the difficulty level of the trail "PR11 CVL – Porta da Estrela" and determine how many sections have different difficulty levels.

- **Bug:** Some issues found with search bar functionality
- **Improvement:** Recommended additional filtering options

5. Find the minimum and maximum elevation of the trail "PR11 CVL – Porta da Estrela".

6. Find the altitude at the midpoint of the same trail.

   - **Improvement:** Graph missing the X axis, which was confusing

7. Check if the trail "Percurso pela FCT" includes Braille signage.

8. View the 3D animation of the trail "Percurso pela FCT".

   - **Improvement:** Requested option to switch map layers

9. From the trails page, go t the location of the trail "Percurso pela FCT" on the map.

10. Find out the temperature forecast for the trail "PR11 CVL – Porta da Estrela" two days from now at 14:00.

    - **Issue**: Majority of users went to the Details tab first, when the weather was in the Accessibility Tab

11. Identify the terrain type for the section with "Difficult" difficulty on the trail "PR11 CVL – Porta da Estrela".

    - **Improvement**: Suggested that difficulty also be shown when navigating a trail, not just in the trails page

12. Find the name of the narrative associated with the trail "Percurso pela FCT" and check how many stops it contains.

13. Complete all steps of the narrative associated with the trail "Percurso pela FCT". While navigating the narrative, fast-forward, rewind, pause, and resume the audio or video content.

    - **Issue**: Several issues with intuitiveness
    - **Issue**: Uncertainty of which direction to go in a circular narrative/trail
    - **Issue**: Users did not have the initiative to pull up the bottom bar
    - **Issue**: Many users did not notice the "Unlock" button
    - **Issue**: Confusing lack of feedback for trail and narrative buffering

- **Improvement**: Asked for screen to stay awake
- **Improvement**: Requested fullscreen

3 SUS Results

Participant	Age	Experience w/ Similar App	SUS Score
1	18-30	Low	90
2	18-30	High	75
3	18-30	Low	82.5
4	18-30	Medium	75
5	51-60	High	87.5
6	18-30	Low	87.5
7	51-60	Medium	90
8	51-60	Medium	67.5
9	18-30	None	72.5
10	18-30	Low	92.5
11	18-30	Medium	72.5
12	41-50	Medium	67.5
13	41-50	Low	77.5
14	18-30	Medium	85
15	18-30	None	70
16	18-30	Low	82.5
Average			77.25
Std. Deviation			8.58

Table 1: SUS Scores with Age and Experience Level

Usability Testing Report - Phase 2

Kiara Ventura

The usability testing for Phase 2 was conducted with 6 users, all repeated from Phase 1. Since only new features were tested in this phase (and none of the ones previously tested in Phase 1), the pool of participants needed to involved users familiar with the platform.

1 Use Cases

The following use cases were designed to assess the various new added functionalities of the trails app. These use cases only take into account the new features, and not the ones tested in Phase 1.

1. Users can view points of interest (POI) on the map and filter them by categories.
2. Users can search for narratives.
3. Users can add and remove bookmarks for a trail or narrative and manage all their bookmarks.
4. Users can find narratives based on their categories.
5. Users can filter trails by distance, time, and other accessibility considerations (e.g., Joelette chairs).
6. Users can view a 3D preview of the map, and change the layer and pitch during the preview.
7. Users can download trails and narratives for offline use and manage their downloads.
8. Users can use the app offline, which includes:
    - Viewing downloaded trails and narratives.
    - Navigating downloaded trails and narratives.

9. While navigating a trail (online or offline, if downloaded), users can:
    - Ensure they're following the correct path.
    - Show or hide trail difficulty information (and its legend).
    - Show or hide details about the user's altitude and speed.
    - View alternate or intersecting trails and switch to them.
10. While navigating a narrative (online or offline, if downloaded), users can:
    - Unlock stops as they approach their location and view the respective text, image, or audio content.
    - Fast-forward, rewind, pause, resume, or view videos in *full screen*
11. Users can track their progress, which includes:
    - Viewing the trails they've started and marking them as complete.
    - Viewing narratives they've started, checking their completion percentage, and marking them as complete.
    - Removing trails or narratives from the list of those being tracked.
12. Users can resume previously started or completed narratives from the last unlocked stop *(Not tested)*
13. Users can view all previously unlocked stops when resuming a narrative *(Not tested)*

2 User Tasks

The following tasks were assigned to users during the second phase of usability testing. Their feedback and any issues noted during the task completion are also included.

1. In the map, view nearby lodging options and then check if any parks are available near trail "PR11 CVL – Porta da Estrela"
    - **Improvement:** Requests for other names for the categories
2. Search for the narrative "Risos no Rio Beijames" and add it to your favorites. Then, view all your bookmarked trails and narratives.
3. Find how many narratives are categorized under "Historico-Cultural"

4. Filter trails in Covilhã and Castelo Branco that have a maximum distance of 20km and include a Joelette chair.
    - **Issue:** Bugs detected with the interaction between the filtering system and the search bar
    - **Improvement:** Smaller phones had issues with filter sliders' size
5. Enter the first trail from the filtered results and view its 3D preview. Change the map layer while the animation is running.
6. Download the trail "Verdelhos e o Rio Beijames" and its associated narrative for offline use.
    - **Issue:** Not clear how to download a narrative
7. After the download finishes, enter navigation the trail "Trilho pelas Ruas Amarelas" and check its difficulty.
8. In the navigation view, display your current altitude and speed.
9. Switch to an intersecting trail from the navigation view.
    - **Issue:** Lack of loading feedback when selecting an intersecting trail left users confused whether the new trail was loading or not
10. View the trails you've already started and mark the first one as complete. Start monitoring the associated narrative and remove one of the trails being tracked.

3 Untested Functionalities

Although tasks were designed to test certain new functionalities related to narrative navigation and progress tracking, these features were deferred to the third phase due to their reliance on real-world navigation scenarios. These functionalities include:

- Offline Navigation
- Resuming previously started or completed narratives from the last unlocked stop.
- Viewing previously unlocked stops when resuming a narrative.

Usability Testing Report - Phase 3

Kiara Ventura

Phase 3 of the usability testing involved 21 participants, 8 of whom had participated in previous phases, while the remaining 13 were new. This phase introduced only two additional functionalities: the ability for users to change the app's language and a new button that shows the direction to a trail's start point, and served as an overall evalutation of the entire platform. The testing also included the System Usability Scale (SUS).

1 Use Cases

1.1 Language & Map

1. Users can change the app's language to their preferred language (EN, ES, or PT).
2. Users can navigate through map controls and layers.
3. Users can see points of interest (POIs) on the map and filter them according to categories.
4. Users can easily differentiate between map markers and narrative markers.
5. Users can view basic trail information directly from the map.
6. Users can search for trails using the map.
7. Users can navigate from the map to a trail or narrative's detail page.
8. Users can move through different tabs in the app and understand the content shown on each tab.

1.2 Trails

9. Users can filter trails by district, municipality, distance, time, elevation, presence of narratives, and accessibility features.
10. Users can search for trails.
11. Users can view basic trail information such as distance, time, and elevation.
12. Users can view a trail's elevation profile on the map, trail page, or during navigation.
13. Users can understand and manipulate the elevation graph.
14. Users can navigate to a trail from their current location using an external app.
15. Users can see accessibility information for a trail.
16. Users can view trails in 3D mode on the map.
17. Users can change the layer of the 3D map and see an animated preview of the trail path.
18. Users can find trails on the map starting from the trail page.
19. Users can view weather information for a specific trail.
20. Users can view terrain types and difficulty information for different trail sections.
21. Users can check if a trail has a narrative and navigate to that narrative's page.

1.3 Narratives

22. Users can search for narratives.
23. Users can filter narratives by their categories.
24. Users can view detailed narrative information, including the number of stops, estimated time, and distance.
25. Users can view a narrative's trail on the map and navigate to its page.

1.4 Bookmarks

26. Users can bookmark trails and narratives.
27. Users can remove bookmarks.
28. Users can view all their bookmarked items.

1.5 Downloads & Offline

29. Users can download a trail (and its narrative if applicable) for offline use.
30. Users can remove their downloaded content.
31. Users can view all their downloaded trails and narratives.
32. Users can use the app in offline mode.
33. Users can manage their downloads and view trail/narrative details while offline.
34. Users can navigate downloaded trails and narratives while offline.

1.6 Navigation

35. Users can navigate a trail or narrative (both online and offline).

During navigation (trails and narratives):

1. Users can confirm whether they are following the correct path.
2. Users can toggle the visibility of trail difficulty information.
3. Users can toggle the visibility of altitude and speed information.

During navigation (trails only):

1. Users can switch to alternate or intersecting trails during navigation.

During navigation (narratives only):

1. Users can unlock stops as they approach, revealing text, images, videos, or audio content.
2. Users can fast-forward, rewind, pause, and resume video/audio content.
3. Users can view videos in fullscreen mode.

1.7 Progress Tracking

4. Users can track their progress by viewing trails they've started and mark them as complete.
5. Users can view narratives they've started, check their completion percentage, and mark them as complete.
6. Users can remove trails or narratives from their progress tracking list.
7. Users can resume previously started narratives from the last unlocked stop.
8. Users can view all previously unlocked stops when resuming a narrative.

2 User Tasks

During Phase 3, users were assigned a series of tasks to evaluate their interaction with the app and its new functionalities. Below is a list of the tasks assigned to the users, along with any feedback or issues noted during the task execution.

It should be noted that trail names used in the tasks were not always the same for all participants, since different users often had to navigate different trails.

1. Set the app to your preferred language (EN, ES, or PT).
2. Switch the map layer to "Satellite" and zoom out to see the whole country. Then, switch back to the base layer and center the map on your current location.
3. View lodging options near your location (POI). Then, check if there are any nearby parks.

4. On the map, check the distance of a trail without a narrative, followed by a trail that has a narrative.
5. Check how many trails are near you and how many narratives are available overall.
6. On the map, view the difficulty level of the trail “Verdelhos e o Rio Beijames” and check how many sections have different difficulty levels.
7. View the minimum and maximum elevation of the trail “Verdelhos e o Rio Beijames.”
8. Check the approximate altitude halfway through the trail.
9. View the 3D map of the trail “Verdelhos e o Rio Beijames” and change the map layer.
10. Check the type of terrain in the section marked as "Moderate" and verify if it is accessible by wheelchair.
11. Add the trail “Verdelhos e o Rio Beijames” to your favorites.
12. Filter trails in Covilhã and Castelo Branco that are under 20km in length and have a Joelette chair available.
13. Find how many narratives are classified as “Historical-Cultural.”
14. Check the weather forecast for the trail “Caminho pelo Montijo” in two days at 13:00.
15. Check if the trail “Caminho pelo Montijo” has signs with Braille language.
16. Locate the trail “Caminho pelo Montijo” on the map.
17. On the map, view the stops of the narrative associated with the trail “Caminho pelo Montijo.”
18. Check which narrative is associated with the trail “Caminho pelo Montijo” and its expected duration.
19. Download the trail and narrative for “Caminho pelo Montijo” for offline use.
20. Enter your first bookmarked trail and start its navigation. In the navigation view, show your current altitude and speed and check the difficulty of the trail sections.

21. Remove this trail from your favorites.

22. View the trails you've already started and mark the first one as complete. Add the associated narrative to your progress tracking list.

23. Check how to get to the trail "Caminho pelo Montijo" from your current location using an external app and follow the route to get there.

24. Start navigating the trail and, on the map, switch to an intersecting trail when you approach its intersection.

25. Disconnect your phone from the internet and navigate the downloaded narrative.

26. Follow the trail and go through the steps of the narrative. During the process:

    - Fast-forward, rewind, and pause any videos or audios encountered, or watch the video in fullscreen.

27. During Stop 2, close the app, enter it again, and then resume the narrative from where you left off.

28. After finishing the narrative, check its completion percentage and stop tracking the trail "Verdelhos e o Rio Beijames."

29. Remove the trail "Caminho pelo Montijo" from your downloads.

(SUS Results in next page)

3 SUS Results

Participant	Age	Experience Level	Previous Testing Phases	SUS Score
1	18-30	Low	All Phases	100
2	18-30	High	All Phases	97.5
3	18-30	Low	All Phases	85
4	18-30	Medium	All Phases	90
5	51-60	High	All Phases	100
6	18-30	Low	1 Phase	87.5
7	51-60	Medium	1 Phase	92.5
8	51-60	Medium	1 Phase	95
9	41-50	None	-	87.5
10	18-30	Medium	-	100
11	18-30	Low	-	77.5
12	18-30	Medium	-	90
13	18-30	Low	-	95
14	41-50	None	-	90
15	31-40	None	-	80
16	18-30	Low	-	95
17	18-30	Low	-	97.5
18	51-60	High	-	97.5
19	18-30	Low	-	100
20	>60	None	-	82.5
21	31-40	Low	-	90
Average				91.90
Std. Deviation				6.63

Table 1: SUS Scores with Age, Experience Level, and Previous Testing Participation, ordered to show repeat participants first

G

Usability Questionnaire - Phase 1

Questionário de Usabilidade - Fase 1

Obrigado por participar nos testes.
Por favor, responda às seguintes perguntas sobre a sua experiência.

Informações sobre os seus direitos e privacidade:

- **Confidencialidade:** As suas respostas serão mantidas confidenciais e usadas apenas para fins estatísticos e para melhorar a plataforma. Os seus dados são completamente anonimizados.
- **Participação Voluntária:** A participação neste questionário é completamente voluntária. Pode optar por parar o questionário a qualquer momento.
- **Direito de Acesso:** Tem o direito de aceder aos dados recolhidos. Se desejar rever ou eliminar os seus dados, por favor contacte-me através do email kv.silva@campus.fct.unl.pt.

* Indica uma pergunta obrigatória

1. Idade *

Marcar apenas uma oval.

- ◯ <18
- ◯ 18-30
- ◯ 31-40
- ◯ 41-50
- ◯ 51-60
- ◯ >60
- ◯ Prefiro não responder

2. Qual a sua experiência com aplicações deste género? *

Marcar apenas uma oval.

- ◯ Nenhuma
- ◯ Pouca
- ◯ Média
- ◯ Elevada

3. Diga qual foi a facilidade das seguintes tarefas: *

1 = Pouco intuitivo 5 = Muito intuitivo

Marcar apenas uma oval por linha.

	1	2	3	4	5	N/A
Interagir com o mapa						
Distinguir entre os markers de trilhos e de narrativas						
Ver o caminho do trilho no mapa						
Pesquisar um trilho						
Aceder a informação sobre o trilho						
Aceder a informação sobre a narrativa						
Aceder a Informação de dificuldade / tipo de terreno						
Aceder a Informação Acessibilidade						
Aceder a Informação Metereológica						
Mexer no gráfico de Altitude						
Visualização 3D						
Navegação						
Navegação Narrativa						
Interação com vídeo/áudio						

4. Na aplicação, o quão intuitivo acha que é aceder à informação que se procura? *

Marcar apenas uma oval.

	1	2	3	4	5	
Pou						Muito Intuitivo

5. Achou as informações fornecida sobre o trilho úteis? *

Marcar apenas uma oval.

- ◯ Sim
- ◯ Sim, mas insuficientes
- ◯ Não

6. Se respondeu 'Sim, mas insuficiente', que informação adicional adicionaria?

7. Sente que as informações de acessibilidade são adequadas? *

Marcar apenas uma oval.

- ◯ Sim
- ◯ Sim, mas insuficientes
- ◯ Não

8. Se respondeu "Sim, mas insuficiente", que informação de acessibilidade adicional sugeria?

9. Como avalia o design / estética da aplicação *

Marcar apenas uma oval.

	1	2	3	4	5	
Pés	◯	◯	◯	◯	◯	Excelente

10. O que gostou menos?
(sem medo de me ferir os sentimentos!)

11. O que gostou mais?

12. Algumas sugestões?

Este conteúdo não foi criado nem aprovado pela Google.

Google Formulários

H

Usability Questionnaire - Phase 2

Questionário de Usabilidade - Fase 2

Obrigado por participar nos testes.
Por favor, responda às seguintes perguntas sobre a sua experiência.

Informações sobre os seus direitos e privacidade:

- **Confidencialidade:**
  As suas respostas serão mantidas confidenciais e usadas apenas para fins estatísticos e para melhorar a plataforma. Os seus dados são completamente anonimizados.
- **Participação Voluntária:** A participação neste questionário é completamente voluntária. Pode optar por parar o questionário a qualquer momento.
- **Direito de Acesso:**
  Tem o direito de aceder aos dados recolhidos. Se desejar rever ou eliminar os seus dados, por favor contacte-me através do email kv.silva@campus.fct.unl.pt.

* Indica uma pergunta obrigatória

1. Idade *

   Marcar apenas uma oval.

   - ◯ <18
   - ◯ 18-30
   - ◯ 31-40
   - ◯ 41-50
   - ◯ 51-60
   - ◯ >60
   - ◯ Prefiro não responder

2. Qual a sua experiência com aplicações deste género? *

   Marcar apenas uma oval.

   - ◯ Nenhuma
   - ◯ Pouca
   - ◯ Média
   - ◯ Elevada

3. Participou na fase anterior de testes? *

   Marcar apenas uma oval.

   - ◯ Sim
   - ◯ Não

4. Diga qual foi a facilidade nas seguintes tarefas (Introduzidas na 2ª fase): *

1 = Pouco intuitivo 5 = Muito intuitivo

Marcar apenas uma oval por linha.

	1	2	3	4	5	N/A
Ver pontos de interesse no mapa						
Filtrar trilhos						
Ver categorias das narrativas						
Adicionar e gerir Favoritos						
Adicionar e gerir Downloads						
Funcionamento offline						
Navegação: ver informações do trilho (dificuldade, altitude, velocidade, etc)						
Navegação: mudar para um trilho intersectante						

5. Na aplicação, o quão intuitivo acha que é aceder à informação que se procura? *

Marcar apenas uma oval.

	1	2	3	4	5	
Pou						Muito Intuitivo

6. Achou as informações fornecida sobre o trilho úteis? *

Marcar apenas uma oval.

- Sim
- Sim, mas insuficientes
- Não

7. Se respondeu 'Sim, mas insuficiente', que informação adicional adicionaria?

8. Sente que as informações de acessibilidade são adequadas? *

Marcar apenas uma oval.

- ◯ Sim
- ◯ Sim, mas insuficientes
- ◯ Não

9. Se respondeu "Sim, mas insuficiente", que informação de acessibilidade adicional sugeria?

10. Como avalia o design / estética da aplicação *

Marcar apenas uma oval.

	1	2	3	4	5	
Pés	◯	◯	◯	◯	◯	Excelente

11. O que gostou menos?
(sem medo de me ferir os sentimentos)

12. O que gostou mais?

13. Algumas sugestões?

Este conteúdo não foi criado nem aprovado pela Google.

I

Usability Questionnaire - Phase 3

Questionário de Usabilidade - Fase 3

Obrigado por participar nos testes.
Por favor, responda às seguintes perguntas sobre a sua experiência.

Informações sobre os seus direitos e privacidade:

- **Confidencialidade:**
  As suas respostas serão mantidas confidenciais e usadas apenas para fins estatísticos e para melhorar a plataforma. Os seus dados são completamente anonimizados.
- **Participação Voluntária:** A participação neste questionário é completamente voluntária. Pode optar por parar o questionário a qualquer momento.
- **Direito de Acesso:**
  Tem o direito de aceder aos dados recolhidos. Se desejar rever ou eliminar os seus dados, por favor contacte-me através do email kv.silva@campus.fct.unl.pt.

* Indica uma pergunta obrigatória

1. Idade *

   Marcar apenas uma oval.

   - ◯ <18
   - ◯ 18-30
   - ◯ 31-40
   - ◯ 41-50
   - ◯ 51-60
   - ◯ >60
   - ◯ Prefiro não responder

2. Qual a sua experiência com aplicações deste género? *

   Marcar apenas uma oval.

   - ◯ Nenhuma
   - ◯ Pouca
   - ◯ Média
   - ◯ Elevada

3. Participou em algumas das fases anteriores de testes? *

   Marcar apenas uma oval.

   - ◯ Sim, uma fase
   - ◯ Sim, duas fases
   - ◯ Não

4. Diga qual foi a facilidade nas seguintes tarefas (Introduzidas na 1ª fase de testes): *

1 = Pouco intuitivo 5 = Muito intuitivo

Marcar apenas uma oval por linha.

	1	2	3	4	5	N/A
Interagir com o mapa						
Distinguir entre os markers de trilhos e de narrativas						
Ver o caminho do trilho no mapa						
Pesquisar um trilho						
Aceder a informação sobre o trilho						
Aceder a informação sobre a narrativa						
Aceder a Informação de dificuldade / tipo de terreno						
Aceder a Informação Acessibilidade						
Aceder a Informação Metereológica						
Mexer no gráfico de Altitude						
Visualização 3D						
Navegação						
Navegação Narrativa						
Interação com vídeo/áudio						

5. Diga qual foi a facilidade nas seguintes tarefas (Introduzidas na 2ª fase): *

1 = Pouco intuitivo 5 = Muito intuitivo

Marcar apenas uma oval por linha.

	1	2	3	4	5	N/A
Ver pontos de interesse no mapa						
Filtrar trilhos						
Ver categorias das narrativas						
Adicionar e gerir Favoritos						
Adicionar e gerir Downloads						
Funcionamento offline						
Navegação: ver informações do trilho (dificuldade, altitude, velocidade, etc)						
Navegação: mudar para um trilho intersectante						

6. Diga qual foi a facilidade das seguintes tarefas (Introduzidas nesta 3ª fase): *

1 = Pouco intuitivo 5 = Muito intuitivo

Marcar apenas uma oval por linha.

	1	2	3	4	5	N/A
Mudança de linguagem da aplicação						
Encontrar direções para chegar ao trilho						

7. Na aplicação, o quão intuitivo acha que é aceder à informação que se procura? *

Marcar apenas uma oval.

	1	2	3	4	5	
Pou						Muito Intuitivo

8. Achou as informações fornecida sobre o trilho úteis? *

Marcar apenas uma oval.

- Sim
- Sim, mas insuficientes
- Não

9. Se respondeu 'Sim, mas insuficiente', que informação adicional adicionaria?

10. Sente que as informações de acessibilidade são adequadas? *

Marcar apenas uma oval.

- Sim
- Sim, mas insuficientes
- Não

11. Se respondeu "Sim, mas insuficiente", que informação de acessibilidade adicional sugeria?

12. Como avalia o design / estética da aplicação *

Marcar apenas uma oval.

	1	2	3	4	5	
Pés						Excelente

13. O que gostou menos?
(sem medo de me ferir os sentimentos)

14. O que gostou mais?

15. Algumas sugestões?

Este conteúdo não foi criado nem aprovado pela Google.

Google Formulários

J

SUS Questionnaire

Questionário de SUS

1. 1. Acho que gostaria de utilizar este produto com frequência

   Marcar apenas uma oval.

	1	2	3	4	5	
Disc	◯	◯	◯	◯	◯	Concordo Totalmente

2. 2. Considerei o produto mais complexo do que necessário

   Marcar apenas uma oval.

	1	2	3	4	5	
Disc	◯	◯	◯	◯	◯	Concordo Totalmente

3. 3. Achei o produto fácil de utilizar

   Marcar apenas uma oval.

	1	2	3	4	5	
Disc	◯	◯	◯	◯	◯	Concordo Totalmente

4. 4. Acho que necessitaria de ajuda de um técnico para conseguir utilizar este produto

   Marcar apenas uma oval.

	1	2	3	4	5	
Disc	◯	◯	◯	◯	◯	Concordo Totalmente

5. 5. Considerei que as várias funcionalidades deste produto estavam bem integradas

   Marcar apenas uma oval.

	1	2	3	4	5	
Disc	◯	◯	◯	◯	◯	Concordo Totalmente

6. 6. Achei que este produto tinha muitas inconsistências

   Marcar apenas uma oval.

	1	2	3	4	5	
Disc	◯	◯	◯	◯	◯	Concordo Totalmente

7. 7. Suponho que a maioria das pessoas aprenderia a utilizar rapidamente este produto

Marcar apenas uma oval.

	1	2	3	4	5	
Disc	◯	◯	◯	◯	◯	Concordo Totalmente

8. 8. Considerei o produto muito complicado de utilizar

Marcar apenas uma oval.

	1	2	3	4	5	
Disc	◯	◯	◯	◯	◯	Concordo Totalmente

9. 9. Senti-me confiante a usar o sistema

Marcar apenas uma oval.

	1	2	3	4	5	
Disc	◯	◯	◯	◯	◯	Concordo Totalmente

10. 10. Tive que aprender muito antes de conseguir lidar com este produto

Marcar apenas uma oval.

	1	2	3	4	5	
Disc	◯	◯	◯	◯	◯	Concordo Totalmente

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Trail Characterization Guidelines

Trail Characterization Guidelines

1 INTRODUCTION

This document provides guidelines for collecting various trail information (in accordance to the standards of the OGC) and the information necessary for the creation of trail narratives. When collecting this data, it is asked that users consider not only the trail's physical attributes but also its accessibility features across different segments

2 CLASSIFICATION

To accurately classify a trail, it is essential to consider both the trail's characteristics and its surrounding environment.

2.1 Metrics

Currently, there are two main types of metrics through which to evaluate and classify a trail: the proposal outlined in ISO 3021:2023 (*Adventure tourism — Hiking and trekking activities — Requirements and recommendations*), and the approach presented on the *Walk Hike Portugal* website[1]. However, the system is also designed to accommodate other classification methods.

2.1.1 ISO 3021:2023 (Adventure tourism — Hiking and trekking activities — Requirements and recommendations). This metric is composed by four distinct values:

- Severity of the environment
- Route navigation orientation
- Terrain conditions
- Physical exertion

The first step in classifying a trail using this metric is to divide it into segments with similar characteristics. Subsequently, the final classification of the route is determined by using the highest value for each parameter from the segments.

Severity of the environment

To calculate the "severity of the environment" parameter, start by counting the number of factors that occurred. Each factor is counted once as a cumulative number of occurrences. It has nothing to do with probabilities. As the example below shows, you can bring a checklist with all the factors to make it easier.

- ☐ Expose to spontaneous detachments of stones.
- ☐ Expose to detachment of rocks caused by the group itself or others.
- ☐ Falling into a crevasse or down a steep slope.
- ☐ Existence of a passage where the use of hands is necessary to progress.
- ☐ Exposure to sections that are permanently slippery, rocky or flooded.
- ☐ Exposure to slippery or flood stretches due to rain.
- ☐ Crossing rivers or other bodies of water with a current by fording (without a bridge).
- ☐ High probability of heavy or continuous rainfall.
- ☐ High probability that at night, the temperature will drop below 0° C.
- ☐ High probability that the temperature will fall below 5° C and relative humidity will exceed 90
- ☐ High likelihood of exposure to strong or cold winds.
- ☐ High probability that the relative humidity will be less than 30
- ☐ High probability of heat exposure at temperatures above 32° C.
- ☐ Long stretches of high sun exposure.
- ☐ Total activity time of 1 hour or more of hiking and trekking without passing an inhabited place, a distress telephone (or cell phone signal or radio) or an open road with traffic.
- ☐ Total activity time of 3 hours or more of hiking and trekking without passing an inhabited place, a distress telephone (or cell phone signal or radio) or an open road with traffic.
- ☐ The difference between the time required to complete the route and the number of daylight hours remaining at the end of the day is less than 3 hours.
- ☐ Decreasing visibility due to atmospheric phenomena that considerably increases the difficulty of orientation or locating people.
- ☐ Route through dense vegetation or uneven terrain that makes it difficult to orientate or to locate people.
- ☐ Region or sections without access to drinking water.

The table below will convert the number of occurrences to the parameter's value.

Number of occurrences	Level	Name
3 or less	1	Low Severity
4 or 5	2	Moderately Severe
6 to 8	3	Severe
9 to 12	4	Quite Severe
13 or more	5	Very Severe

Route navigation orientation

In order to calculate the value for "Route navigation orientation", it is crucial to grasp the conversion process. While walking along the trail, take note of:

- signalling
- definition of intersections
- awareness of the path to follow

The list below will convert the perception of these three characteristics to the parameter's value.

- **Level 1 – Well-defined or signposted paths and intersections** - Well-marked or signposted main paths, with clear intersections with explicit or implicit indication. Staying on the path requires no exertion to identify the path. It might be necessary to follow a line marked by an unmissable land form (ex.: beach or lake shore).
- **Level 2 – Paths or signposts indicating continuity** – There is a clear path layout over the terrain, or signage indicating the continuity of the route. This path demands attention to both its continuity and its intersections with other paths.This condition typically applies to signposted

[1] https://www.portugalwalkhike.com/

paths that incorporate various types of trails, featuring multiple intersections along the same route - whether they are roads, pedestrian trails, riding paths, or well-maintained fields.

- **Level 3 – Requires identification of land forms and cardinal points** – Even if the itinerary develops via a trail, trails are marked by geographic features (e.g. rivers, valley bottoms, coasts, ridges) or other people's crossing marks. The choice of the appropriate route depends on the recognition of geographic features and cardinal points.
- **Level 4 – Requires off-track navigation skills** – There is no path over the terrain, no security of having landmarks on the horizon. The itinerary depends on an understanding of the terrain and route design.
- **Level 5 – Requires navigation to use previously unknown alternative routes** – The route depends on an understanding of the terrain and route layout, and requires navigation ability to complete it. Itinerary direction can be unexpectedly interrupted by obstacles that need to be circumvented.

Terrain conditions

To calculate terrain conditions, we should also take note of the following factors while walking along the trail:

- type of surface
- inclinations on the trail
- obstacles along the trail

The list below will convert the perception of these three characteristics to the parameter's value.

- **Level 1 – Route on flat surfaces** – Roads and tracks for vehicles, regardless of their elevation. Paths with steps on flat and regular ground. Beaches (sand or gravel) with level and firm ground.
- **Level 2 – Route though paths without obstacles** – Paths through diverse terrain that maintains the regularity of the ground, and are well-marked. Trails that do not have steep slopes or obstacles that require great physical exertion to overcome. Routes across uniform terrain, such as sloping fields and postures.
- **Level 3 – Route on staggered trails or uneven terrain** – Route along trails with uneven obstacles or steps of different sizes, heights, and inclinations. Off-track and uneven terrain. Crossing of rocky or outcropped areas (stone slabs). Loose rock stretches, unstable quarries, heavily exposed roots, sand, or erosion.
- **Level 4 – Route with obstacles** – Obstacles route that require jumping or the use of hands up to grade I SUP [2].
  - **Grade I** – It is the easiest kind of scramble. Frequent use of hands is required to support balance and hand and footholds must be trusted.
- **Level 5 – Route requiring vertical techniques** – Segments requiring climbing techniques from grades II and III SUP. Requires the use of specific equipment and techniques.
  - **Grade II** – Climbing that requires the movement of a limb at a time and a proper setting of the movements. Holds and supports are still abundant.
  - **Grade III** – The rock structure, already more steep or even vertical, rarely offers holds or supports, and can already require the use of force.

[2]International Climbing and Mountaineering Federation (UIAA) grading for climbing or vertical progression

Physical exertion

To calculate the physical exertion required by a trail, we need to determine which sections have similar characteristics, and then perform a series of calculations using the following formulas:

$$T_h = \frac{D_p}{V_h}$$

T_h = horizontal displacement time

D_p = distance travelled on the path

V_h = average horizontal velocity

$$T_u = \frac{G}{V_u}$$

T_u = time going uphill

G = gap

V_u = vertical velocity uphill

$$T_d = \frac{D}{V_d}$$

T_d = time going downhill

D = distance travelled on the path

V_d = vertical velocity downhill

When calculating the exertion index we must take into account the average velocity:

- In easy paving (roads and slopes): 4 km/h
- Moderate paving (trails, smooth paths, meadows) : 3 km/h
- In difficult paving (ungroomed, stony paths, riverbeds): 2 km/h
- Uphill: 200 m/h
- Downhill: 300 m/h

After discovering the exertion index, we can convert it to the parameter's value using the table below.

Total time	Level	Name
less than 1h	1	Low Exertion
1h to 3h	2	Moderate Exertion
6h to 8h	3	Significant Exertion
9h to 12h	4	Intense Exertion
Over 13h	5	Extraordinary Exertion

2.1.2 Walk Hike Portugal. Using this metric instead of the ISO requires the analysis of only 4 characteristics of the trail:

- Distance
- Cumulative ascents and descents (Elevation)
- Rest periods
- Duration

This metric can also be applied by dividing the trail into sections. The final trail rating is determined based on the section that exhibits the highest difficulty value. From there, we can analyze the data and determine the corresponding difficulty level for this trail, as shown in the list below:

- **Level 1 - Very Easy** – Short Courses, 4-6km, with low cumulative ascents and descents. Duration between 2-3h with rest periods included.
- **Level 2 - Easy** - Paths of relative short distance, 5.5-7.5 km, with cumulative ascents and descents not exceeding 350m each. Duration between 4-6h with rest periods included.
- **Level 3 - Moderate** - Paths media to media / long distance, 7.5-12.5 km, with cumulative ascents and descents between 350m and 650m each. Duration between 4-6h with rest periods included.
- **Level 4 - Difficult** - Paths media / long distance, 7.5-12.5 km, with cumulative ascents and descents between 700m and 1,000 m for each. Duration around 6 hours with rest periods included, and sometimes in rugged terrain.
- **Level 5 - Very difficult** - Long distance routes, over 12km, with cumulative ascents and descents over 1,000m for each. Lasting more than 6 hours, often over rough terrain, or snow and ice.

2.2 Surface Type

In order to accurately classify a trail, it's important to understand the type of terrain present along its length. The surface type can be applied to the entire trail or specific segments of it. During the journey, choose one of the following surface types that best suits the trail or indicated segment:

2.2.1 Dirt/Forest Floor. Dirt or forest floor trails can vary from "cushion-y", narrow paths winding through spruce forests surrounded by roots or leaf-covered terrain. The condition of these trails depends on the soil type, and they may become muddy or wet after rain or during spring

Figure 1: Example Surface Dirt/Forest Floor

2.2.2 Boardwalk/Bog Bridging. Boardwalks are usually made from wooden boards, but can also be made from composite or plastic materials.

Figure 2: Example Surface Boardwalk/Bog Bridging

2.2.3 Gravel/Crushed Stone. Gravel and crushed stone are used to create a uniform trail surface. Compacted rock dust surfaces can harden sufficiently to allow various types of wheelchairs and strollers to travel over them.

Figure 3: Example Surface Gravel/Crushed Stone

2.2.4 Pavement. Usually the trails are paved with asphalt, but there are also brick and cement paths. Sometimes roots growing under the paved trail can create bumps that are hazardous to people using wheelchairs, strollers or other wheel-based mobility equipment.

Figure 4: Example Surface Pavement

2.2.5 Rock/Ledge. Ledge trails, typically found in mountainous regions, are rated as strenuous and advanced. However, it's worth noting that some easier coastal trails may also traverse ledges.

Figure 5: Example Surface Rock/Ledge

2.2.6 Woodchips. Wood chips create a more even surface on trails. They can vary greatly because, unlike gravel, they decompose over time.

2.2.7 Grass. Mowed trails through meadows, occasionally adorned with wildflowers. The grass height can vary tremendously depending on the mowing schedule.

Figure 6: Example Surface Woodchips

Figure 7: Example Surface Grass

2.2.8 Sand. Mostly along the coast, though some lakeside trails also go through sandy areas.

Figure 8: Example Surface Sand

2.2.9 Groomed Snow. Groomed trails provide a smooth surface on which to ski or bike. Many wider trails have a smooth section for skate skiing and two narrow grooves (i.e. tracks) for classic skiing.

Figure 9: Example Surface Groomed Snow

2.2.10 Ungroomed Snow. Ski trails that are not groomed.

3 NARRATIVES

Trail narratives are meant to *enhance* the hiking experience by providing context, fostering appreciation, and connecting visitors to the environment and its historical or cultural background. As such, several points need to be considered when designing a narrative for a trail:

3.1 Purpose and Research

The narratives can serve different purposes: they can educate hikers about the trail's history, geology, flora and fauna, or they can entertain by sharing local historical legends or cultural anecdotes.

Figure 10: Example Surface Ungroomed Snow

When designing a story for a trail, we need to understand the trail's context - whether it's a wilderness rich with wildlife, a site of great historical value, or simply a scenic coastal path will inform very differently the type of narrative we're attempting to build. The narratives are categorized into 5 distinct categories:

3.1.1 Historico-Cultural. - Narratives that recreate or delve into historical events and landmarks, as well as local cultural practices, traditions and legends. By sharing legends, myths, or tales associated with the trail, we can deepen visitors' understanding of the local culture, traditions and customs;

3.1.2 Environmental. - Narratives of a more educational nature, focusing on the biodiversity of the trail (flora, fauna, aquatic life), the different types of species in it and their ecological relationships with each other. This can foster greater appreciation for the environment;

3.1.3 Fictional Storytelling. - Stories mostly or entirely fictitious;

3.1.4 Trail Guidance. - Guides and information on the physical challenges of the trail, and how to traverse its more difficult paths;

3.1.5 Other. - Narratives that do not fit neatly into the other categories.

The historico-cultural category can often mix fictional elements as well, in order to engage the users in a story. For example, in a historical or cultural narrative we might invite hikers to "retrace" the steps of a soldier during a famous battle that occurred along the trail, or to immerse themselves in the life of a legendary local figure who once roamed that area. Whether this is classified under the *Historico-Cultural* or the *Fictional Storytelling* category will often vary based on individual users' perceptions.

It should be noted that not every trail necessitates the inclusion of a narrative, and often, shorter trails or those with minimal historical, cultural or scientific significance may not require extensive storytelling - fictional or otherwise.

3.2 Narrative Structure and Story Stops

The narrative is divided in several ordered *"Story Stops"* across the trail. However, before adding these stops, we should provide basic information of the narrative:

- **Main Image** - Image identifying the narrative or the story;
- **Title** - Name of the narrative;
- **Description** - Short description of the content of the narrative.

There is no need to input the approximate completion time as it is calculated based on the number of stops and the trail's expected duration.

Afterwards, the *"Story Stops"* should be defined, **less than 10** so the narrative is not overlong. When a user approaches a stop, the information specific to that point in the narrative is revealed, so the system only allows the stops to be **within the trail** path (or very close to it).

For these stops, identify key points along the trail. These could be specific landmarks, viewpoints, or historical sites. Then, provide the information below:

- **Title** - Name for the stop;
- **Text** - Textual description or information about that step in the narrative;
- **Coordinates** - Selected from a map, the coordinates for that stop. Must be within or close to the trail;
- **Image** *(optional)* - Not necessarily a photo from the location itself, but images which are relevant for the story (e.g. painting of a historical figure relevant to the narrative);
- **Audio** *(optional)* - Audio file about that stop;
- **Video** *(optional)* - Short video about that stop.

Even if there is audio or video, a textual description should be provided for accessibility considerations (e.g. a transcript of the audio).

3.2.1 ***Media Types***. The aforementioned stops can convey the narrative through various media formats, and it should be considered what would be the best ones for the narrative in question. The options are presented in the table below:

Text	Descriptive passages, Transcripts for other media types
Images	Photos, paintings, graphs Other illustrations
Audio	Narration, interviews, ambient sounds, audio recreations of events, audio guides;
Video	Visual footage of the wildlife, videos of historical events, interviews

Table 1: Examples of narrative's media types

4 ACCESSIBILITY

In order to ascertain the different needs of hikers according to their abilities, age and accessibility needs, various trail aspects need to be analyzed when traversing the trail. The more relevant ones are:

- **Surface type** - So users can be aware of the type of surface they're navigating on. Divided by trail sections;
- **Wheelchair Accessibility** - Referring to whether a segment of the trail is able to be traversed via wheelchair. Also divided by trail sections
- **Slope** - Altitude changes throughout the trail
- **Accessibility Features**:
  - **Trail Assistants** - personnel which is available to provide assistance of various types throughout the trail
  - **Joëlette Chair**[3] - if the trail provides Joëlette chairs or other types of specialized mobility equipment
  - **Braille Signage** - if the trail signs and plaques include braille for visually-impaired hikers
  - **Assistants fluent in sign language** - if any of the assistants are fluent in sign language to aid hearing-impaired users
  - **Rest Areas** - Availability of rest areas with seating for hikers who may need to take breaks
  - **Shade and Shelter** - Availability of sheltered areas to protect hikers from sun or other weather hazards
  - **Water Stations** - Availability of water stations along the trail
  - **Trailhead Accessibility** - The ease of accessing the start of the trail, and whether it is accessible via car or public transportation

Both the terrain type and wheelchair accessibility attributes of the trail are divided by trail sections, while the availability of accessibility features (joelette chair, trail assistants, etc.) is considered for the entire trail.

Some of these attributes, like surface type and elevation, are calculated and addressed within the context of trail classification, as detailed in Section 2.

[3] A Joëlette Chair is a one-wheeled chair designed to be used in rugged terrain, allowing people with mobility impairments to be transported by one or two assistants