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The Application of a User-Centered Design Framework to a Static Topographic Ski Touring Map

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Master thesis

The Application of a User-Centered Design Framework to a Static Topographic Ski Touring Map

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Statement of Authorship

Herewith I declare that I am the sole author of the submitted master's thesis entitled:

"The Application of a User-Centered Design Framework to a Static Topographic Ski Touring Map"

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

Dresden, 09.09.2022 Vivien L.E. van Dongen

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Abstract

This research fills the cartographic gap in ski touring maps with a new user-centered design (UCD) framework that links the ski tourers' needs and demands to a new map design. Ski touring is an activity where the recreationists ascend and descend the mountain outside the slopes of ski resorts. Ski tourers use maps for planning, navigating, and reflecting on ski tours. Static maps generally follow a traditional map production process, in which the user is considered but not involved (Darkes, 2017). This research incorporates two UCD approaches of Roth, Ross and MacEachren (2015) and Tsou and Curran (2008) into the production process, resulting in a new UCD framework that leads to a more tailored and user-central end product.

The developed approach was applied to create a ski touring map of the Schladming-Dachstein area (Steiermark, Austria). This new UCD framework involves (i) accommodating the needs and demands of the target group through an in-depth literature review, comparing existing ski touring maps and interviewing the target group; (ii) establishing the map's purpose and design considerations; (iii) designing the map itself; (iv) evaluating the map using a survey by ski tourers, and (v) finalizing the design tailored to the needs and demands for ski touring.

The final product of this research is a ski touring map design, where a user-centered design framework was successfully followed. The map design met the needs and demands of the ski tourers determined in this research. This research not only fills the niche market of ski touring maps but can also inspire other cartographers with step-to-step research on user-centered cartographic design for static maps.

Keywords: *static map production, user-centered design, ski touring*

Contents

CHAPTER 1

Introduction

1.1 Motivation and Problem Statement

1.1.1 Research Context

Every winter, approximately 700.000 outdoor recreationists in Austria are drawn to the mountains for ski touring (Östereichische Alpenverein, 2012). Ski touring is a winter activity where the recreationists ascend and descend the mountains outside the ski resorts. Ski tourers use maps to get an overview of the area, choose a specific tour, navigate during a tour, and reflect on the tour.

A major threat to ski tourers are snow avalanches. Around 100 people die in the Alps annually due to snow avalanches (Techel et al., 2016). In 94% of the cases that a snow avalanche occurs, the victims themselves or other outdoor recreationists triggered the avalanche (Rainer et al., 2008; Techel et al., 2016). An avalanche is more likely to occur if the slope is steeper than 30 degrees (Vontobel, Harvey & Purves, 2013). For ski tourers to be well prepared for avalanche risk, it is crucial that they have access to detailed and accurate maps and can determine where the areas are steeper than 30 degrees.

This research focuses on popular ski touring maps, which can be divided into two categories. The first category consists of topographic ski touring maps designed by National Mapping Agencies, which are time-consuming and cost-intensive. They are highly accurate and display all ski tour trails on the map. The other category contains the maps in guidebooks for ski touring. These maps are less time-consuming and cost-intensive to produce but do often not reach the same quality and accuracy as the topographic ski touring maps.

Even though ski touring is a popular sport, no research has been conducted on user-centered ski touring map design. This research was set out to produce a map design for ski touring maps following a user-centered design (UCD) framework.

The traditional static map production process does consider but does not involve the user during the process (Darkes, 2017). However, involving the user in an early stage is beneficial for the mapping process (Roth et al., 2015) and improves the quality of the web mapping applications (Tsou & Curran, 2008). Slocum, Sluter, Kessler and Yoder (2004) had a different approach and involved the user in a relatively late stage in the process, but they argue that interacting with the target user in an earlier phase would have been advantageous for the project. This research will therefore incorporate two UCD approaches of Roth et al. (2015) and Tsou and Curran (2008) in the static map production process and follow a new UCD framework to produce a user-centered map design for ski touring. To make this map design accessible and affordable to anyone, and in particular to creators of ski touring maps in guidebooks, solely open data will be used.

By developing a new UCD framework, this research contributes to the field of cartography by providing cartographers with a rigor, thorough and cost-efficient approach to incorporate user experiences in the production of static maps. By applying this UCD framework to the ski touring map production, it fills the niche market of user-centered ski touring maps.

1.2 Research Objective

The main research objective is to create a user-centered ski touring map design following a UCD framework, solely using open data. This research objective can be split up into the three following objectives:

RO 1 Examining the needs and demands of ski tourers for ski touring maps.

RO 2 Applying a user-centered framework to a ski touring map design using open data.

RO 3 User testing the new map design in terms of map use in order to fulfill the user-centered framework.

1.2.1 Research Questions

To fulfill the research objectives, the following research questions need to be answered:

RQ 1 What are the needs and demands of ski tourers for ski touring maps?

- **RQ 1.1** What is the current use of a ski touring map?
- **RQ 1.2** Which map attributes are currently present in ski touring maps?
- **RQ 1.3** Which map elements are most important to serve the goal of a ski touring map?

RQ 2 Can a user-centered framework be successfully applied to a user-centered production?

- **RQ 2.1** Can it use open data solely?

RQ 3 Does this map design meet the needs and demands of ski tourers?

- **RQ 3.1** Did new needs and demands come to light during the user study?

1.3 Structure of the research

This research is divided into nine chapters. This introduction chapter is followed by the theoretical background, which contains in-depth literature research and provides a better understanding of ski touring, cartographic production and Volunteered Geographic Information.

The next chapter discusses different UCD approaches and the new UCD framework will be shaped. The following five chapters cover the five phases of this UCD framework, in which the target users and their needs and demands are determined, and the map design is created, evaluated, and improved.

This research's last chapter is the conclusion, where the research questions are answered, and the limitations of this research and potential future research are discussed.

CHAPTER 2

Theoretical background

2.1 Ski touring

There are three subcategories to skiing. The first one, the most well-known one, is front-country skiing. The skier stays within the ski resort's boundaries and has access to the lifts and emergency services of the ski resort. The second is side-country skiing, where the skier still uses the lifts of the ski resort but will not limit themselves to the ski slopes by going off-piste. The third is back-country or alpine ski touring, also called ski mountaineering, and from now on, called ski touring. While ski touring, the skier only tours outside the boundaries of ski resorts (Mueller et al., 2019). The best explanation of ski touring might come from Arnold Lunn, The Alpine Ski Club founder in the United Kingdom. He once wrote at the beginning of the twentieth century:

> "Ski mountaineering [sic] is the result of the marriage between two great sports, mountaineering and skiing" (Volken, Schell & Wheeler, 2007).

Ski touring is an activity that involves not only skiing downhill but also climbing uphill with the skies tied to your feet(Bortolan et al., 2021). Ascending the slope uphill with skies is possible because of special equipment. Anti-slipping skins can be attached to the skis, which ensures that the skis do not slip on snow, making it possible to ski up the hill (Bortolan et al., 2021; Mueller et al., 2019). The ski bindings do also differ from the binding used in front-country skiing. The heel can move freely up and down in the binding for ski touring, while the heel is stationary in the binding for front country skiing (Mueller et al., 2019).

2.1.1 A history of ski touring

Skiing has been a human occupation with a long history, for at least 7000 years. Cave drawings have been found in Norway and Sweden from around 5000 B.C. (Martinescu-Bădălan & Stănciulescu, 2019). Using skis, humans were helped in food gathering and hunting. The oldest pair of skis found date from 2500 B.C, in a swamp in current Sweden (Martinescu-Bădălan & Stănciulescu, 2019; Street, 1992). For a long time, skis were made of wood, and fur was attached to the bottom for resistance. While skis were initially used for hunting, food gathering, and later on for wars, at the end of the 19th century, skiing became a leisure activity for the elite (Denning, 2015). As the ski lifts were only invented between the first and second world wars, skiers had to ascend the hills without external help up until then. Only after the second world war more ski resorts opened, and front-country skiing became a better accessible activity in Europe Denning (2015). However, even with the availability of ski lifts, many still prefer ski touring over front country skiing. In Austria alone, the Östereichische Alpenverein (2012) estimates that there are 700.000 ski tourers.

2.1.2 Ski touring maps

Ski touring maps are used to visualize ski tour trails in the area. Popular ski tour maps can be categorized into topographic ski touring maps and ski tour maps in ski tour guidebooks.

Topographic ski touring maps

The first kind of available maps are the topographic ski touring maps. They are often made by National Mapping Agencies or other official mapping institutions. Examples of these maps can be seen in Appendix A. These agencies have the resources to collect their data and design accurate and detailed maps. The maps cover a large area, with all possible ski touring trails.

Ski tour guidebook maps

Besides the topographic maps, there are also maps in ski tour guidebooks. Examples of these maps can be seen in Appendix A. Those guidebooks typically contain descriptions of routes accompanied by a smaller map with one or a few routes. The cartographic style of these maps is very diverse. They can be topographic, sketched, panoramic, orthoimagery, or more. Smaller publishers often make these guidebooks. Unlike the National Mapping Agencies, the guidebook publishers do not have decades of experience with map making nor the resources for extensive data collection.

2.1.3 GPS for ski touring

New technology allows ski tourers to bring a GPS device for navigation during ski touring. The advantage of carrying a GPS device is that it can indicate position, give bearing and distance to the target point, and record the route. On the other hand, several risks and downsides come with using GPS devices for ski touring navigation. First, the small screen size of devices reduces both the navigation skills of the user, as well as their spatial understanding of their surroundings (Chae & Kim, 2004). Having spatial understanding while ski touring is essential for assessing avalanche risk and re-planning the route in case of unforeseeable circumstances. Second, GPS devices can suffer from technical failures, such as lost connectivity and battery drains due to low temperatures. Lastly, there are some practical downsides of using GPS devices during ski touring. For instance, it can be challenging to operate a GPS device with gloves, and the sun's reflection can make it significantly challenging to read the screen.

2.1.4 Navigation during ski touring

Navigating is an essential part of ski touring. In general, human navigation can be split into two elements: locomotion and wayfinding Montello (2005). Locomotion is the element of human movement, where humans must take their surroundings into account to move safely. This can either be by walking, running, in a car, or on tour skis. Wayfinding is about solving "behavioral problems involving explicit planning and decision making – problems such as choosing routes to take, moving toward distal landmarks, creating shortcuts, and scheduling trips and trip sequences" (Montello, 2005, p. 259). Wayfinding is very important for ski tourers, as they have to make impromptu decisions during their route and assess avalanche risks from the map and the current state of the terrain. This can also involve changing their route drastically. How ski tourers find their way was researched.

Ski tourers frequently rely on landforms like summits, hollows, valleys, and slopes to find their way in the mountains (Rehrl & Leitinger, 2008). However, which landmarks are used for navigation differs from summer to winter. For instance, Kettunen, Irvankoski, Krause and Sarjakoski (2013) and Kettunen and Sarjakoski (2015) show that landforms are more prominent navigation landmarks in the winter, as these are more visible due to the snow cover. Other landmarks, such as passages and roads, are significantly less important in winter navigation, as these are invisible due to the snow.

2.1.5 Avalanche risk

Avalanches are a considerable risk during ski touring: around 100 people die in the Alps annually due to snow avalanches, of which a large share are tour skiers and off-piste skiers (Techel et al., 2016). A good ski touring map should aim to aid ski tourers in assessing avalanche risk.

Four factors play a role in the cause of avalanches, which can be seen in Figure 2.1.

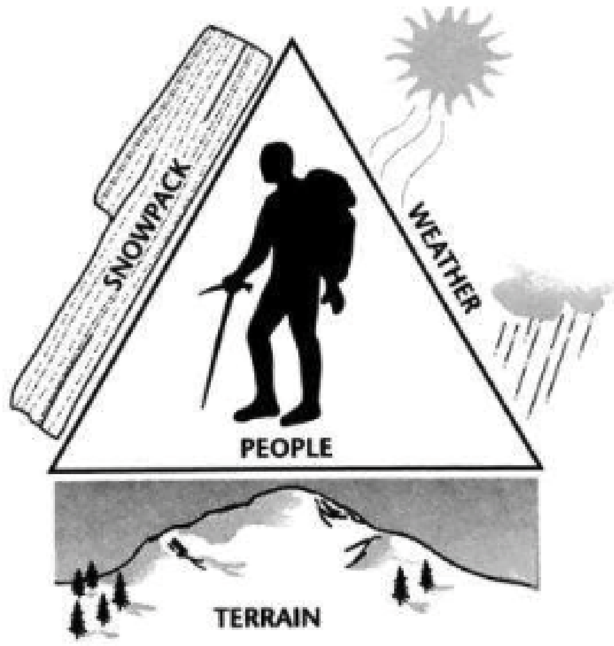

Figure 2.1: The triangle of factors that can cause snow avalanches (Fredston & Fesler, 1994)

The first factor is the human factor, namely the behavior of outdoor recreationists. In 94% of the cases that a snow avalanche occurs, the victims themselves or other outdoor recreationists triggered the avalanche (Rainer et al., 2008; Techel et al., 2016). Ski tourers should be aware of avalanche risks and be able to assess the risks, and take precautions to prevent avalanches.

The other factors are geographical. Weather conditions like rain, fresh snow, and hail influence the avalanche risk, as well as heavy winds, air temperature, and sun exposure (Techel et al., 2016; Tremper, 2008). The second geographical factor is the snowpack. Depending on how the snowpack is build-up, the avalanche risk can increase. Because these factors are dynamic, it is impossible to map the snowpack and heavy wind on a static map.

Unlike the first two geographical factors, the third factor, terrain does not change over time and space. Vontobel et al. (2013) researched which terrain properties are most likely to cause snow avalanches. They found that if the slope is above 30 degrees, the risk is significantly higher for an avalanche to happen. However, the risk decreases again if the slope is above 45 degrees because the snow cannot accumulate on such steep slopes. Also, the slope's shape and aspect play a role in the occurrence of avalanches. An avalanche is more likely to occur in a concaved terrain(Vontobel et al., 2013). However, they mention that more research should be conducted before drawing conclusions from this. In most cases, if the slope is facing north or east, an avalanche is more likely to occur because the snow faced less sun exposure, and therefore more snow layers could be accumulated (Tremper, 2008). principles

2.2 Cartographic production

According to Kent (2009), little research has been conducted on the design or symbology to classify the topographic style, given its popularity. Kent and Vujakovic (2017) researched the similarities and differences between the topographic maps of 20 European countries and found that the maps are stylistic very different.

Build-up in the topographic map

A topographic map is often a build-up of multiple layers, namely landform, land cover, and vector layers (Brewer, 2015). Representation of landforms can be derived from a Digital Elevation Model (DEM). A DEM is a raster grid where each cell contains its height value. From this DEM, there are four methods to show the landform. The first one is elevation coloring, where a cell in the raster gets a specific color based on its height; this can either be continuous or classified. The second method is contour lines, where each line represents a specific height. The third method is hill shading. Hill shading can be one-directional, where the standard setting for the illumination is northwest, or multi-directional, with illumination coming from multiple sides. The last method is curvature, which can be used to show the curves in the landforms if the hill shading does not suffice.

Land covers can be visualized in different ways. One way is to use orthoimages. This image shows the landscape from a nadir view and can be put on a layer representing landform. Another method uses vector or raster data containing land cover derived from remote sensing or field measurements.

On top of those two layers, more layers can be added, namely hydrography, boundaries, and points of interest. These are most often vector data in polygons, polylines, or points. At last, toponyms are added to the map, as well as grids, scale bars, and north arrows.

Font and labels

In cartographic design, there are many guidelines for fonts and labels. This section briefly summarizes the essential design principles for topographic maps. Topographic maps contain text for different elements, like titles, legend, and labels on the map. Brewer (2015) advises using two fonts on topographic maps, a serif font for labeling physical elements and a sans serif font for labeling cultural elements. They also mention choosing two fonts that match well and support the map's purpose.

The labels in a map can create a hierarchy of the elements. The elements can be classified using a different font, posture, color hue, or arrangement. Visual hierarchy can be created by giving the elements a different size label, different thickness of the letters, or different color lightness. The preferred order of the position placement of the labels can be seen in Figure 2.2. The best position for a label is the top right of the point element. However, if there is a line, point, or another element in this position, the following position in the labeling hierarchy should be chosen

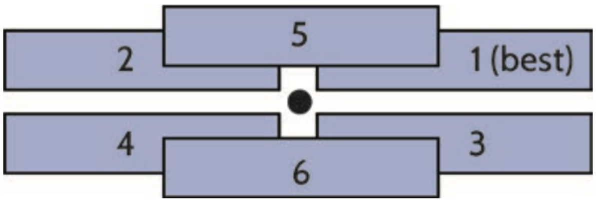

Figure 2.2: Label placement hierarchy from Brewer (2015)

Color

The coloring for paper maps is different than for digital maps. On a computer screen, the colors are called additive primaries, meaning they are created from light, making it possible to visualize the entire color spectrum. The primary colors are red, green, and blue, known as RGB. However, while printing on paper, it is not possible to create colors from light. Therefore, the colors are printed with a combination of four different inks. This is called subtractive printing. The specific colors are cyan, magenta, and yellow. For black, a separate ink is used, which is labeled a K. This is known as CMYK. Mapping software and vector editing programs have a function to convert the RGB colors to CMYK colors.

2.3 Volunteered Geographic Information

National Mapping Agencies used to be the only geographic map producers, as they had access to the geographic data (See et al., 2017). However, since the start of Volunteered Geographic Information (VGI), a term created by Goodchild (2007), individuals can create their maps. VGI is a collection of geographic data created, assembled, and distributed by citizens (Goodchild, 2007). VGI data can be contributed actively or passively (Harvey, 2013, as cited in See et al., 2017). Passive contribution is when individuals make their geographic information available but do not know for which specific goal this information will be used, for instance, social media, where people can attach their location to photos and messages. Active contribution means that the volunteers collect the data for a specific goal. An example of this is OpenStreetMap (OSM).

2.3.1 OpenStreetMap

OSM is one of the most well-known examples of VGI and the world's largest VGI of geographical data. In OSM, individual volunteers actively collect data to map the world together. In countries with limited access to geographic information, OSM's database is often the best source for citizens' data for citizens (Goodchild, 2007). OSM consists of a base map, and its volunteers can create new features on its base map. Moreover, they can also edit and update features. One challenge of OSM is data accuracy and control. Everyone can make a volunteer account and contribute to OSM, which can lead to vandalism. A solution for this could be that new volunteers should be checked, but this is not implemented (Mooney, Minghini et al., 2017).

OSM structure

OSM data consists of three elements: nodes, ways, and relations (OpenStreetMap, 2022). A node can be a single point in space, but it can also be a part of a way in OSM. Coordinates and a tag define a node. A way consists of a list of nodes that together form a polyline and contains a tag. Unlike nodes, it does not represent a single point in space but a line feature like a river. The element relation is a data structure that consists of two or more OSM elements. As the relation can be built up from a combination of nodes, ways, and other relations, this relation needs to be defined by a tag. OSM contributed can tag nodes, ways, and relations. An element can be defined with a tag, as it describes the elements. A tag consists of a key and a value. A key describes the category, and the value provides more detail. An example of tags for the Hoher Dachstein Peak in Austria is "ele = 2995", "natural = peak", "name = Hoher Dachstein".

The pitfall of VGI is that anyone can contribute, which causes a difference in the data quality (Senaratne, Mobasheri, Ali, Capineri & Haklay, 2017). They mention the following reasons for this: "data is produced by heterogeneous contributors, using various technologies and tools, having a different level of details and precision, serving heterogeneous purposes, and a lack of gatekeepers" (Senaratne et al., 2017, p. 139). A cartographer should therefore be aware of this pitfall and, where possible, check the data before using it.

CHAPTER 3

A user-centered design for static maps

In Chapter 2, it became clear that there are many aspects to ski touring and ski touring maps. Moreover, there are guidelines for cartographic production, but there is also room for artistic freedom, as shown in the research of Kent and Vujakovic (2017).

Over recent years, UCD has taken a rise in cartography. Traditionally, maps were produced following a procedure that consists of "a basic sequence which is generally followed" Darkes (2017, p. 287). The first phase in this process is understanding what purpose the map should serve and understanding the user's requirements. The second phase is to determine the practical criteria of the map. The data is collected and analyzed in the third phase, and in the fourth and final phase, the map is designed and produced (Darkes, 2017).

3.1 User centered design approaches

Although this traditional cartography process is functional, it may not address all the needs and demands of the target users. A UCD is beneficial for cartographers in interactive mapping projects (Roth et al., 2015), and improves the quality of the web mapping applications(Tsou & Curran, 2008), as it allows for low-cost and efficient map production. Roth et al. (2015) came up with the Three U's of Interface Success for interactive maps: Users, Utility, and Usability. It is crucial to understand the interconnectivity between the users, utility, and usability of the map. This relationship can be seen in Figure 3.1.

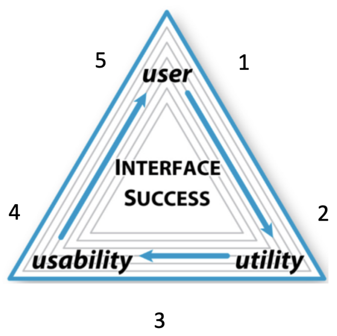

Figure 3.1: The three U's of Interface Success, adapted from Roth et al. (2015)

According to Roth et al. (2015), it should first be determined who the map user is. Only then can the usefulness be evaluated. The user is not a single person but the target users of the map. The target group of the map has specific needs and demands for the map, as well as specific expertise in the domain.

Utility and usability are criteria when evaluating the usefulness of a map (Robinson, MacEachren & Roth, 2011; Roth et al., 2015). Utility describes how useful the map is for the user group to complete their wishes and needs. This can be quantified by how the map fits the users' tasks. Roth et al. (2015) has suggested two strategies for the evaluation of utility in interfaces:

- Benchmark tasks: the user's performance is evaluated against a set of benchmark tasks. Is the map suitable for fulfilling the needs and demands of the user group?
- Analytical products: what are the decisions made by the user while using the map, and what is their generated hypothesis? How well do the users understand the map?

Usability is the ease of using a map to accomplish the user's goals/objectives and is a quality attribute that defines how well the map supports users. Usability is not easily quantified, but Nielsen (1992) proposed a strategy to measure usability in five steps:

- Learnability: How quickly can the interface be used for the first time
- Memorability: How fast can the interface be used after not using it for some time

- Efficiency: How fast can the interface be utilized if it is learned, to complete the task
- Error frequency and severity (error rate): How many mistakes are made with the new interface, and what is the effect of those mistakes
- Satisfaction: How do the users like the interface

The three U's of interface success by Roth et al. (2015) is an iterative process, the so-called user-utility-usability loop. In phase 1, the target group and their needs and demands are determined. Knowing the user can set the utility threshold in phase 2 to assess the target groups' needs and characteristics. Phase 3 is to improve usability. Phase 4 is to return to the user and determine if the map's usefulness is increased. Depending on the outcome of the user test, a new loop is initiated if necessary in phase 5.

According to Roth et al. (2015), there are three different methods for map evaluation in the fourth phase:

1. Expert-based methods: Feedback and evaluation are done by consulting experts without any prior knowledge.
2. Theory-based methods: Cartographers reflect on their own map using a scientific framework.
3. User-based methods: Feedback is given by the target group of the map.

The other UCD approach used in this research is described by Tsou and Curran (2008), which originates from a book on UCD design for web maps from Garrett (2002). Tsou and Curran (2008) describe five iterative stages for web mapping applications:

1. Strategy plane: What do we want to get out of this site? What do our users want?
2. Scope plane: Transformation of strategy into requirements: What features will the site need to include?
3. Structure plane: Giving shape to scope: How will the pieces of the site fit together and integrate?
4. Skeleton plane: Making structure concrete: What components will enable people to use the site?

5. Surface plane: Bringing everything together visually: What will the finished product look like?

Tsou and Curran (2008) point out that the stages can be overlapping. They give as an example that stage 3, the giving shape to the scope, can already start before the scope is finalized. In case of major changes in one phase, those changes can already be re-evaluated in the other phases.

Two other analyzed UCD approaches on how much user interaction is beneficial were Slocum et al. (2004) and Robinson, Chen, Lengerich, Meyer and MacEachren (2005). Slocum et al. (2004) approach to UCD was to involve users at a relatively late stage in the process. They only interacted with the target user after prototyping. In hindsight, they argue that interacting with the target user in an earlier phase would have been advantageous for the project. Robinson et al. (2005) argue that user interaction throughout the whole process and in different stages of the iterative UCD can be valuable.

3.2 User-centered design framework for static maps

Despite that, as discussed above, UCD approaches are beneficial to both the process and outcome of cartography, but such approaches have not been applied to static ski touring maps. To be able to use UCD in this domain, a new UCD framework was created for this research. In this new framework, the UCD approaches from Roth et al. (2015) and Tsou and Curran (2008) were combined and fitted within the map production process of Darkes (2017).

This research UCD framework is as follows: In the first phase, the target user and their needs and demands were determined. In the second phase, the map's design purpose was defined and specified which elements the map should contain. In the third phase, the map design was created and applied. Then, the map design was evaluated in the fourth phase. The fifth phase consisted of improving the map design based on the outcome of the map's evaluation. This combined framework applied user interaction in the phases where possible.

The utility and usability testing strategies described in this chapter are focused on interfaces. Nonetheless, the benchmark task of Roth et al. (2015) and the satisfaction strategy of Nielsen (1992) were usable in the new framework and were applied in the fourth phase.

CHAPTER 4

Phase 1: Target users and their needs and demands

The first phase of this UCD framework determines the map's target users and their needs and demands. This is done by comparing ski touring maps and interviews with the target users. This chapter first describes the method and result of comparing the ski touring maps, and the next section discusses the interviews with ski tourers. In the last section of this chapter, the needs and demands of ski tourers are determined.

Roth et al. (2015) state four noteworthy axioms for this phase. (i) the target users are often not represented by experts in the domain, as these experts have more experience than the typical user. (ii) the target users are not aware of their own needs, and the cartographer should therefore construct their needs. (iii) the target users will develop over time, and the interface should adapt to this. (iv) the target users can be diverse in their needs and demands.

The target users for this map design are ski tourers. Their experience level is unimportant; they can be completely new in the sport up to very experienced. One prerequisite was that the ski tourers should be familiar with topographic maps.

Ski touring maps were compared to get a better overview of the state-of-the-art. The design of the maps and use of symbols and elements were assessed and classified into the components that produce a ski touring map. This method provided a foundation for the final map design and of which elements a ski touring map consists while also allowing this research to generate new design ideas simultaneously.

The user-based method of conducting interviews was chosen because this method allows open input from participants and is, therefore, suitable for this phase of orientation (Kessler, 2000; Slocum et al., 2004, as cited in Roth et al., 2015). Another sound method to determine the needs and demands was the focus group. However, since the participants were representative of the target users and were geographically dispersed, the interview method was the best method.

4.1 Map comparison

4.1.1 Methods

A comparative study between the state-of-the-art ski touring maps was conducted to gain better insight into the available maps and their design. Four ski touring guidebooks and three topographic maps for ski touring were purchased at the freytag&berndt map store in Vienna. All the maps can be viewed in Appendix A.

Balzarini, Dalmasso and Murat (2015) set out an experiment to test skiers' understanding of ski resort maps. They focused on different visual aspects of the map. In the thesis of Janssen (2020), the author was guided by these visual aspects to compare two different maps on content and design. Kent (2009) found a methodological approach for analyzing cartographic style. For comparing ski touring maps, it is essential to know how ski tourers navigate and which landmarks they use most often for navigation. Kettunen et al. (2013); Kettunen and Sarjakoski (2015); Rehrl and Leitinger (2008) researched which landmarks are most often used for navigation in winter. They found that the participants often use landforms in winter. Therefore, the four maps will also be compared on their landform visualization.

The research mentioned above were combined to compare the four ski tour guidebook maps and the three topographic maps on different visual aspects and cartographic style. The criteria can be seen in Table 4.1.

Basemap	**Geomorphology**	**Manufactures**	**Nomenclature**	**Cartography**
Terrain representation	Terrain	Trails	Signage trail	North arrow
Perspective	Peaks and ridges	Settlements	Peak names	Scale
Hill shading	Slopes	Roads	Water	Color usage
Contour lines	Rocks, cliffs	Point of Interest	Point of Interest	Visual hierarchy
	Trees		Settlements	
	Water			
	Snow and Ice			
	Glaciers			
	Landform			

Table 4.1: Criteria for the map comparison

The four ski touring guidebooks all contain multiple ski tours routes descriptions, accompanied by a map. The guidebooks were chosen for their diverse map styles. The first two guidebooks are published by Schall-Verlag and berg&karte, covering ski touring routes in east Austria. The third guidebook is called 'Skitouren in Meerblick' published by Anavasi, and describes ski tours in Greece. The last guidebook covers the Haute Route, a one-week ski tour from France to Switzerland, published by JMEditions.

The three topographic maps are from the Austrian and German Alpine club (so-called Östereichische Alpenverein and the Deutsche Alpenverein, shortened to OAV and DAV) and from the Bundesamt für Landestopografie in Switzerland (swisstopo). These map publishers have a long history of map-making and much experience.

In the thesis of Janssen (2020), the difference in spatial understanding by map readers using panoramic and planimetric maps has been researched. The findings were that both base maps were helpful in different navigation tasks. The panoramic map is the most used map in the European and American ski resorts (Janssen, 2020). However, Balzarini and Murat (2016) states that the panoramic view leads to local distortions in the mountains. Balzarini et al. (2015) found that map users have trouble with wayfinding and orientation when using drawn panorama maps. Therefore, panoramic maps are not reliable for navigation and were not included in this map comparison.

Materials

Schall-Verlag (Map A) The first map is from Schall Verlag, an Austrian company that sells guidebooks for ski touring, hiking, and climbing. Schall&Verlag published two guidebooks for ski touring. The first guidebook covers east Austria, namely Niederösterreich/Wiener Alpen, Oberösterreich, Steiermark, Salzkammergut, Lungau. This most recent version of this book was published in November 15, 2021. The other guidebook covered west Austria, namely Salzburg, Tirol, and Vorarlberg, and was published in 2014. Even though the maps in the two books are very similar, this research will focus on the most recent maps of the guidebook of east Austria.

The map consists of two layers. The first layer is the base map Östereichische Karte (ÖK) made by the Bundesamt für Eich- und Vermessungswesen (BEV) in Austria. On top of the ÖK is the layer with ski trails and additional information.

According to the Bundesamt für Eich- und Vermessungswezen (2021), the base map can be used for hiking, planning principles, as the basis for thematic applications, forest overview maps, path studies for road and rail projects, as basis for data collection, and as Information level in GIS (as KM50). There is no specific mention of usability for winter activities, let alone ski touring. The ski trails, points of interest, and other information are put on BEV's base map as a new layer. No changes in the base map have been made. By putting the top layer on top of the first one, the readability of the base map decreases, as the top layer sometimes covers essential elements in the base map. This is solved by adding the information again in the top layer.

The map displays the recommended and described routes and gives alternative route possibilities on the map. In addition to the map, a panoramic picture is provided with the tracks drawn on top of the pictures.

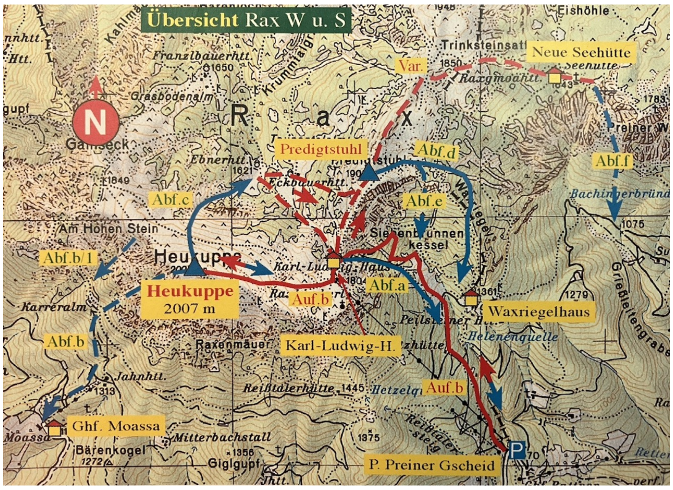

Figure 4.1: Map A

berg&karte (Map B) The second map is of the company berg&karte, and dates from 2011. This map is designed with the same base map as the map of Schall-Verlag, namely the ÖK50. However, contrary to Schall-Verlag, the base map is changed rigorously. The first main difference is that they change the colors of the terrain to have a more winter-oriented map. They also omitted trail markers and administrative boundaries because these can be confused with the trails.

The other difference is the 3-dimensional visualization of the map. On top of the base map is a DEM with an accuracy of 25 meters. Then, Arc Scene was used to create the 3-dimensional scene and put on the 2-dimensional map. After that, the routes and the pictogram of the beginning- and end points are added. No scale is provided to the map.

Figure 4.2: Map B

Anavasi (Map C) The third map is in the guidebook Skitouren mit Meerblick and dates from 2016. It covers 23 ski tours all over Greece. The author claims that the ski touring guide is “probably the first guidebook that is also usable for non-ski tourers, as the routes are also accessible in summer for hiking”.

The base map is a shaded relief map made with a DEM model. The base map colors are green to white, with green as low elevation and white as higher elevation. Contour lines also support the height visualization. No difference in land covers like vegetation, rocks, or scree is displayed.

The scale is different per map in the guidebook. The names of the mountain ranges and villages are given in Greek and Slavik, taking up a significant amount of space.

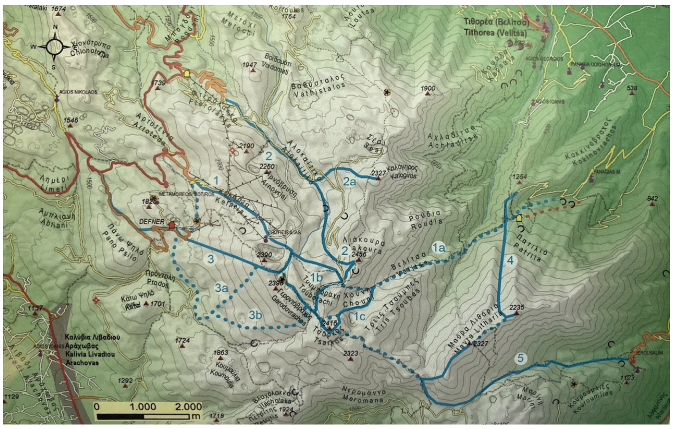

Figure 4.3: Map C

JMEditions (Map D) The last map is from a guidebook that covers the Haute Route, a long-distance ski tour in France and Switzerland. The book is published in 2012. The book's author describes the map as a sketch map and recommends that ski tourers bring a 1:25.000 or a 1:50.000 map for orientation. The tour guide included pictures of the terrain for some segments, where the point of view is either panoramic or from the ski tourer.

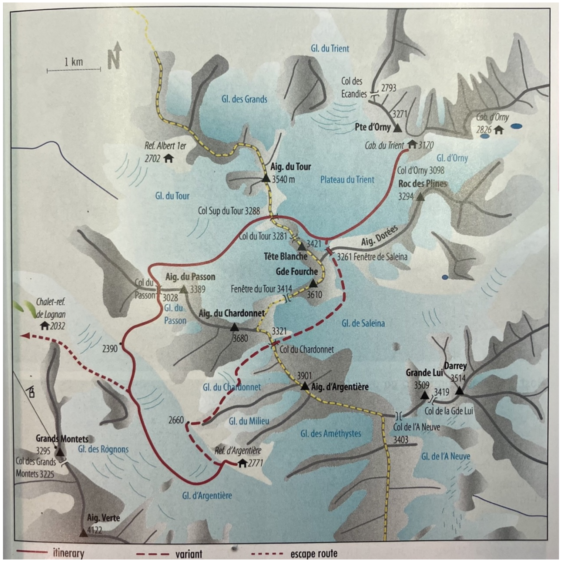

Figure 4.4: Map D

Figures 4.1, 4.2, 4.3, and 4.4 can be seen in larger format in Appendix A.

Topographic maps

Bundesamt für Landestopografie (Map E) A famous Alpine map publisher is the Bundesamt für Landestopografie (swisstopo). They produce maps of Switzerland with scales varying from 1:10.000 up to 1:1.000.000. The maps of swisstopo are especially well known for "The Swiss style of rock drawing". The style is based on shaded hachures, which demand artistic skills from the cartographer and is time-consuming (Hurni, Dahinden & Hutzler, 2001, as cited in Jenny, Gilgen, Geisthövel, Marston & Hurni, 2014). One square centimeter takes approximately one hour if a new rock formation is drawn. Revising and updating rock formation on maps is less time intensive but requires time and artistic knowledge. This knowledge is passed down through the generations of cartographers at swisstopo.

However, the design rules are not set and depend on the area. Figure 4.5 shows an example of the famous rock drawing style.

Figure 4.5: An example of Swiss rock drawing with hachures (Jenny et al., 2014)

Another conspicuous map element of the swisstopo maps is the pink shading of slopes steeper than 30 degrees. This visualization shows the at-risk snow avalanche areas and can clearly be seen on top of the Piz Cotchen mountain in Figure 4.6. A map from 2014 for ski touring in Tarasp in Switzerland was compared.

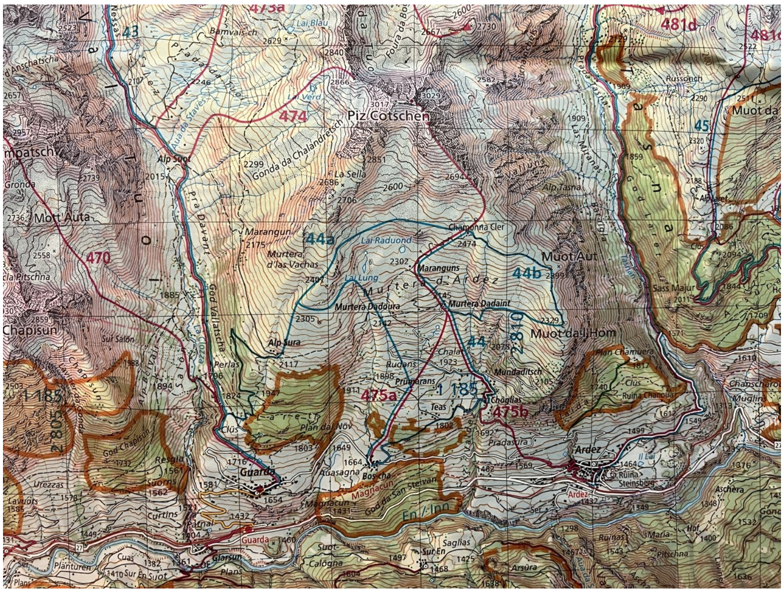

Figure 4.6: Map E

Östereichische Alpenverein (Map F and Map G) In Austria and Germany, the Alpine clubs of Austria and Germany produce maps of the Eastern Alps. So far, they have produced 43 maps covering the Eastern Alps, an additional 24 maps of Bavaria, and 16 trekking maps. Their focus is to revise their current maps; they update around seven maps of the Eastern Alps annually, so each map is revised every six or seven years. The maps covering the Eastern Alps are published in different editions. The "Skirouten" editions contain trails for ski touring. The "Weg und Ski" maps contain both ski touring trails as well as hiking trails. They also produce the so-called "Weg" maps, where only hiking routes are visualized. The maps are published with a scale of 1:50.000 or 1:25.000.

For this research, two maps of the Östereichische Alpenverein were compared. The first one is the "Skirouten" edition, covering the Tuxer Alpen in Austria, dating from 2016 (Map F) The second one is the "Weg und Ski" edition, covering the Dachtsteingebirge, dating from 2012 (Map G). A part of Map F can be seen in Figure 4.7, and a part of the "Weg und Ski" edition can be seen in Figure 4.8.

Figure 4.7: Map F

Only a small part of the topographic map can be seen in the Figures 4.6, 4.7, 4.8, because the format of the maps are too large. The figures can be seen in larger format in Appendix A.

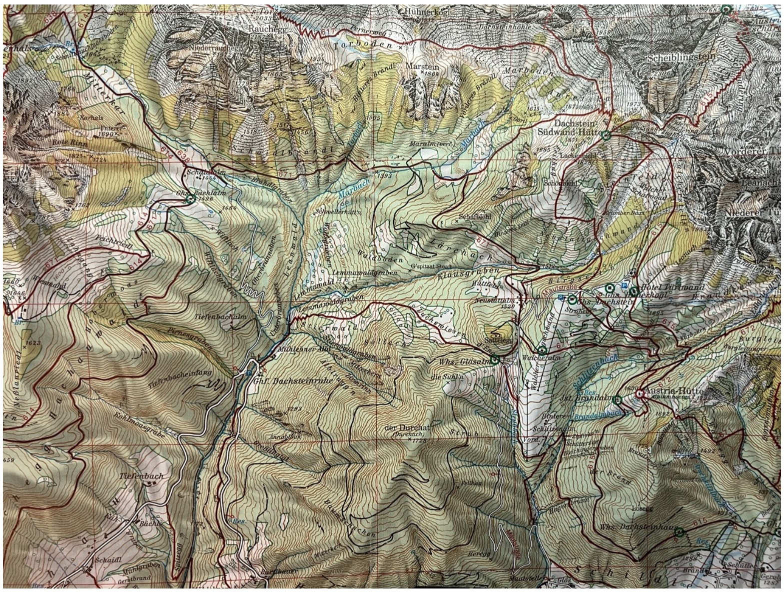

Figure 4.8: Map G

4.1.2 Result comparison ski tour guidebook maps

A table with an overview of the map comparison can be seen in Appendix B. The four maps serve different purposes. Map D is meant to provide the ski tourer with an overview of the area, not for navigation. Maps A, B, and C are also meant to be used for navigation during the tour. An explanation of the tours accompanies all maps. Below, the four maps are compared according to the aforementioned criteria.

Basemap Maps A and B both have a topographic base map, while map C is an elevation map, and Map D is a sketch map. The perspective of the maps is orthogonal. Hill shading and contour lines are used in every map, except for map D.

Geomorphology In maps A and B, there is more distinction between different land covers than in maps C and D. All maps show the peaks of the mountains, including a height indication. The maps differ most regarding the representation of rock and cliffs. In maps A and B, the rocks and cliffs are visualized with the hatching technique, while in map C, the rocks are not visualized. In map D, a larger area of rocks and cliffs is visualized but significantly simplified.

Manufactured Maps A and B are more detailed for manufactured landmarks than maps C and D. Buildings are shown individually in settlements, while maps C and D show them as a grey polygon or grey dot. Also, maps A and B show more kinds of points of interest (POIs).

Nomenclature Maps A and C refer to their trails in their text by number, maps B and D do not do this. The peaks are named on the maps, except for map D.

Cartography Maps A, C, and D face north, while map B does not. The scale is often inconsistent for the maps. The maps all have a visual hierarchy on their map, making the ski tour trails stand out.

4.1.3 Result comparison topographic maps

A table with an overview of the map comparison can be seen in Appendix B. Two of the three topographic are designed for ski touring, and the other one is designed for ski touring and hiking. Below, the maps are compared according to the aforementioned criteria.

Base map The topographic maps are very similar in some aspects in this comparison. They all have an orthogonal perspective, illumination from northwest, and contour lines. Only map G has contour lines every 10 meters, while Map E and F every 20 meters.

Geomorphology The topographic maps are all detailed. They show the land covers and water, the peaks with a small cross, and their height. The glaciers are shown with contour lines, and the landforms can be detected. The rocks are all drawn with hachures, following the famous Swiss technique. The most significant difference between the maps is the slope representation. The slope can be seen in all the maps with the help of hill shading and contour lines. However, map E has a distinct visualization for slopes steeper than 30 degrees, with a pink layer on top.

Manufactured The maps all show settlements, individual buildings, and different kinds of roads. Points of interest are shown with pictograms. Map E contains fewer points of interest than Map F, and G. Map E and F are designed for ski tourers, while hikers and ski tourers can use Map G. This is visible in the design of the ski tour trail in Map G. It is a light blue transparent line. Looking closely at Figure 4.8, a blue line going north can be detected from the parking at Dachsteinruhe.

Nomenclature In the maps, almost all the names for the peaks and their height are given. Also, the water, points of interest, and settlements are named.

Cartography The three maps are all facing north. Map E has a scale of 1:25.000, while Map F and G have a 1:50.000 scale. Map E and F have a high visual hierarchy between the ski tour trails and the rest of the map, while the visual hierarchy is very low for Map G for ski tour trails.

4.1.4 Conclusions of the map comparison

The maps in the ski tour guidebooks differ for almost all criteria. The purposes of the maps are different, which also asks for a different level of map accuracy and quality. Their base map, geomorphology, and cartographic production are diverse. The maps are more similar for the manufactured and nomenclature criteria. The topographic maps share more similarities to the criteria than the guidebook maps. The most significant difference is that the swisstopo map visualizes slopes steeper than 30 degrees, while the other two maps only show the steepness with contour lines. Another significant difference is the use of color in their maps, as all the maps have their unique color combinations. Also, map G, an edition of the “Weg und Ski” maps, is more focused on summer hikers than tour skiers and, therefore, less suitable for tour skiers. The topographic maps are more detailed than the ski tour guidebook maps.

As described in Chapter 2.2, there are few rules for topographic map production. This allows for artistic freedom in ski touring maps, which can be seen in the very diverse map designs.

The compared maps were chosen for their diverse map style. However, there are other map styles that were not compared, like orthoimagery and panoramic maps, which might have given different results. Nonetheless, the results of this research provide valuable insights into the components that make a ski touring map and serve as a valuable source for design inspiration.

4.2 Interviews

4.2.1 Methods

Participants and recruitment

One of the Roth et al. (2015)’s four axioms described at the beginning of this chapter was that the target users are often not represented by experts in the domain. Therefore, interviews were conducted with ski tourers of different levels to have a fair representation of the target user. The interviews provided a better understanding of ski touring, how ski tourers prepare their tours, and how they navigate and assess avalanche risks. The interviews were all anonymous and can be found in Appendix C. A total of five ski tourers were found for an interview. One interviewee was found via Social Media, and the other four were found via the national alpine association for students and alumni in the Netherlands, called the XSAC. The interviewees were all male, aged 27 to 67.

Before participating in the interview, they all received an e-mail with information about the interview and the four maps from the guidebooks, which can be seen in Appendix A. All interviews were held on Zoom. Preliminary to the interview, the interviewees were asked for their consent. Three interviews were held in Dutch, and two interviews were in English.

Interview questions

For this thesis, the semi-structured interviewing technique was followed. This allows the interviewer to ask follow-up questions in case answers were unclear, or new questions came up. The interviews were held online in an informal setting. The interview consisted of four parts, all with open questions. The first part of the interview aimed to get a better insight into the participant's ski touring experience. The second part consisted of questions on their map use. The interviewees were also shown the four maps via screen sharing in this part. Their opinion on the usability of those maps was asked. The third part of the interview focused on assessing avalanche risks. In the last part, the interviewees had the opportunity to give final remarks or to ask questions. The interviewer did not correct the interviewee in case of mistakes. However, in case of uncertainty, the interviewer provided the correct answer.

4.2.2 Result of the interviews with the ski tourers

All the interviews can be read in Appendix C.

Experience Ski tourer 1 (ST1) is an experienced ski tourer. He makes around 150 trips per year. Ski tourers 2 and 3 (ST1 and ST2) have over 30 years of experience making ski tours yearly. Ski tourer 4 (ST4) started with downhill skiing when he was two or three years old and has been active with ski touring since 2019. The last ski tourer (ST5) went on many ski tours when he was younger and also gave some ski touring courses. In the last years, he ski tours while on family winter sports vacations.

Preparation for ski tour ST1, ST2, and ST3 all prepare for the ski tour by closely monitoring the avalanche reports during the season. They decide their area and ski tours based on the avalanche risk and the safest possibilities. ST4 first goes to the area and will check which tours they will do from there, and also ask for recommendations. They check the avalanche risk afterward. This is also the case for ST5 if he knows the area.

Everyone except for ST2 and ST5 uses mostly websites on the internet to find new tours. ST2 searches for routes on a topographic map, preferably as detailed as possible with a scale of 1:25.000. If ST5 does not know the area, he starts searching for routes on maps and online from home to get an overview beforehand. ST4 uses the internet because it is a free source.

Use of maps ST2, ST3, and ST5 all use paper maps for navigation. ST2 and ST3 really prefer to bring a topographic map, preferably as detailed as possible. ST5 mentions that he prefers the ski touring guide books, as they often contain more recent information than the topographic map, or he brings a description from the internet. ST1 and ST4 use their phone for navigation. ST1 says because it is easier than a paper map, ST4 mentions that he uses his phone to determine his location.

Important elements All the ski tourers agree that it is very important to have the degrees of the slope visualized on the map, with either a separate shading for steep slopes above 30 degrees, or with the contour lines. ST5 mentions that with contour lines it is difficult to estimate how steep the slope is. ST3 says that the scale bar and the kilometer grid are important for estimating distances. He misses indications for difficult passages in the current maps, specifically aimed at ski touring. For ST1 is the aspect of the slope an important element as well.

ST3 and ST4 both mention that they use the summer paths for navigation and that it is important that the map provides information on the glacier's position date, due to the decreasing size of glaciers.

Map A The interviewees all think that this map does not contain enough details to use the map. They mention that the yellow stickers take up too much important space, as they would prefer to see more of the map below it. ST1 mentions that the map is north oriented, which makes it easier to know the aspect of the mountain. ST3 says that the map also does not contain enough information to provide an overview of the area.

Map B The opinions on Map B are more diverging. ST1 thinks the map is bad because it does not face north and there is no scale. ST4 critiques that the map is not detailed enough to have the 3D representation and that 2D would have been better. However, he mentions that it is easier to see where the downhill skiing areas are (so-called “tubes”). ST2, ST3, and ST5 mention that the map is more useful because it is more detailed.

> ST2: I think it is more useful than the previous map in preparing for a trip

Map C Again, the opinions on this map are different. ST1, ST3, and ST4 miss the details on land cover in this map, while it is important to know where the trees and rocks are. ST2 mentions that the map is not even very bad, and he would use it if no better maps were available. ST5 said that the map contains few details and is very concise.

Map D The ski tourers all agree that this map has the sole purpose of giving a good overview before starting a ski tour. However, they say it is not detailed enough to be used for planning a ski tour or navigation during the tour. The contour lines are missing, the crevasses are randomly drawn, and it is hard to decipher how difficult the routes are.

> ST5: the crevasses look random because they are changing every year. So that’s actually really dangerous information

Avalanche risk Ski tourers have different approaches to assessing avalanche risks before or during a tour. As mentioned before, ST1, ST2, and ST3 keep track of the news related to ski touring from the start of the ski touring season. They follow the weather reports and avalanche reports and try to find recent pictures of the tour. They have a more detailed look at the tour before starting and assess the risk by looking at the map, determining where the slopes are steeper than 30 degrees, what the tour aspect is, and where the forests are. ST4 and ST5 firsts choose the tour and will check in the avalanche bulletin if it is safe to start the tour. They both check with more experienced people if the chosen route is safe enough.

During the tour, ST4 and ST5 feel the firmness of the snow. If they don’t think it is safe, they stay away from avalanche-risk areas. ST1 also examines the snow during the tour and has several ways to check the snow condition. He makes a snow profile to check the stability of the snow. If it looks dangerous, he does an extended column test to determine if he continues or stops the tour. For ST2, the local assessment is important, and he compares this assessment with the news he has read during the preparation phase. He checks if the local conditions are similar to the avalanche report.

4.2.3 Conclusions of the interview

Five ski tourers of different levels were interviewed. The ski tourers agreed that the four maps of the guidebooks are insufficient for orienteering and assessing avalanche risks. The ski tourers' opinions on the maps are as follows; Map A has a very detailed base map, but some are covered by ski touring elements like the trails and nomenclature. Map B is too distorted for orientation. Map C does not contain any terrain information, and Map D its sole purpose is to give an overview of the area.

The interviewees do not all use paper maps. However, no matter the format of the map, they all mentioned that slope representation is important in ski touring maps, either with the contour lines but preferably the swiss pink shading. Besides, for navigation, the ski tourers need detailed maps containing accurate information.

In hindsight, asking the ski tourers similar questions on the topographic maps of Chapter 4.1 as on the guidebook maps would have been valuable. This would have provided more insight into the usefulness of those topographic maps and on the importance of map elements, which could have inspired and guided the design process further into the research.

By conducting interviews with ski tourers of different ages and experiences, it was tried to have a sound sample representation of the target users. Nevertheless, only five interviewees may not have representative opinions and needs and demands of the larger ski touring population. Therefore, the interviewees' individual needs and demands should be critically reviewed before mapping them.

4.3 Needs and demands of the ski tourers

In the first phase of this research UCD framework, the target users, and their needs and demands were determined. At the beginning of this chapter, the target users were defined as ski tourers of all levels, as long as they are familiar with topographic maps. The needs and demands of the target users can be determined from the in-depth literature review in chapter 2, the comparative map design, and the interviews with the ski tourers. The research questions posed in Chapter 1.2.1 are the framework for determining the needs and demands.

RQ 1.1 What is the current use of a ski touring map?

Ski tourers use maps in different ways. Some ski tourers find their ski tours using internet websites, others use guidebooks to find tours, or people determine their own tours with the help of topographic maps. Ski tourers who use topographic maps to plan their route also often use those maps for navigation during the tour. The advantage of finding the route online is that ski tourers can download the route as a GPX file and use a GPS device for navigation. However, due to the possible failure of the device, as described in Chapter 2.1.3, it is essential to bring a topographic map as a backup. Guidebook maps are barely used for navigation, partly due to lack of quality in the map and partly due to weight.

RQ 1.2 Which map attributes are currently present in ski touring maps?

Ski touring maps' attributes differ per map and purpose. The maps in guidebooks that aim to give an overview of the area are less detailed than topographic maps and can take more artistic freedom. The topographic maps are a very detailed terrain representation of the area. They show different land covers, contour lines, heights, all ski trails, points of interest, settlements, and more. Both guidebooks and topographic maps show the ski tours or trails with a large visual hierarchy between the base map and the ski tours. The swisstopo map excels in visualizing steep areas, as they put a shade of pink on areas where the slope is steeper than 30 degrees.

RQ 1.3 Which map elements are most important to serve the goal of a ski touring map?

The goal of the map determines which elements are important. The less detailed maps often found in guidebooks depend less on certain elements. However, there are no contour lines in map D, which was an element that all ski tourers missed. Detailed topographic maps contain many important map elements.

Avalanche risk is a hazard that ski tourers should be aware of and should be able to assess. Geographical factors that can cause avalanches are weather, snowpack, and terrain. Weather and snowpack are factors that change over time and space, but the terrain is a factor that does not change. Therefore, the visualization of the terrain is important in ski touring maps. Avalanches are likely to occur if the slope is steeper than 30 degrees. Contour lines can help determine if a slope is steeper than 30 degrees. Additionally, the swisstopo technique of adding a shade for areas of 30 degrees was important to the ski tourers interviewed. Another terrain element to assess avalanche risk is forest areas, where avalanches are not likely to occur. Therefore, forest areas should be identifiable on maps. Lastly, the aspect of the slopes should also be clear. To determine on which side of the mountain the slope is, there should always be a north arrow on the map, and preferably, the map should face north.

In the research on how ski tourers navigate, it was found that some landmarks play a dominant role in navigation. Ski tourers use landforms for navigation, as those are clearly visible when covered in snow (Kettunen et al., 2013; Kettunen & Sarjakoski, 2015; Rehrl & Leitinger, 2008) Therefore, landforms should be distinguishable in ski touring maps.

In both the maps in the guidebooks and the topographical maps, trails are depicted for ascending and descending. However, ski tourers often don't follow a specific trail but use a larger slope area when they ski downhill. ST1 said that it is useful to know where the whole downhill skiing area is. Those areas are not visualized in the compared ski touring maps.

Important cartographic elements are a scale bar, kilometer grid, and a north arrow.

CHAPTER 5

Phase 2: Map design considerations

The map's target users and their needs and demands were determined in the previous phase. The next phase in this research UCD framework was to determine the purpose of the user-centered map design and to determine several considerations of the map production. This chapter first discusses the fundamental design considerations applicable in different map productions. The next section outlines design considerations specifically aimed at ski touring map production.

The new user-centered map design should be used for planning, navigating, and reflecting on ski tours. It is aimed at ski tourers who are used to topographic maps. The map provides detailed information about the tours, landscapes, and important elements for preparing ski tours and navigation during the ski tour, according to the ski tourers' needs and demands determined in Chapter 4.3. The map design focuses on using solely open data.

5.1 Fundamental design considerations

Before starting the design process in the next phase, several general considerations on the design and production are made. This is also described in the production process of Darkes (2017).

Area

The map displays the Dachsteingebirge in Austria. This area is chosen because of the landscape variety and the numerous possible ski tours. The mountainous region has glaciers, high peaks, forests, and smaller hills. The highest peak is the Hoher Dachstein at 2995 meters. The village closest to this peak is Ramsau am Dachstein, at 1120 meters. There are several ski tours in the area, often with the possibility of taking a break or staying at an alpine hut.

Format

The ski touring map is designed for paper printing for the reasons given in Chapter 2.1.3, on A2 format paper. This allows multiple tours to be visualized and gives the ski tourers a good overview of their surroundings.

Scale

The map's scale is set to 1:25.000, meaning that one centimeter on the map represents 250 meters. This is a so-called large-scale map. The maps compared in Chapter 4.1 have different scales. The interviewees all mentioned that they prefer the map to be as detailed as possible. 1:25.000 allows for details, which helps ski tourers with navigation. A larger scale than 1:25.000 would have been too large for printing, as multiple tours should fit on one map and a smaller scale is not detailed enough.

Color

The map design uses color. Color is an essential aspect of cartography, as it allows for creating a visual hierarchy. Since the map design is created for paper maps, it is important to use the CMYK coloring, as described in Chapter 2.2.

Data

For this map design, only open data is used. Almost all data is from OpenStreetMap, downloaded via Overpass-Turbo (www.overpassturbo.com), a website where OSM data can be retrieved with the help of data queries. The DEM used in this data set is made available by the Austrian government.

5.2 Specific design considerations

For this research map design, specific design considerations were considered before starting the map design production. These considerations arose from the needs and demands of the target users determined in Chapter 4.3.

Land cover

Land cover on maps helps ski tourers with navigation and with avalanche assessment. As mentioned by ski tourer 1 and 3 in Chapter 4.2, avalanches are less likely to happen in forests. Ski tourer 3 also wants to know where the forests are while planning a route. Forests were therefore clearly visible on the map. Ski tourer 3 mentioned that rocks and scree are important as well, especially earlier in winter when there is the risk that the snow might not cover all the rocks yet. Land cover like grass heath and meadow are likely covered in snow and cannot be distinguished in situ. Consequently, these land covers did not need to be clearly visible. Accordingly, forests, scree, and bare rock are visualized separately.

Slope

As concluded from the literature research in Chapter 2.1.5 and from the needs and demands of the ski tourers in Chapter 4.3, avalanches are more likely to happen if the slope is steeper than 30 degrees. Maps can be a helpful tool for assessing the avalanche risk if the slope is visualized. This map design shows the slope with hill shading, contour lines, and shading.

Orientation

Avalanche risk also depends on the aspect of the slope. The amount of sun and the direction of the wind on the slope influence the snowpack and, consequently, the avalanche risk. This map design faces north and contains a north arrow to easily determine the slope's aspect.

Ski tours

Six ski tours of different levels are visualized on the map. They are distinguishable based on their color. Four ski tours contain a descend slope visualization. This visualizes which part of the slope the ski tourers can use to descend.

Summer trails

In the conducted interviews, only ST3 and ST4 mentioned that they use summer trails for navigation. However, based on the research of Kettunen et al. (2013); Kettunen and Sarjakoski (2015); Rehrl and Leitinger (2008), recreationists use different landmarks for navigation in winter, and visualizing summer trails would overload the map design. Therefore, the summer trails are not visualized in the first version of the map design.

CHAPTER 6

Phase 3: Map design production

The third phase of this research UCD framework concerns the map design production. In the last chapters, target users and its need and demands were determined, as well as the purpose of the ski touring map design and general and specific considerations. This chapter describes the method of map design production and the resulting map design.

6.1 Map production

6.2 Methods

The design and development process of the ski touring map was guided by the drawn conclusions from in-depth literature research, comparative study, and interviews with the ski tourers.

Data

A Digital Elevation Model (DEM) of the Bundesamt für Eich- und Vermessungswezen (2022) was downloaded for this map design. This DEM has a 1-meter resolution. All the land cover, hydrography, and POI data were downloaded from OSM via Overpass-Turbo. The land cover and hydrography are polygons and polylines, the POI data were data points. The ski tours were downloaded from Bergfex.at, an Alpine mountaineering platform.

Software and techniques

The data layers in this map were compiled in ArcGIS Pro (ESRI). After this, the map was exported as a PDF to Affinity Designer for the final changes in the design. This allowed for changes in label placement and the creation of an aesthetic legend. Affinity Designer has the function to change RGB coloring to CMYK coloring, necessary for printing as described in Chapter 6.1. QGIS is open software available online, which would be a free alternative for ArcGIS Pro. Vector editing software like Inkscape, a free and open-source vector graphics editor, could replace Affinity Designer.

6.3 Result

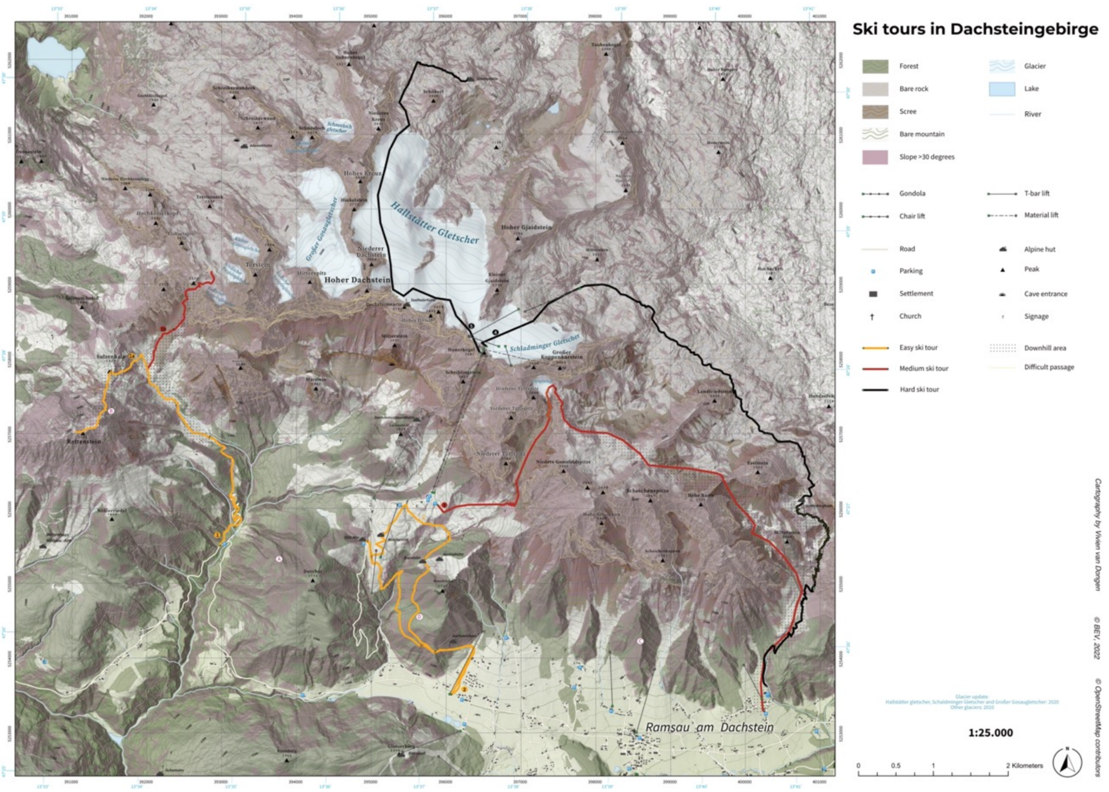

Figure 6.1: Result map design phase 3

The map design can be seen in Figure 6.1 and in Appendix D. The guidelines of Brewer (2015) on topographic maps were followed for this map. As described in Chapter 4.1.4, there is space for artistic freedom in the design process of topographic maps. Brewer (2015) described that a base map of a topographic map consists of several layers. The layers of this map can be seen in Figure 6.2. Some layers are partly transparent because they are stacked.

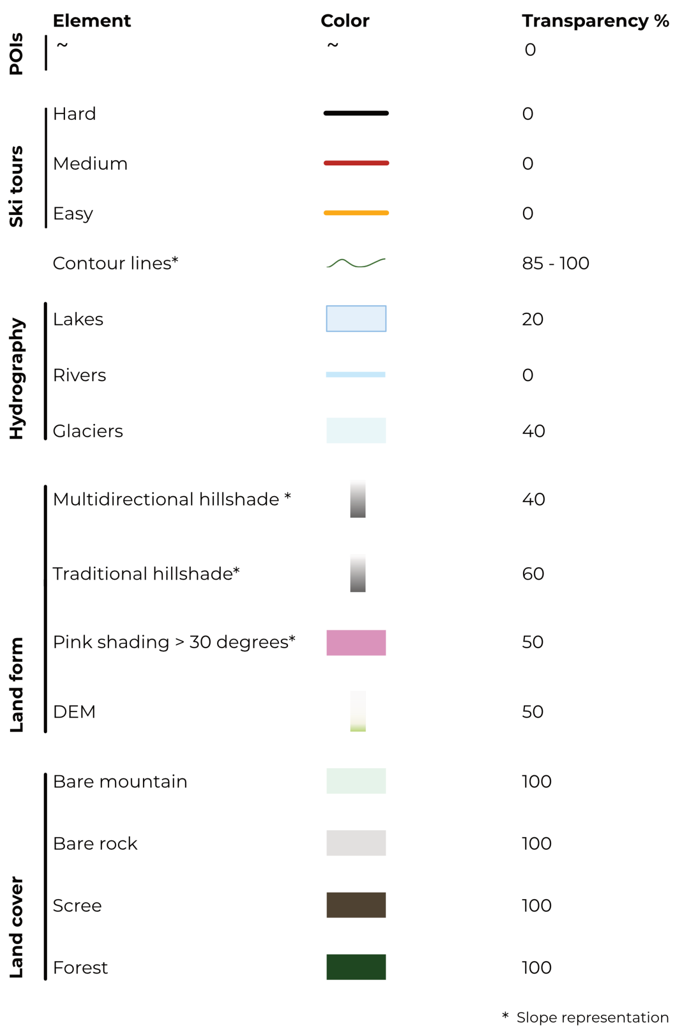

Figure 6.2: Layers of the map and their colors and transparency

The first layer of this map design is the land cover. The land cover, downloaded from OSM, consists of polygons. The polygons are colored similarly to the maps compared in Chapter 4.1 or according to artistic freedom. Forest, scree, and bare rock have a noticeable color on the map, since these land covers are important to ski tourers. Grass, heath, and meadow are categorized as bare mountains and given a less prominent color, because they are more likely to be covered in snow. Another option for land cover would have been to use orthoimages for visualization. However, this was less suitable for this map design because the land covers forests, bare rocks, and scree needed a stronger coloring, while the other land covers could be categorized and less prominently colored.

On top of the land cover layer is the DEM. To represent the snow colors in the map, the DEM has a gradient coloring from green for the lower elevation to white for the higher elevation, since there is more snow in the higher elevations. This DEM has a transparency of 50%. To create landforms and visualize the slope on the map, two layers of hill shading are added on top of this DEM, with transparency of 60% and 40%, respectively. The first layer is traditional hill shading, with illumination from the northwest and an azimuth angle of 60. The second layer is a multi-directional hill shading to accentuate the shape of the landform even more.

Glacier data was added on top of the hill shades. The light blue color has a transparency of 40%, such that the hill shading is visible through it.

Besides hill shading, this map contains two more visualizations for the slope: slope shading and contour lines. The slope shading is pink-colored for areas where the slope is steeper dan 30 degrees. The color pink is inspired by the color used by swisstopo and matches the rest of the colors on the map. Even though the pink shading has a transparency of 60%, it made it harder to distinguish the different layers of the base map. To solve this issue, contour lines were placed on top of the map, and the colors of the contour lines differ per land cover. By doing this, the user of the map can determine the land cover from the contour line only. The contour lines are 20 meters apart; every 100 meters, the contour line is slightly thicker.

The next layer is hydrography. The rivers and lakes were given the color blue, a typical color for hydrography as can be seen in the compared maps in Chapter 4.1.

The ski tours were colored according to their difficulty. The colors orange, red, and black were chosen for easy, medium, and hard ski tours. For downhill skiing maps, the color for the easiest slope is often blue. However, because blue is too similar to the coloring of the rivers, the warning color orange was chosen in stead. Even though the ski tour has level easy, it is not a sport without risk, and the color orange warns ski tourers of potential hazards. A green dot has been added at the beginning of the ski tour to indicate its start, and a grey dot is added at the end.

The top layers contain man-made elements and points of interest like lifts, alpine huts, settlements, churches, peaks, and cave entrances. The same visualization as for the ski tours was added to indicate the start and end of the lift. The last step was to add labels and height to the elements on the map. The names and heights of most elements were included as tags in the OSM data.

Hatching was added for four ski tours to show the descend slopes. Hatching those areas allowed showing the descend zone without covering too important information below it.

The last steps in ArcGIS Pro were to add a graticule grid, a measured grid, and a scale bar to the map's design.

For the labeling and the fonts, the design principles described in 2.2 were followed. Two different fonts were used on the map; Source Sans Pro for labeling physical elements and Source Serif Pro for the cultural elements. The labels placed in ArcGIS Pro often overlapped other elements, so the labels were positioned in Affinity Designer according to label placement guidelines which can be seen in Figure 2.2.

Lastly, the map was checked for accuracy against the map of the OAV of the Dachtsteingebrige. As described in Chapter 2.3.1 the maps' data was downloaded from OSM, and errors can occur. One mistake was found on the map; the peak Mitterstein occurred at three different locations at the same height, which can be seen in Figure 6.3. After comparing this map with the map from the OAV, two peaks were deleted.

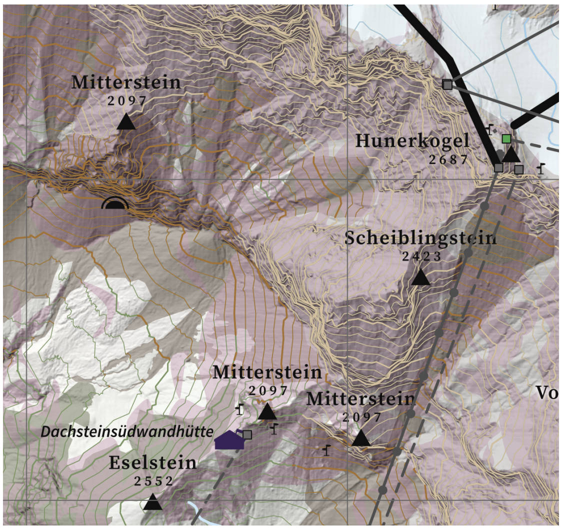

Figure 6.3: An error in the OSM data

6.4 Conclusion

During the design process, the cartographic guidelines on topographic maps were followed. The map layers were built up according to the topographic map design of Brewer (2015). The needs and demands determined in Chapter 4.3 were visualized. However, artistic freedom plays an important role in every map production process. This is also the case for this map design, as many design decisions are not only based on the guidelines but also on the personal taste of the designer.

CHAPTER 7

Phase 4: Map evaluation

The fourth phase of the UCD approach is to evaluate the map design in order to get informed feedback. Roth et al. (2015) described three methods for map evaluation, as discussed in Chapter 3. For this research, the user-based method was chosen. Conducting a survey allows for a larger number of participants than interviews and is not time-consuming for the participants. Moreover, it was possible to conduct the survey online.

A survey covering different topics was conducted with ski tourers, the target group of the map. This chapter first discusses the recruitment process and user study design in section 7.1. The results of this study can be seen in the next section 7.2. In the last section, 7.3, a conclusion summarizes the user study and the results.

7.1 Methods

7.1.1 Participants and recruitment

A total of 20 participants were recruited for the survey. Participants were recruited via the personal network of the author and professor Georg Gartner, the national student association for climbing in the Netherlands, and the mailing list for mountaineering students of Stanford University. The participants received a link to the survey hosted by Survey123 (Esri). Before continuing to the survey, the participants could read about the risks and data protection. Before the survey was sent for recruitment, it was tested by two people.

7.1.2 Design of the survey

The design of the survey existed of both quantitative and qualitative questions. The quantitative data were collected from single choice or Likert scale questions, while qualitative data were collected from open questions related to the participant's opinion on the maps.

The survey was split up into multiple pages with different topics, namely: general information, map legibility, understanding of the tour, assessment of avalanche risk, use of the map and final questions. In the sections map legibility, understanding of the tour and assessment of avalanche risk, the benchmark task of Roth et al. (2015) described in Chapter 3 is tested. In the final section, the satisfaction strategy of Nielsen (1992) is applied. The survey can be seen in Appendix E.

General information

This section asked for the participant's gender and age. Two questions were asked about ski touring. The first question was many days of ski touring the participant has done in his life, and the second was how many days per year the ski tourer. The second question was added for time reference and for people who have experience with ski touring in the past but no longer go ski touring.
After the general information, participants were prompted to open the map via the provided link in the survey and download it as a PNG file. The map that the participants received can be seen in Appendix D. In the provided map, four locations were added with a small circle and a letter; every ski tour shown on the map received a number. This made it possible to ask questions about these specific locations and routes. See Figure 7.1 for a small part of the map, including the exact Location A and D and Route 2 and 3.

Map legibility

For this section, the participant needed to examine the map thoroughly to answer the questions. The answers to the questions provided quantitative data. The questions were related to how well the participants can read the map. First, four questions on geography were asked, to find if the participant knew where the north is on the map and if the participant understood contour lines. Two questions were: "Is the Austriahütte north or south of Dahsteinhaus?" and "Is the Durchat peak higher or lower elevated than the alpine hut Walcheralm?".

During the test run, the participant took a long time to find the asked elements in the map. For this reason, an indication of the location of the elements was added to the survey: "Both elements can be found in the lower center of the map".

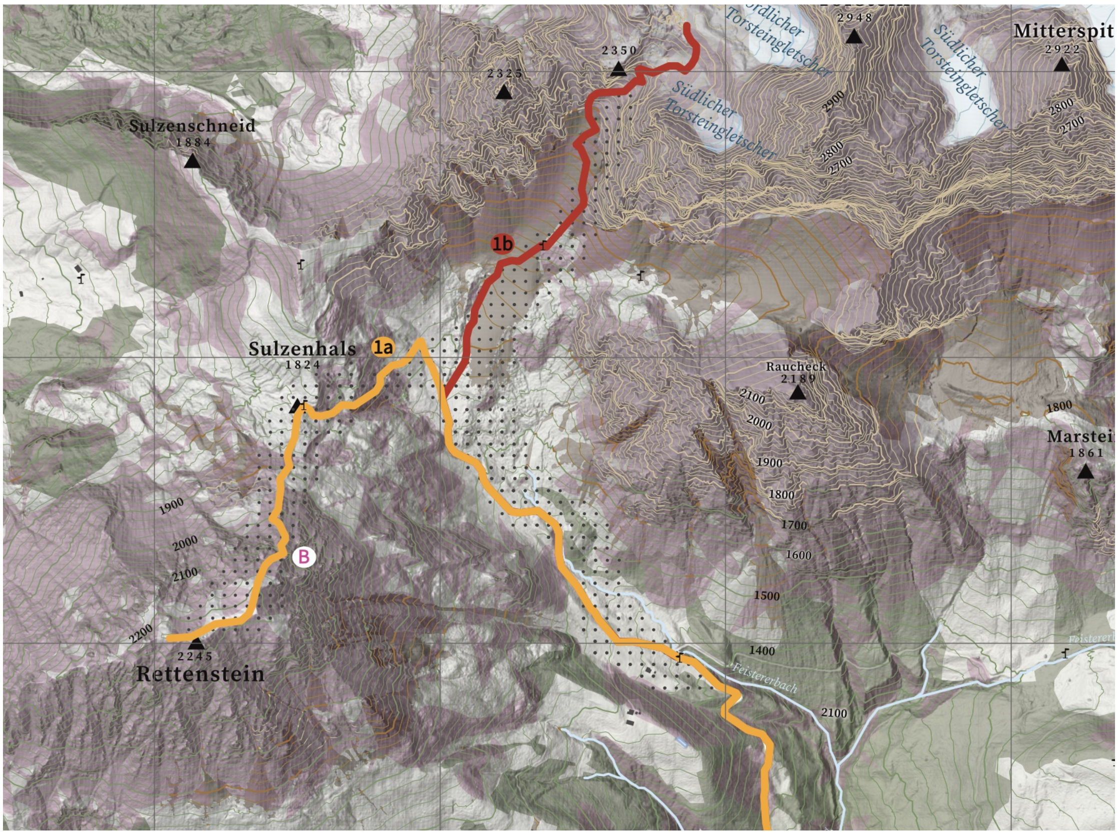

Figure 7.1: A small part of the map indicating specific locations and the routes.

The following three questions were related to the participant's understanding of the terrain cover and the morphological structure at specific locations. The first two questions asked about the land cover at Locations A and B. The third question asked if the morphological structure at Location C was a mountain ridge or a gorge. For this question, the participant had to understand the hill shading and the contour lines to answer the question correctly.

Understanding of the tour

This section explored the participants' understanding of the ski tours by asking three questions, which all provided quantitative data. The first question was, "how many kilometers is route 4 approximately". The participant had to check the scale and measure the route length for these questions. The participant had to use the legend for the second and the third questions. The second question asked what the dashed yellow line means, and the last question concerned the direction of Route 5.

Assessment of avalanche risk

As snow avalanches create a high risk for ski tourers, it is essential to know if the map is suitable for assessing avalanche risk. The participants were asked if an avalanche was likely to take place at locations D and B. To answer this question, participants are expected to know from previous ski tour experience that snow avalanches are most likely to occur if the slope is steeper than 30 degrees and that it is not likely for an avalanche to occur in forests areas. The next question asked the participants if this map was sufficient for assessing avalanche risks with a Linkert scale. Following this question, they were asked to elaborate on their answer.

Use of the map

The participants were given a Likert scale with three statements to rate the map's usefulness. The three statements were "This map is useful for planning a ski tour", "this map is useful for navigating a ski tour", and "this map is useful for reflecting a ski tour". The participants could choose between strongly disagree, disagree, neutral, agree, and strongly agree.

Final questions

On the last page of the survey were the final questions. This section started with a Likert scale and the statement "I like the design of this map". The following questions allowed the participant to write down if they would change anything on the map, if they missed any elements and if any elements on the map were unclear.

7.2 Results

In this section the result of the user study can be found. The qualitative results can be found in Appendix F. In the figures, the correct answer is provided in bold.

Description of the participants

This section provides an overview of the participants. Of the 20 participants, six were female, and fourteen were male. The age range was from 25 to 76, with a mean age of 46. Every participant had at least some experience in ski touring. There were five ski tourers very experienced who had made over 100 tours. Eight participants were experienced ski tourers who had made 25 - 100 ski tours. Five ski tourers were intermediate, and the final two ski tourers were novices with less

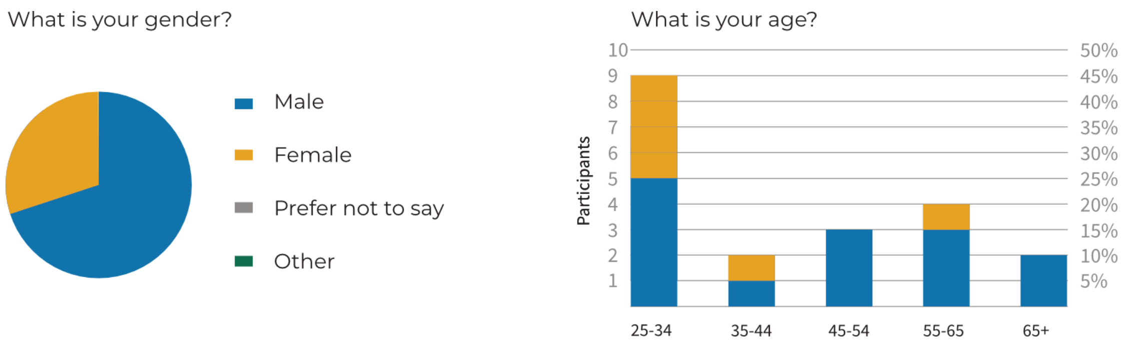

Figure 7.2: General overview of the participants

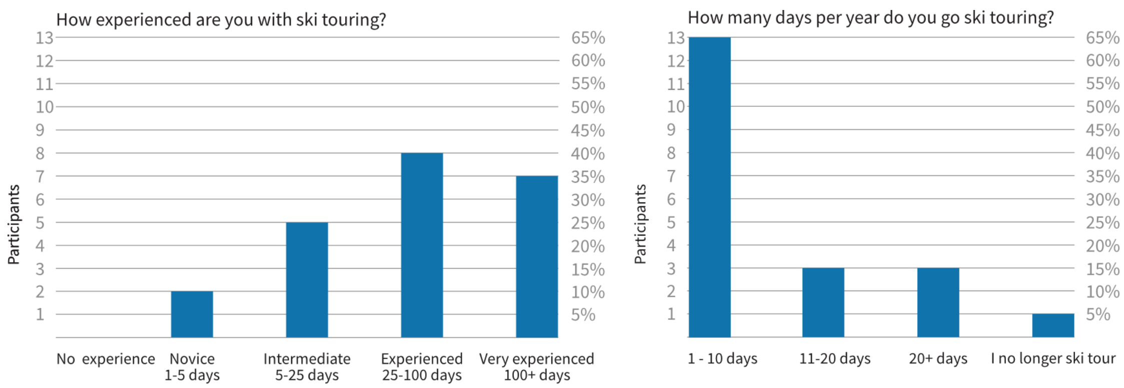

Figure 7.3: General overview of the participants's experience

than 5 tours. The majority of the participants stated that they ski tour 1 - 10 days per year, and three ski tourers 11 - 20 days per year and three 20+ tours per year. One participant no longer ski tours.

Map legibility

The participants were given the link to download the map in this section. The following questions focus on how well the participant can read and understand the map. The results of the first four questions can be seen in Figure 7.4.

The first question in this section was if the Austriahütte is north or south of Dachsteinhaus. The majority of the participants answered correctly that the Austriahütte is north of Dachsteinhaus. The two participants who answered south were the two novices in ski touring.

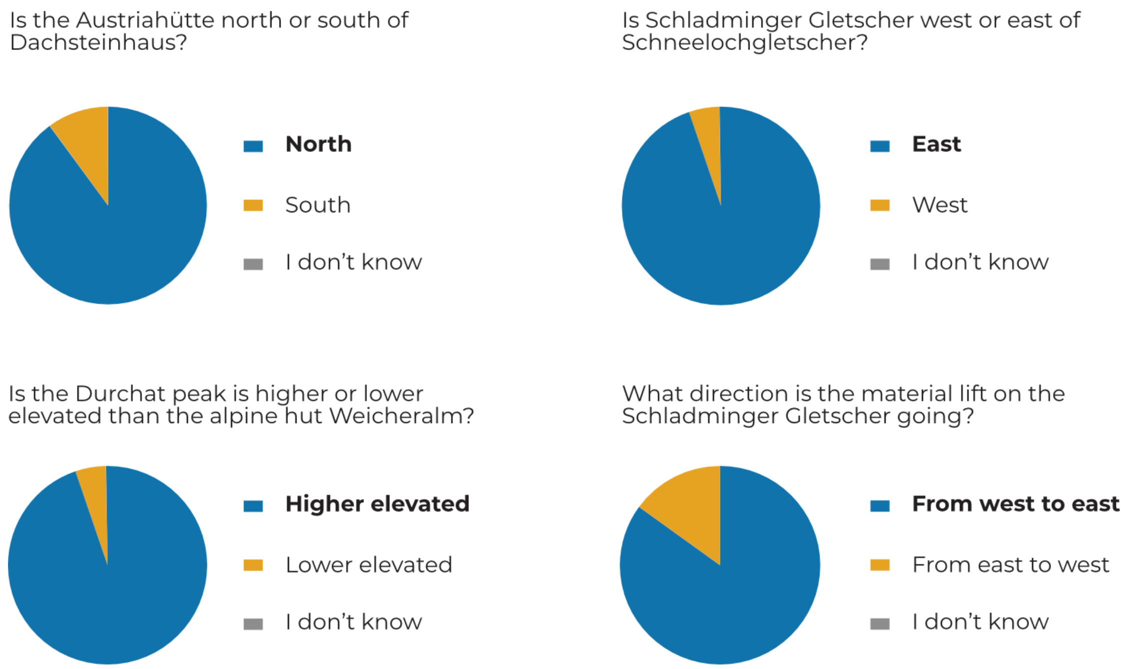

Figure 7.4: Results of the first four questions to the map legibility questions

The second question was whether the Durchat peak is higher or lower elevated than the alpine hut Weicheralm. Everyone except for one participant, a very experienced tour skier, answered this question correctly with higher.

The next question was whether the Schladminger Gletscher is west or east of Schneelochgletscher. Again, every participant except for one very experienced ski tourer answered this question correctly, namely that the Schladminger Gletscher is east of Schneelochgletscher.

The last questions was on what direction the material lift is going. The vast majority of the participants answered this question correctly, namely west to east. Three participants answered this question incorrectly; two were very experienced ski tourers, and one was a novice.

Participant 14 (P14) mentioned that they would change the legend and explain that green is the start of the lifts.

> P14: Adding a legend item explaining that green is the start of the lifts could be easy and nice, it took me a while to figure that out.

The following two questions relate to the morphological understanding of the map. The questions were to determine what the land cover at points A and B are.

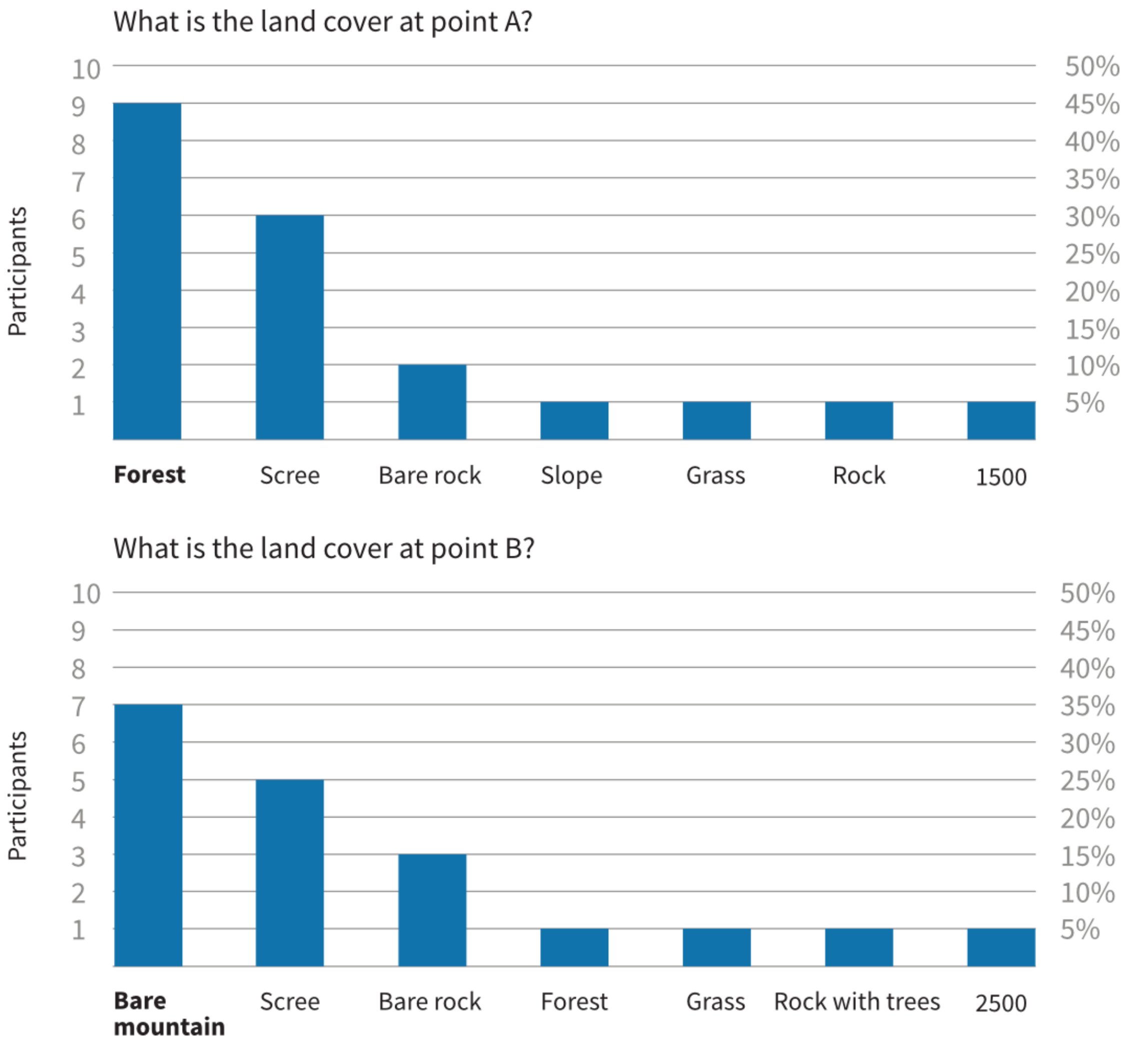

Figure 7.5: Results of two questions related to morphological understanding

The participants had more trouble answering these two questions. which can be seen in Figure 7.5. Nine participants answered correctly that the land cover at point A was forest, but only seven knew for point B that the land cover was bare rock. In total, only four participants answered both questions correctly. One participant understood the question incorrectly, as they gave the height of the location and not the land cover

The last question in this section was to determine if point C is along a mountain ridge or in a gorge. This question is answered correctly by everyone.

Understanding of the tours

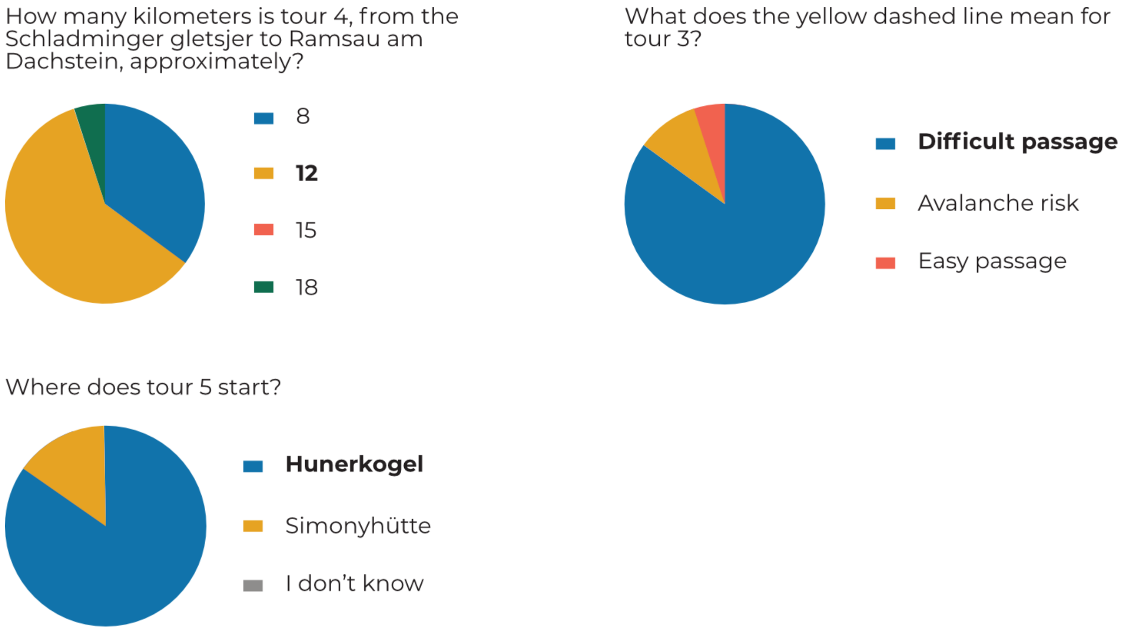

Figure 7.6: Results of the questions related to the understanding of the tour

This section started with the question of how many kilometers tour 4 is. A slight majority, 12 participants, estimated the length of the tour correctly. As the survey was filled in on a computer, zooming in and out changed the size of the scale bar, which could have made this question particularly difficult to answer. The participants might have had to zoom to the scale bar and then zoom to tour 4.

The second question was what the yellow dashed line meant for tour 3. The vast majority knew that the yellow dashed line means a difficult passage for tour 3. There was one participant who answered easy passage and two participants who thought it was meant for avalanche risk.

Two participants mentioned that the difficult passage marking is useful for planning a ski tour. Another participant wrote that they would change the color, as the color of the dashed line is similar to the color for an easy ski tour.

> P19: The "difficult passage" marking is definitely really useful.

P4: Yellow is for easy, but also for difficult passage.

The last question in this section was to determine where tour 5 starts. For this, the participants had to check the legend and understand that the left side of the stroke is the beginning part, with the green dot. 17 people answered this correctly, and 3 were incorrect. Interestingly, out of the three people answering this incorrectly, two also answered the question of where the material lift is going incorrectly. Two participants mentioned that it was unclear where the lifts start.

Assessment of avalanche risk

This section of the survey tests if the map is suitable for avalanche assessment. The first two questions were if it was likely for a snow avalanche to happen at locations B and D, the results can be seen in Figure 7.7.

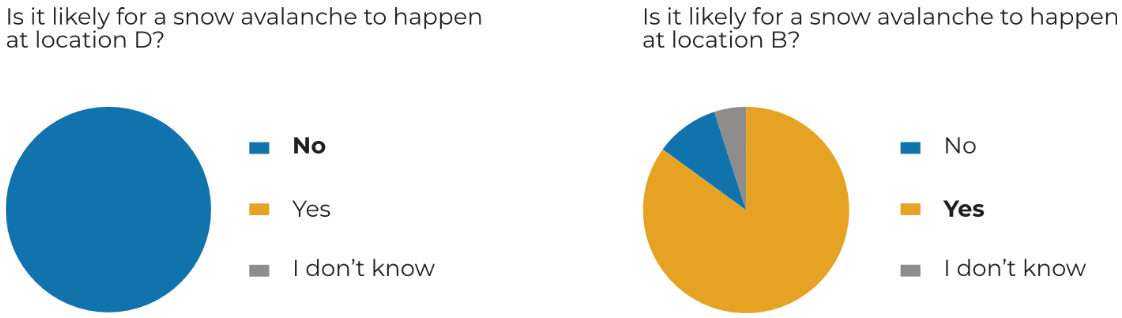

Figure 7.7: Results of the questions if a snow avalanche is likely to happen

All the participants assessed that it was not likely for an avalanche to happen at location D on the map. For location B, however, participants 16 and 11 answered no, and participant 20 responded that they didn't know.

The third statement in this section is if the map provides the map user with enough information to assess the snow avalanche risk. About half of the participants disagree and say that the map does not provide enough information, and three strongly disagree. The result can be seen in Figure 7.8

The three participants who strongly disagreed with this statement are all experienced ski tourers. They elaborated that a map is a necessary tool for assessing avalanche risk but that more information is needed to assess the avalanche risk, besides the slope and land cover. One of them, participant 13, said the following.

P13: The map shows terrain cover and slope angle, which are most useful in context of the snow condition for assessing avalanche risk.

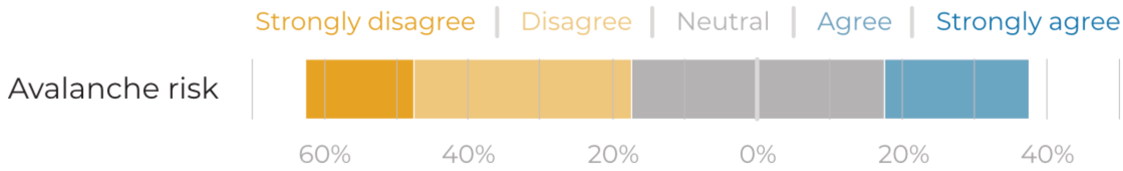

Figure 7.8: Results of the statement the map is useful to assess avalanche risk

> Without the context of snow condition and history, this map is not very useful with the exception of choosing very conservative lines to minimize avalanche risk across all possible snow conditions (like point D).

> P18: What is the current snow condition? What is the avalanche bulletin of today? What is the typical problem at hand at this moment?

The six participants who disagreed with this statement also mentioned that a map alone is not enough for assessing avalanche risk. Some participants also mentioned that it would be useful to know the history of avalanches in the area and the aspect.

> P16: It is helpful to have differentiation between terrain types and distinction given to terrain over a 30 degree slope angle. However, this information alone is not enough to assess avalanche risk - weather and snowpack conditions are also vital information for assessing avalanche risk, especially for routes that traverse more difficult terrain. Information about historic avalanche locations would also be extremely helpful.

Seven participants were neutral on this statement; one novice mentioned that his knowledge of avalanche assessment was too limited. Another participant responded that the map gives approximate slope angle, forest cover, and terrain features like ridges which are useful for assessing avalanche risk but are far from complete without up-to-date avalanche forecasts for the specific terrain feature.

The three participants who agreed with the statement mentioned that the slope > 30 degrees is helpful, but that it is still hard to distinguish sometimes.

> P11: The colour used for the >30 degrees slope is at some place hard to distinguish from the basic map colours. I would add a sample of distance between contour-lines for a 30 degrees slope into the map

> legend. Or a kind of scale for contour line distances between 20 and 40 degrees. P14

In hindsight, the statement should have been phrased differently, namely "this map is a useful tool for assessing avalanche risk". As explained in chapter 2.1.5, avalanche risk depends on four factors, and only one of those four can be mapped, the terrain. So assessing an avalanche is never possible from a map alone.

Use of the map

This section presented the participants with three statements on the usability of the map and asked the participants to elaborate on their answers.

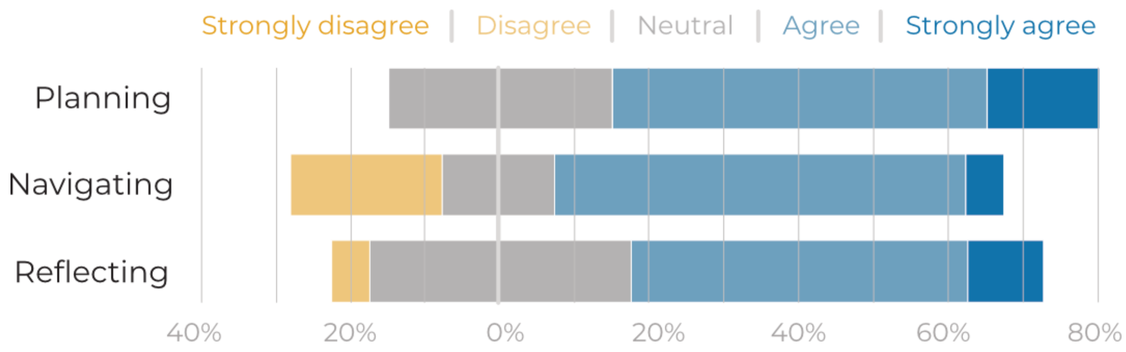

Figure 7.9: Results of the statements on usefulness of the map

The majority of the participants agreed that this map is useful for planning a ski tour. Six participants were neutral, and no one disagreed. The participants mentioned that a scale of 1:25.000 is essential for planning.

> P13: The map has many major features that might be useful to a skier, has common routes, particular hazards are marked, and it is easily readable.

> P3: Slope indication is very useful, including the indication of the terrain. Downhill indication is a nice feature.

Some participants said they would like more information on the ski tour. Two participants thought that the colors of the slope are too similar to the color of scree. Others mention that slope shading is very useful. Participant 9 wrote that they are only missing the height of the alpine huts.

The following statement was on how useful the map is for navigation during a ski tour. The majority of the participants agreed that this map is useful for navigation during a ski tour. Four participants disagreed, and the rest was neutral.

The participants had conflicting opinions on how detailed the map should be for navigation. Two of the participants who disagreed with the statement mentioned that the map is not detailed enough, while another disagreeing participant said that the map is probably too large-scaled for navigation. One agreeing participant said that a more simplified map would be easier for navigation.

> P10: I'd like to have a map with more detail.

> P13: The map is useful for navigation during the tour, by listing obvious cues like lifts, peaks, elevation, and surface cover. The map however is crowded and busy. Making a more simplified map with just the tour(s) you're concerned with for that day could be more easily readable for navigation during the tour.

Three participants mentioned that they prefer to use a GPS for navigation and would use the map if it would be available on their phones. Other participants mentioned that the colors of the contour lines are sometimes hard to distinguish, especially the green on green. The participants also mentioned that the fonts are quite small, especially the fonts indicating the height.

The last statement of this section was on how useful the map is for reflecting on a ski tour. Seven participants were neutral on this statement. The main reason for their neutrality was that they did not understand the question or simply just do not reflect on the ski tour. The one participant who thought this map was useless for reflecting said they reflected on the ski tour with GPS tracks and photos.

Final questions

The last section contained a statement on the design of the map and three questions on the participants' opinions on the map elements.

The majority, 13 participants, agreed that they like the map's design. Three of them strongly agreed with the statement. Four participants were neutral on the design of the map. The other three participants did not like the design of the map.

The next question was an open question on if the participants missed any elements on the map. Participants missed the height of the alpine huts, settlements, and glacier crevasses on the map. The following elements were missed by one or two

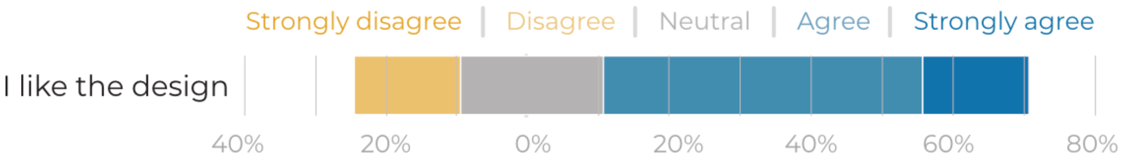

Figure 7.10: Results of the statement on the design of the map

participants: a legend that clarifies how the counter line colors are used, the elevation profile of the tours, the summer trails, glacier crevasses, and the descent option. Two participants from the United States mentioned that they would prefer more information on parking possibilities.

Regarding what participants would change on the map, the font size of the labels was often mentioned, especially of the contour lines. However, it is difficult to estimate how large the font size is on the printed map, as the map was shown to the participants on a computer screen. The participants would also choose different contour lines' colors for more contrast. Some participants mentioned that they prefer the avalanche risk to be in more classes in a smaller range of slope values. Another participant mentioned that the map might be too detailed, depending on the printing format. Participant 14 would add a visualization for previously occured avalanches.

> P14: Would it be possible to flag high avalanche areas based on where lots of previous avalanches have been seen/reported?

Elements that are unclear in the map for two participants are the start and finish of the lift. One of them suggested having an explanation in the legend. Two other participants had trouble understanding the downhill area.

The opinion on the downhill area indication was diverging. It was unclear to three participants what the downhill area meant.

> P1: downhill areas appears after you have planned your tour?

However, participant 4 mentioned that it was a nice feature. On the other hand, two participants had not noticed this area and mentioned that it would be useful if descent options were shown.

One participant would like to receive more information on the route; if the routes are physically or technically demanding, if the difficulty is uphill or downhill, and if additional equipment like crampons and ropes are required.

7.3 Conclusion

The user study's results show that the participants have diverging performances and opinions on the map design.

The participants' performance on the map legibility was high, except for the two questions concerning the land cover at locations B and D. The participants had trouble interpreting the contour lines' colors over the pink shading of the slope. The participants had a good understanding of where the tours started and of the difficult passage.

For the assessment of the avalanche risk, the participants mentioned that more information is needed to assess avalanches than can be provided on the map. The participants had trouble distinguishing the colors for the slope, the base map, and the contour lines.

Most participants agreed that the map is useful for planning, navigating, and reflecting on a ski tour. Most participants agreed that they like the map design.

The survey was conducted on a computer, and participants only had access to a digital version of the map, while it was designed to be printed in A2 format. This has most likely influenced some participants' performances. Especially on the question to estimate the length of tour 5, since they had to zoom in and out to answer this question. Moreover, recurrent feedback was that the font size was too small. This could have been caused by viewing the map on the screen instead of as a printed map as well, as the screen does not display the map in its original size.

Some participants were recruited via the mountaineering network of Stanford University. The needs and demands were partly based on comparing European maps and interviews with European citizens. Ski tourers in the United States can have different needs and demands, for example, the parking possibilities at the start of a tour.

Concluding, the participants excelled at map legibility and understanding of the tour. Elements that were hard for the participants to understand were the colors for both the contour lines and the slope representation.

CHAPTER 8

Phase 5: Map improvement

The next and final phase in the UCD framework of this research was to use the results from the user evaluation to improve the map design according to their needs. This section describes which changes in the map were made.

The recurrent feedback from the participants in the survey was on the color choice of the contour lines and the slope representation. Because the green contour line on forest land cover was hard to differentiate from the green background, those contour lines were made darker green. This creates more contrast with the background. Furthermore, the counter line color of bare mountain was changed from green to brown, so the map users can detect the land cover from the contour only.

Other recurrent feedback was that the font size was too small, especially of the height indications. This could be because the map was viewed on the computer. Nevertheless, the font size was increased, and more white halos were added to increase the legibility. Moreover, more contour lines' heights were added. These changes can be seen in Figure 8.1.

Other minor changes were the added height indications at the huts, and the symbol of the huts was changed to a simpler symbol. This can be seen in Figure 8.2.

Another element that was added to the map to help assess avalanche risk was a pictogram at the location of major previous avalanche occurrences. The data is obtained from LAWIS (2022), a website showing Austria's major avalanches since 2010. Figure 8.3 shows an example of this.

Some participants mentioned that they wanted different ranges in the slope representation. However, due to the colorful layers below the slope shading, having different colors for the slope steepness would be too busy and unreadable. Therefore, there is still one color for the slope shading.

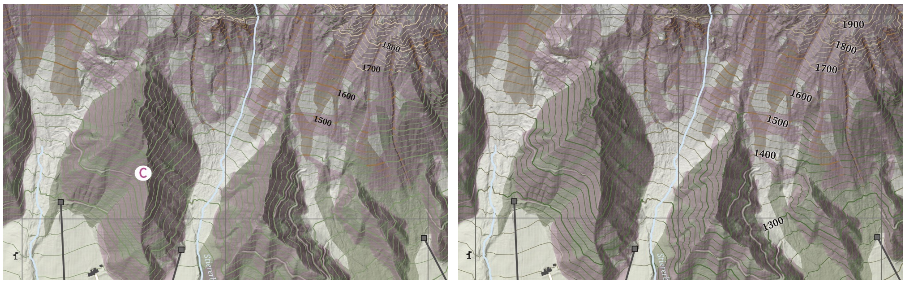

Figure 8.1: Different contour lines, height indication, label size between the map design(left) and improved map design (right)

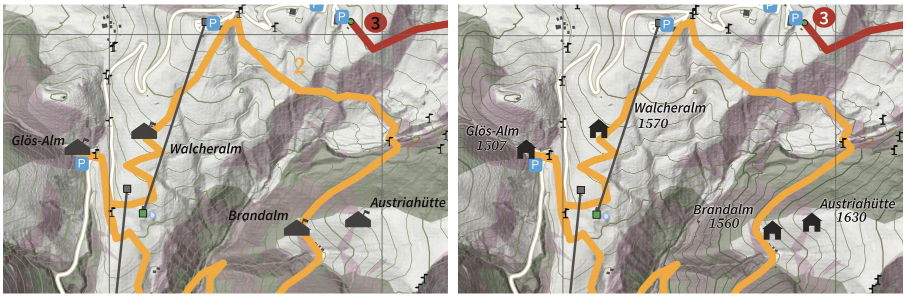

Figure 8.2: Different symbol and no height indication for the hours on the original map design compared to the improved map design (right)

Figure 8.3: Symbal indicating the location of earlier avalanche occurence

The feedback given by only a small minority of the participants was carefully checked against the needs and demands determined in Chapter 4.3 and the rest of the participants' feedback.

This is done for the visualization of summer hiking trails. In Chapter 4.2 can be read that ST3 and ST4 both mention that they use the summer paths for navigation. However, this was not added to the first version of the map in phase 3. In the user evaluation, only one participant missed this information. Therefore, the summer trails were not added to the second version of the map.

Two participants wished for more parking information. This was mentioned by participants from the US, where parking can be a more significant issue than in Europe. Therefore, no changes to parking information were made.

On the other hand, two participants mentioned adding the height of the huts. With the insights obtained from interviews and comparing maps, this information is considered valuable and added to the map. Moreover, only one participant mentioned adding a height profile for the tours, and another participant asked for the distance between the contour lines. Again, this was considered valuable and was added to the map.

Moreover, one participant in the survey mentioned that the color yellow for difficult passages was confusing since the color was similar to the easy ski tour color. Therefore, the color of the dashed line was changed from yellow to white to prevent unnecessary confusion.

The final result of this map design can be seen in Figure 8.4 and in Appendix G.

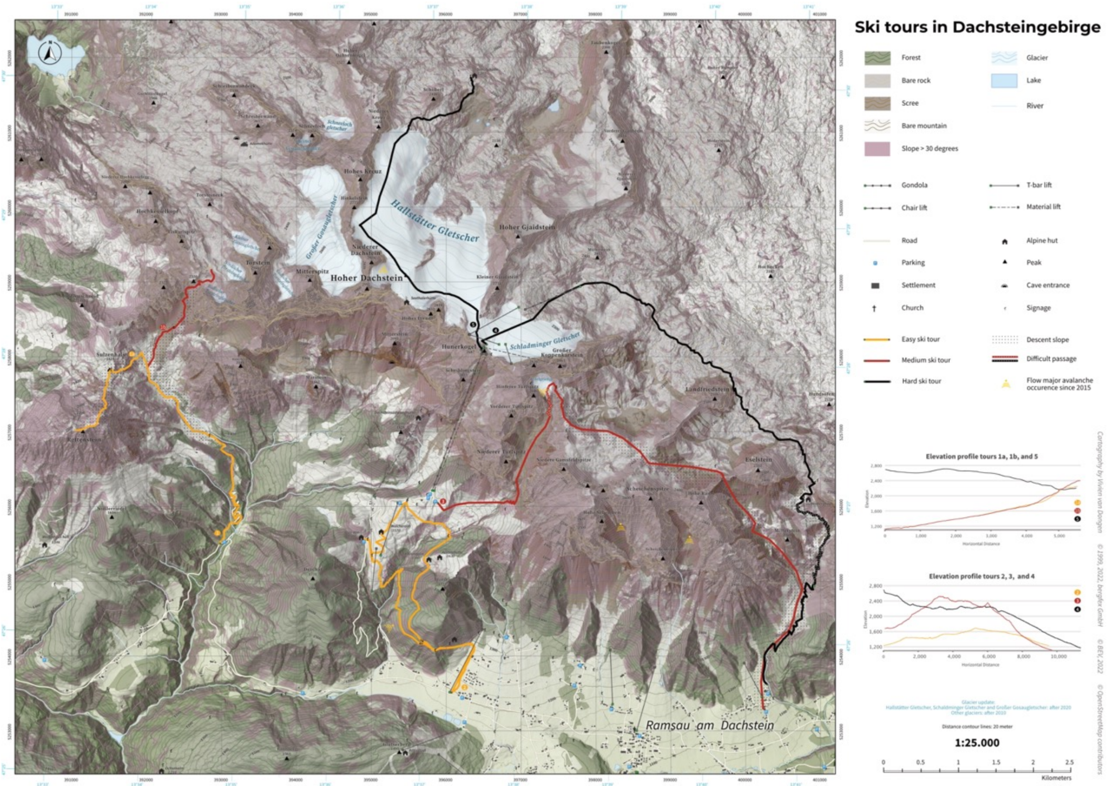

Figure 8.4: Final user-centered ski map design

CHAPTER 9

Conclusion and limitations

This research fills the cartographic gap with a new user-centered ski touring map design and a new UCD framework that directly links the ski tourers' needs and demands to the map design. The first section of this chapter discusses the conclusions, followed by the limitations of this research in the following section. In the last section, future work is described.

9.1 Conclusion

This study's leading research objective was to create a user-centered ski touring map design following a UCD framework, solely using open data. This approach is beneficial for the creators of the ski touring maps in guidebooks, as this allows them to create high-quality maps within a limited budget. The main objective was split up into three research objectives (RO's).

RO 1 Examining the needs and demands of ski tourers for ski touring maps.

Based on the in-depth literature review in Chapter 2, the comparative map design in Chapter 4.1, and the interviews with the ski tourers in Chapter 4.2, the needs and demands of ski tourers were defined. The in-depth literature provided more information on how ski tourers navigate, the use of GPS during ski tours, and avalanche risk. The map comparison on state-of-art answered the research question of what was currently present in ski tour maps and gave more insight into the artistic freedom in ski touring map production. The interviews with the ski tourers gave a better understanding of their opinion on the current maps and how the maps could be improved. They also mentioned how they assess avalanche risks, how maps can be a helpful tool for this, and what important elements on ski touring maps are. In short, the needs and demands for a ski touring map is a topographic map with a scale of 1:25.000. The map should contain detailed information on the slope with contour lines and preferably shading. Also, the height indications and specific points of interest, such as lifts and mountain huts, are important to depict.

RO 2 Applying a user-centered framework to a ski touring map design using open data.

The research question accompanying this research objective was if a user-centered framework can be successfully applied. For this research, a combination of the UCD approaches of Roth et al. (2015) and Tsou and Curran (2008) was applied to the map production process of Darkes (2017), resulting in a new UCD framework. This framework consists of five phases and was applied successfully to the map design. The users were involved by conducting interviews and a user study. The new map design was created in this phase using only open data. Most data was downloaded from OpenStreetMap. However, OSM does not contain data about elevation, so the Austrian government's openly available DEM was used.

RO 3 User testing the new map design in terms of map use in order to fulfill the user-centered framework.

To evaluate the new map design, a survey was conducted with 20 ski tourers. They were asked questions about their understanding of the map and its ski tours and the usefulness of the map for assessing avalanche risk. The participants were also provided with four statements on the map's usefulness for planning, navigating, reflecting, and the map's design. The research question answering this research objective was if the map design meets the needs and demands of ski tourers and if new needs and demands came to light during the user study.

Most participants were able to assess avalanche risk from the map. However, they agreed that the map was not useful for avalanche risk assessment because avalanche risk is not only dependent on terrain and slope. The majority of the participants agreed that the map was useful for planning, navigating, and reflecting. They also agreed that they like the design of the map.

From recurrent feedback received on the survey was clear that some participants had trouble understanding the colors for the contour lines, land cover, and slope shading. Other feedback was that the font size of the height indications was too small. New needs and demands that came to light were more information on the ski tour itself and more details about the history of avalanches in the area.

Therefore, the needs and demands of the ski tourers were partially met in this phase of the research. Even though the map was considered useful for planning, navigation, and reflecting, elements were still missing or hard to understand.

All the feedback was taken into account, and changes on the map were made. The colors of the contour lines were changed to create more distinction between the contour lines and the land cover and slope shading. Newly added elements were the elevation profiles, the height of the huts, and previous avalanche occurrences. Moreover, more height indications of contour lines were added.

No user study was done on the improved version of the map design. Given the feedback considerations and the map's improvement, the overall research objective was met; a new user-centered design for ski touring maps was created successfully. Overall, this research showed the application of a UCD framework to a static topographic ski touring map production. The framework developed in this research advanced the quality of the ski touring map by putting the user central in the development process. This led to a tailored and readable map for ski tourers. Given the feedback considerations and the map's improvement, the overall research objective was met; a new user-centered ski touring map design, following a UCD framework, was successfully created with open data.

9.2 Limitations

The scope of this research is focused explicitly on paper maps for ski touring. The outcome of this research is a user-centered paper map for ski touring. The map design is made for the Schladming-Dachstein area in Steiermark in Austria. This map design is usable for other areas. However, only elements occurring in the Schladming-Dachstein have been designed.

As the focus of this research was to create a map design for ski touring, the map design is not usable for winter sports disciplines like the traditional downhill skiing in ski resorts. Creators of winter sports maps that are more similar to ski touring, like free-riding, cross-country skiing, and snow boot hiking, might benefit from and be inspired by this map design. However, only by applying a user-centered design framework can this be confirmed.

Five interviews were conducted with ski tourers in Chapter 4.2. It was tried to have a sample representation of the ski tourers by interviewing ski tourers of different ages, nationalities, and experiences. Nevertheless, only five interviewees may not have representative opinions and needs and demands of the larger ski touring population. More interviews would have given more insight into the needs of demands of the target users as opposed to the demands of the five individual users.

Open data from OSM and Bundesamt für Eich- und Vermessungswezen (2022) was used for this research. The data of the Bundesamt für Eich- und Vermessungswezen (2022) is continuously updating. However, since volunteers collect the OSM data, this data can be outdated, as was the case for the smaller glaciers in the Dachtstein area. Even though this did not limit this user-centered map design itself, it does limit the map's accuracy.

Twenty ski tourers of different levels completed the user test in this research. The disadvantage of this user test was that the survey was conducted on a computer. The map design was made for printing in A2 format. Showing the participants the map design on the screen could have influenced their understanding of the map, consequently, their performance and feedback.

In hindsight, the question in the survey on the usefulness of the map to assess avalanche risk should have been phrased differently. Avalanche risk cannot be assessed by solely using a map. A map can be a useful tool for the assessment, but other factors that should be taken into account by ski tourers are the snowpack, weather conditions, and the human factor. Therefore, most answers to this statement addressed the problem of this statement and not if the map was a useful tool.

9.3 Future work

Further research could incorporate software for implementing the Swiss rock-style visualization in the map design. The current rock visualization in the final map design provides limited details on the rock characteristics. The creation of Swiss rock-style visualization is time-demanding and cost-intensive. However, software exists to recreate this style. Incorporating this software in the production of this map design would provide more detailed rock information to the ski tourer and improve the ski touring map design's accuracy.

In the case of ski touring maps design, future research should evaluate the map design's usefulness with in-situ user tests in addition to the survey evaluation. This could involve experiments in navigation, local snow avalanche assessment, and spatial awareness. Feedback and results of the in-situ experiments could be used to improve the user-centered map design.

For this research, a new UCD framework, guided by UCD approaches of Roth et al. (2015) and Tsou and Curran (2008), was created. However, different UCD approaches can be combined and guiding for the production of static map design. Future research could evaluate the application of different UCD approaches to static map production to find an optimal UCD approach for static map design.

Moreover, as is explained in Chapter 3, iterating the user-utility-usability loop is essential. The more times the loop has been iterated, the more feedback from the user can be used to improve the map. Due to time restrictions, the UCD framework of this research only allowed for one iteration. Therefore, no user feedback was received after the second (and final) map design. However, a new iteration of user feedback could have been beneficial for concluding if all the needs and demands of ski tourers are met. Future work could focus on the benefit of more UCD iterations and the tradeoff between more iterations and time and costs in UCD frameworks.

List of Figures

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Appendix A: Ski touring maps

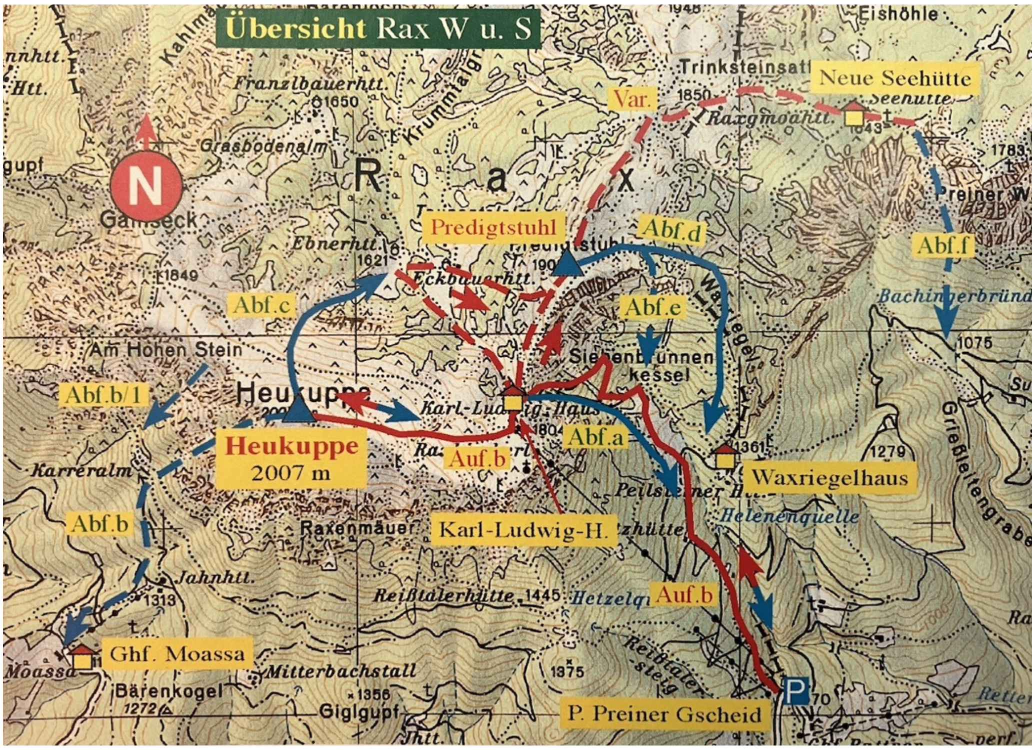


Figure A.1: Map A

Figure A.2: Map B

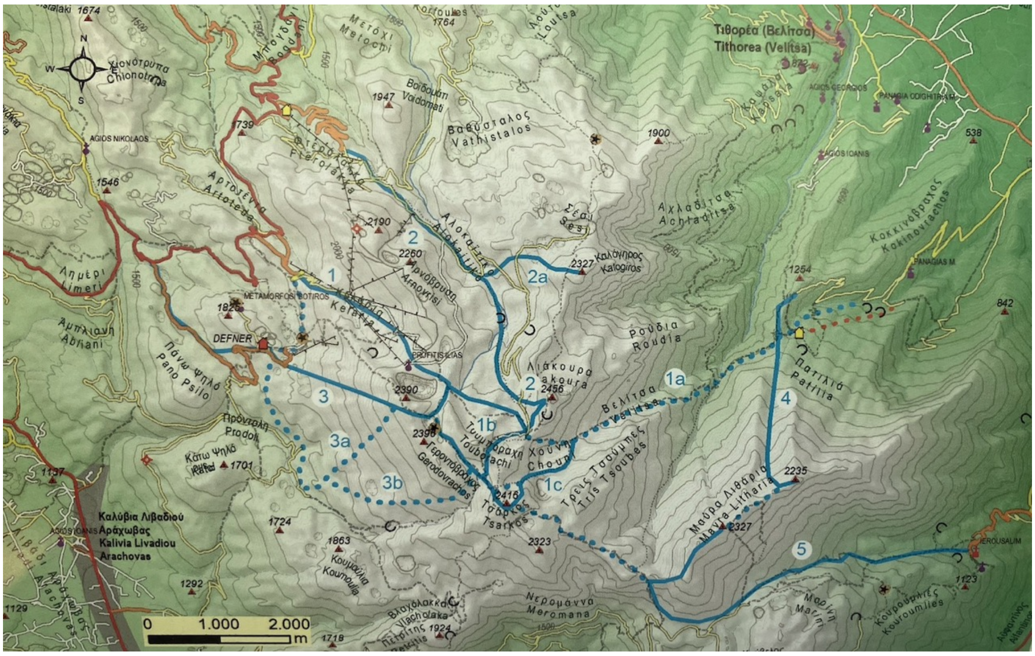


Figure A.3: Map C

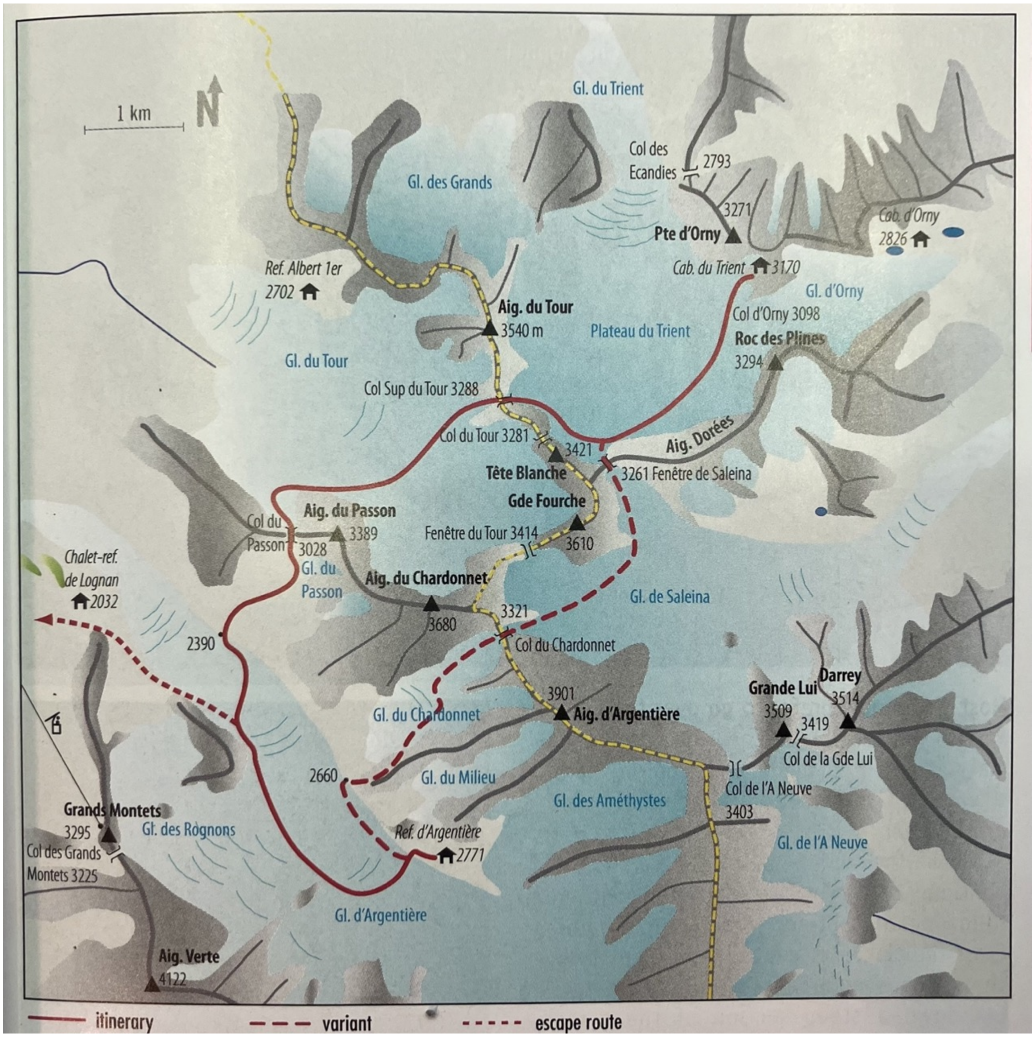


Figure A.4: Map D

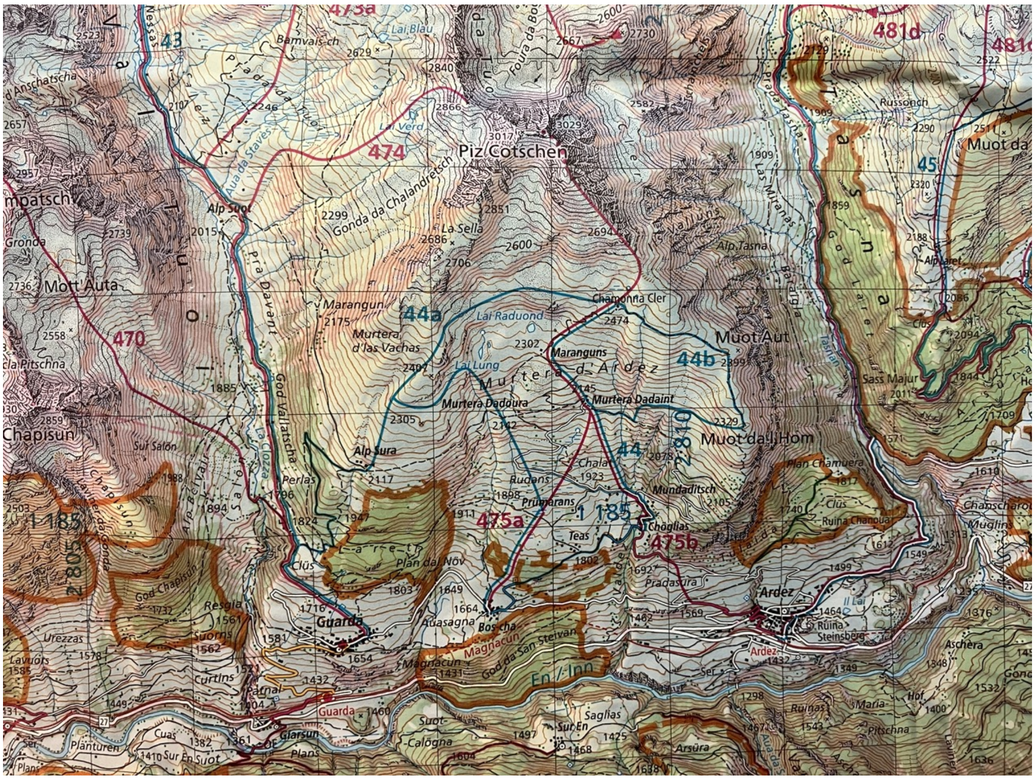


Figure A.5: Map E

Figure A.6: Map F

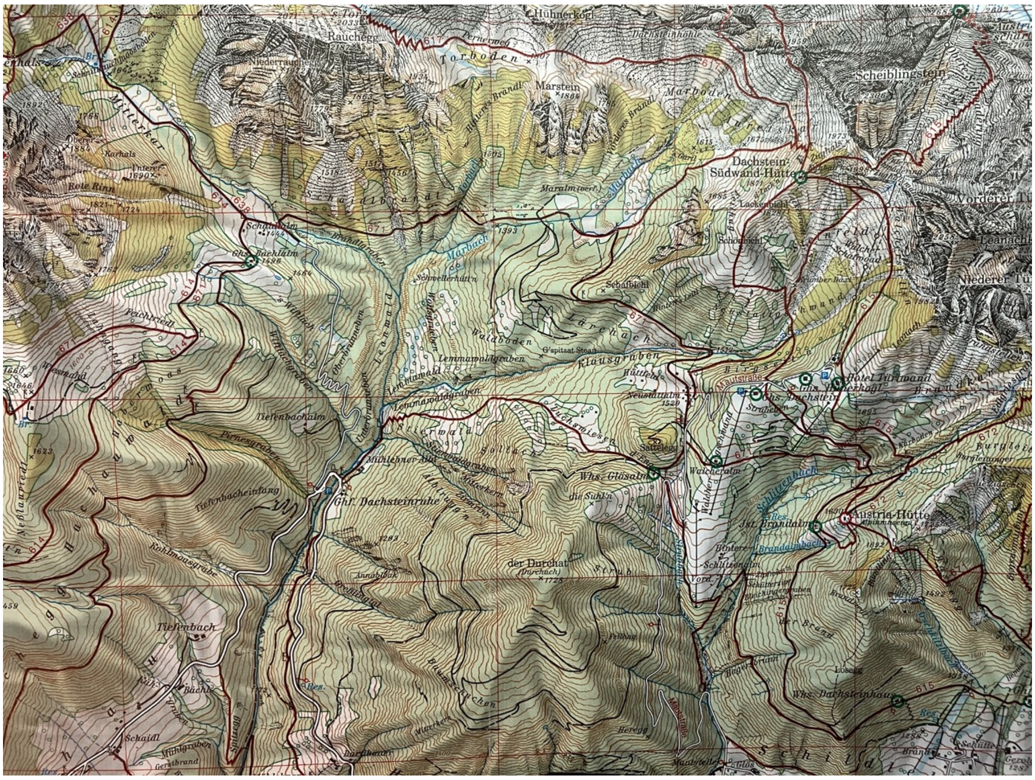


Figure A.7: Map G

Appendix B: Map comparison

Base map	**Map A (Schall-Verlag)**	**Map B (berg&karte)**
	Östereichische Karte (ÖK) of BEV	Östereichische Karte (ÖK) of BEV, but with winter oriented visualization
Terrain representation	Topographical	Topographical
Perspective	Orthogonal	Flying over the area, 3D visualisation on 2D map
Hill shading	Lightning from northwest	Lightning from northwest
Contour lines	Shown with 20 meters distance	Shown with 20 meters distance
Geomorphology		
Terrain	Landcovers are shown	Landcovers are shown
Peaks and ridges	A small cross and the height	A small cross and the height
Slopes	Hill shading and contour lines	Hill shading and contour lines
Rock, cliffs	Hachure technique	Hachure technique
Trees	Distinction between forest, brush and reeds	Distinction between forest, brush and reeds
Water	Rivers and brooks	Rivers and brooks
Snow and Ice	Not shown	Not shown
Glaciers	Shown, including contour lines	Shown, including contour lines
Land form	Shown	Shown, can be distorted by view
Manufactured		
Trails	Red line for ascending, blue line for descending	Red line for ascending, blue line for descending
Settlements	Shown as individual buildings or as unity, depending on size of buidling	Shown as individual buildings or as unity, depending on size of buidling
Roads	Variety of roads	Shown
Point of Interest	Shown with a pictogram	Shown with a pictogram
Nomenclature		
Signage of the trail	Shown	Not shown
Peak names	Pictogram and extra layer of text labels with peak height	Text from base map, little cross with name and height peak
Water	Text label for bigger rivers	Text label for bigger rivers
Point of interests	Pictograms on top of basemap used to denote parking, huts. Also POI's in base map	Only POI's from base map
Settlements	Shown, size of font indicated size of settlement	Shown, size of font indicated size of settlement
Cartography		
North Arrow	Shown, map is facing north	Shown, map is not facing north
Scale	1:50.000, not displayed on map	Ök is originally 1:50.000, but
Color usage	Strong colors for trails	Strong colors for trails
Visual hierarchy	High visual hierarchy between mapped trails and basemap	High visual hierarchy between mapped trails and basemap

Base map	Map C (Anavasi)	Map D (JMEditions)
	Shaded relief map	Graphic map
Terrain representation	Elevation	Sketch
Perspective	Orthogonal	Orthogonal
Hill shading	Lightning from west	Not shown
Contour lines	Shown	Not shown
Geomorphology		
Terrain	Little	Difference between glacier, ridges and some green
Peaks and ridges	A small triangle and the height	A small triangle and the height
Slopes	Hill shading and contour lines	Not shown
Rock, cliffs	Not shown	Not shown
Trees	Not shown	Not shown, only vegetation
Water	Shown with blue line	Shown with blue line
Snow and Ice	Snow colors above certain height	Not shown
Glaciers	NA	Shown, including crevasses
Land form	Shown	Not shown
Manufactured		
Trails	Blue line, alternative routes in either red or dashed blue	Shown as red line, alternative option is dashed red
Settlements	Shown as grey polygon	Shown as grey dot, size depends on size settlement
Roads	Variety of roads	Shown as black line
Point of Interest	Pictograms for huts and churches	Pictogram for huts, chalets, parking
Nomenclature		
Signage of the trail	Shown	Not Shown
Peak names	Not shown	Triangle with name and height
Water	Text label for bigger rivers	Text label for lakes
Point of interests	Churches are indicated with name	Huts are indicated with name
Settlements	Shown	Shown, with height and name
Cartography		
North Arrow	Shown, map is facing north	Shown, map is facing north
Scale	No consistent scale	Consistent scale, 1:100.000
Color usage	Strong colors for trail	Strong
Visual hierarchy	High visual hierarchy between mapped trails,roads and basemap	High visual hierarchy between mapped trails and basemap

Base map	**Map E (swisstopo)**	**Map F (OAV skirouten)**	**Map G (OAV weg und ski)**
Terrain representation	Topographic	Topographic	Topographic
Perspective	Orthogonal	Orthogonal	Orthogonal
Hill shading	Lightning from northwest	Lightning from northwest	Lightning from northwest
Contour lines	Shown with 20 meters distance	Shown with 20 meters distance	Shown with 20 meters distance
Geomorphology			
Terrain	Landcovers are shown	Landcovers are shown	Landcovers are shown
Peaks, ridges	Small cross and height	Small cross and height	Small cross and height
Slopes	Hill shading and contour lines and pink shading	Hill shading and contour lines	Shown with hillshading and contour lines
Rock, cliffs	Hachure technique	Hachure technique	Hachure technique
Trees	No distinction between grass and forest	Distinction between different forests	Distinction between different forests
Water	Shown	Shown	Shown with blue
Snow,Ice	Not shown	Different colors than weg und ski	Not shown
Glaciers	Shown, including contour lines	Shown, including contour lines	Shown, including contourlines
Land form	Shown	Shown	Shown
Manufactured			
Trails	Shown as pink lines	Shown as pink lines	Blue half transparent line for ski trails, red for hiking
Settlements	Shown as individual buildings	Shown as individual buildings	Shown as individual buildings
Roads	Variety of roads	Variety of roads	Variety of roads
Point of Interest	Pictograms	Pictograms	Pictograms
Nomenclature			
Signage of the trail	Shown	Shown	Shown
Peak names	Name and height	Name and height	Name and height
Water	Shown	Shown	Shown
Point of interests	Shown	Shown	Shown
Settlements	Shown	Shown	Shown
Cartography			
North Arrow	Shown	Shown	Shown
Scale	Not in legend	Pictograms	Pictograms
Color usage	Shown	Shown	Shown
Visual hierarchy	High visual hierarchy between mapped trails and basemap	High visual hierarchy between mapped trails and basemap	High visual hierarchy between mapped trails and basemap

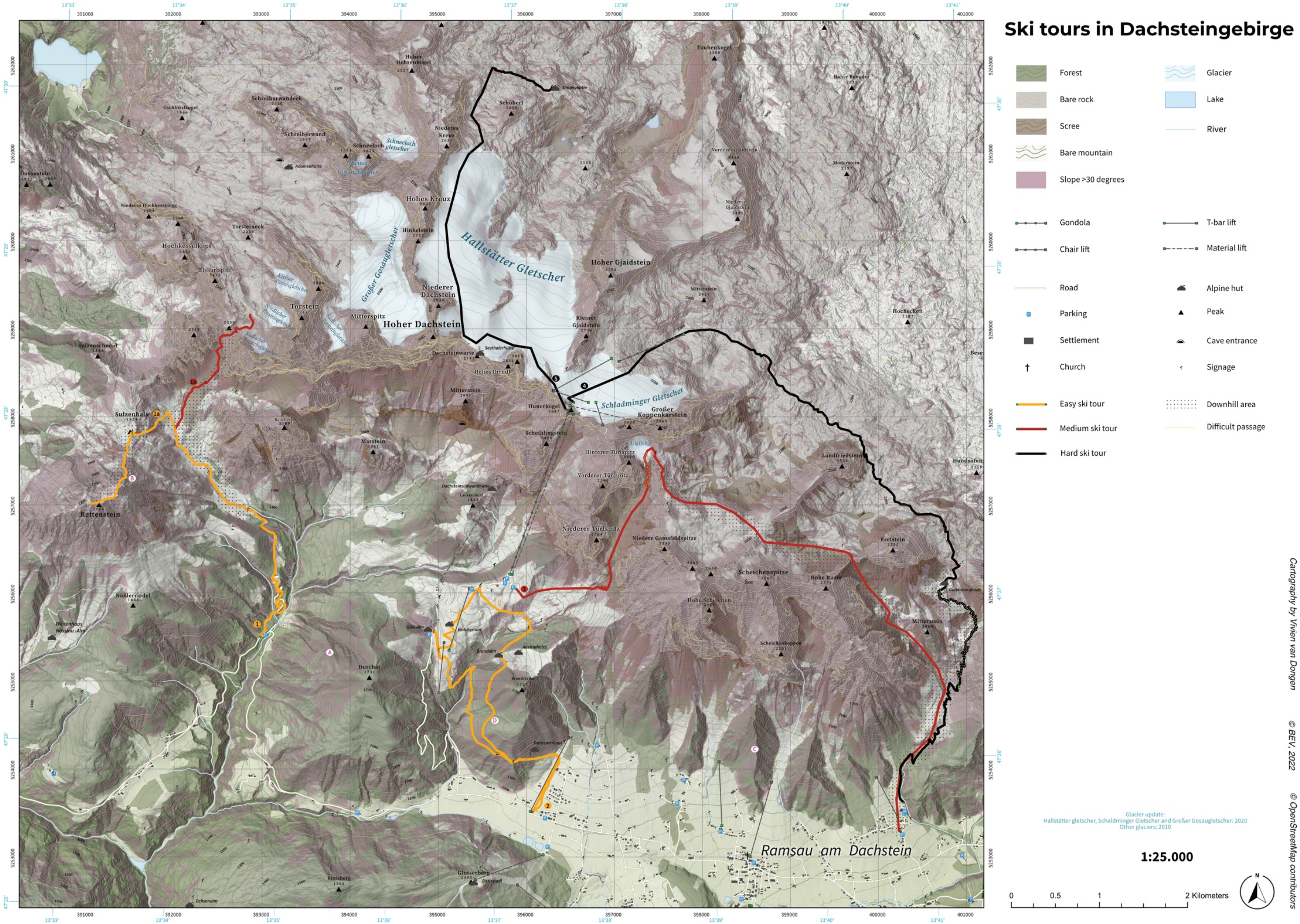
Appendix C: Interviews

https://kartoweb.itc.nl/msc-carto-thesis/materials/vivien_van_dongen/

Appendix D: Map design phase 3

https://kartoweb.itc.nl/msc-carto-thesis/materials/vivien_van_dongen/

Ski tours in Dachsteingebirge



Appendix E: Survey

https://kartoweb.itc.nl/msc-carto-thesis/materials/vivien_van_dongen/

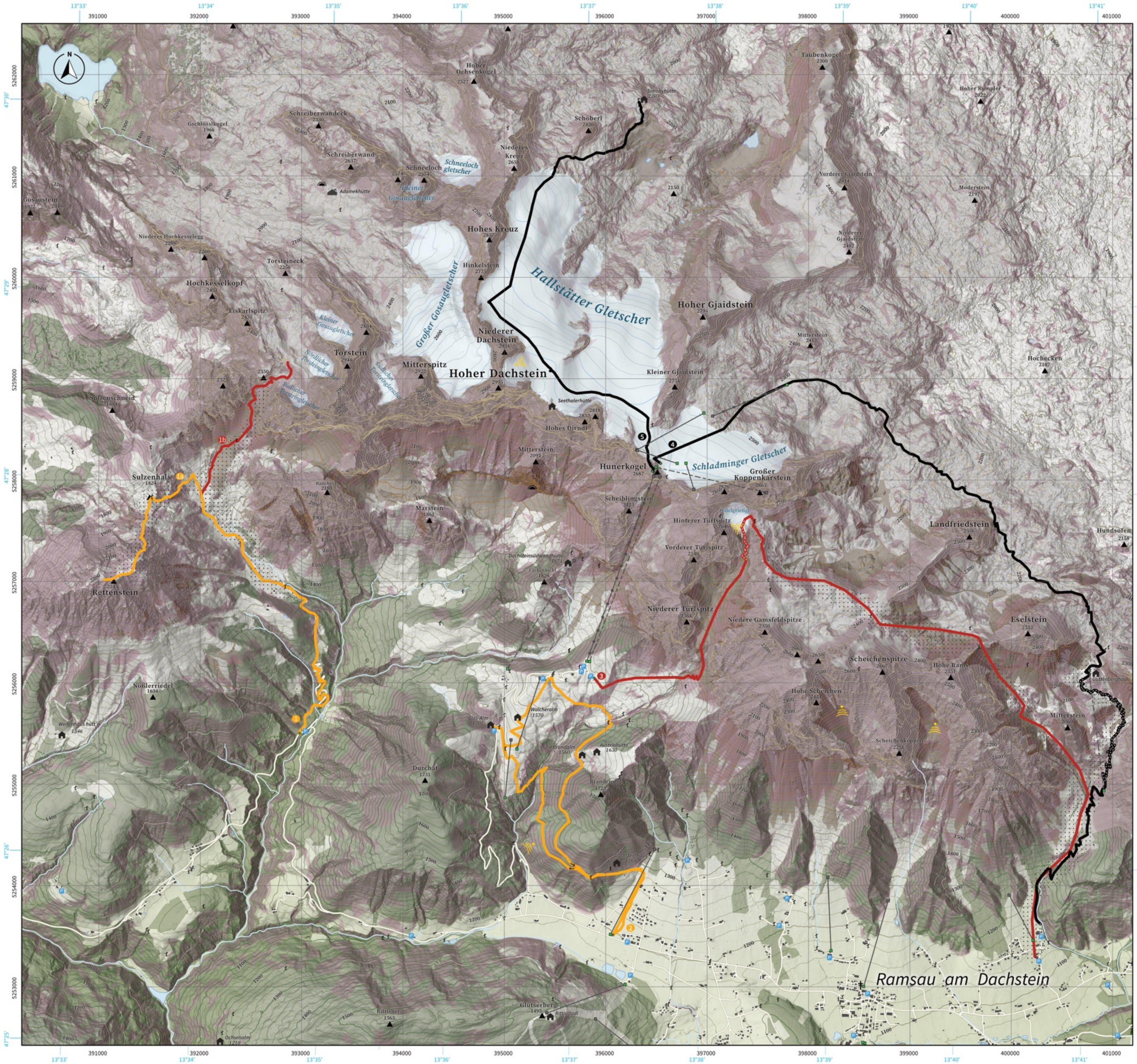
Appendix F: Results user study

https://kartoweb.itc.nl/msc-carto-thesis/materials/vivien_van_dongen/

Appendix G: Final map design

https://kartoweb.itc.nl/msc-carto-thesis/materials/vivien_van_dongen/

Ski tours in Dachsteingebirge



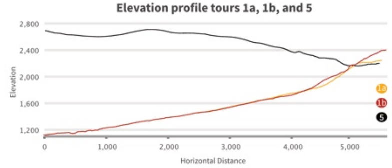
Glacier update:
Hallstätter Gletscher, Schladminger Gletscher and Großer Gosaugletscher: after 2020
Other glaciers: after 2010

Distance contour lines: 20 meter

1:25.000

0 0.5 1 1.5 2 2.5
Kilometers

Elevation profile tours 1a, 1b, and 5



Elevation profile tours 2, 3, and 4