University of Zurich[UZH]

Developing a Virtual Excursion for University Didactics in the Field of High-Mountain Geomorphology

GEO 511 Master's Thesis

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Contents

Figures

Tables

1. Acknowledgements

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2. Abstract

There is an increasing demand for virtual excursions as a tool for education within a regular lecture series and as a substitute in the case of a cancelled field trip. A virtual high mountain geomorphology excursion, including imagery, 360° imagery and interactive tasks in a virtual 3D environment, was developed. The challenges were documented, and the product was evaluated by 54 students in a questionnaire. The feature, which allowed students to view images within the context of a 3D landscape model, was rated the most helpful. Closely followed by the tow exercise, where landforms must be recognised, and past glacier extents are shown in the 3D landscape model. Several more features were tested, evaluated, and discussed resulting in recommendations for implementations for future excursions. Future development of virtual excursion may build upon the findings of this thesis and find ways to implement the suspended features in this thesis and engage in unsolved challenges.

3. Introduction

The UZH course GEO 231 (Vieli & Gartner-Roer, 2023) hosts a yearly excursion covering the high mountain geomorphology, visiting the Steingletscher (Bern, Switzerland). Under several circumstances, such as the corona pandemic or bad weather conditions, the excursion had to be cancelled (for individuals or the whole course), which led to the demand for a virtual excursion.

This master thesis investigates the opportunities and challenges associated with a virtual excursion as a tool for science communication and university didactics, by developing a virtual excursion and documenting the conceptual, and technical aspects of the development. Thus, exploring the following research questions:

> What are conceptual and technical challenges in developing a virtual excursion for science communication and university didactics purposes, in the field of geomorphology?
>
> How do students respond to a virtual excursion as a possible extension or substitute to an in-situ excursion?
>
> How do different features enhance a virtual excursion?

The goal of the excursion developed is similar to the in-situ excursion: to teach aspects of high mountain geomorphology and help students to better recognize geomorphological phenomena in the field. However, a virtual excursion provides a different learning experience with both advantages and drawbacks as compared to an in-situ excursion.

In this thesis the theoretical backgrounds and already existing virtual excursions in the field of geomorphology will be reviewed. For the presented excursion, the selected content will be discussed followed by documentation of the development and evaluation of the presented virtual excursion. The results and development are discussed and the conclusion, that the devised features enhance the experience of a virtual excursion, is drawn.

4. Theoretical Background

Research fields such as digital media in education, excursion didactics and spatial cognition, especially spatial cognition in virtual spaces, provide interesting findings to enhance virtual excursions. Several papers found that digital excursions are popular with students and reported on features which were successful (Evelpidou et al., 2021; Stumpf et al., 2008).

4.1 Media in Didactics

A prominent view in educational theory claims that no media effect on learning exists, the medium itself does not increase learning, but the instructional method does (Mayer et al., 2020). However, different media allow for different instructional methods, which justifies investing in new media for education and studying the influence of media on the learning experience (Mayer et al., 2020).
Tversky et al. (2002) compile approaches which help to better conceive animations in digital media. For example, animations are often too complex or too fast to be accurately perceived (Tversky et al., 2002). Animations therefore should be simple and slow enough. However, if a certain complexity is required, the dynamic drawing principle states that learning can be enhanced with step-by-step graphics, rather than presenting completed graphics (Mayer et al., 2020).
A video lecture or demonstration can be more effective if the student is encouraged to engage in generative learning activities. Those are activities which are performed, while the lesson is ongoing with the intention of improving learning (Mayer et al., 2020).

4.2 Spatial Cognition

Lathrop & Kaiser (2002) show in their study that the orientation within virtual spaces is significantly more challenging than orientation within the real world. The orientation of users in virtual spaces significantly improved when Head Mounted Displays (VR deadsets) were utilized instead of conventional desktop mounted screens. However, applications of head mounted displays come with numerous other drawbacks, such as motion sickness, cost, and increased difficulty in software development for VR headset applications. Thus, for this thesis an application running on a conventional screen was developed.
The disorientation in virtual spaces can be reduced by e.g. avoiding the use of a teleportation feature for movement in the virtual space, as Bakker (2003) found that displacement by teleportation leads to spatial disorientation, at least when a person is not able to anticipate the destination. Even with anticipation, the disorientation is larger than with continuous displacement.

4.5 Excursion Didactics

Seckelmann & Hof (2020) discuss the values of "Work excursions", where students are given the task to file a geomorphological map, a task which lends itself well to geomorphological excursions. To map the geomorphological forms, high level familiarization with the site is required by the students (Seckelmann & Hof, 2020), which make such a task fitting for geomorphological excursions.

4.6 Virtual Geomorphology Excursions

The reviewed virtual geomorphological excursions visit places similar to a real-life excursion (Evelpidou et al., 2021; Stumpf et al., 2008). The excursions utilize different tools like google earth (Evelpidou et al., 2021), a custom created web page (Stumpf et al., 2008) or map.geo.admin (Swisstopo, 2023a).

Some of the reviewed excursions were also published along with an evaluation by the students or a report on the performance of the students in a test on the excursions content after attending the excursion. In general, it is the sentiment that virtual excursions can be a valuable educational tool but do lack the intriguing qualities of real-life excursions, such as conveying the true three-dimensional scale of natural landscapes and the hardship that comes with gathering data in the field. Furthermore, virtual excursions cannot appeal to all senses (Evelpidou et al., 2021; Stumpf et al., 2008). It seems virtual excursion emerged out of necessity for a replacement but turned out to be an additional tool rather than a replacement.

5. Methods

The methods utilized to develop the virtual excursion will be presented, including the decision-making process for the chosen content. Followed by the conception of the excursion; in what virtual form it should take place, and which features should be realized. Followed by the methods used to produce the imagery, as well as the software development section which explains the technical details of the implementation of features. The last section presents the methods employed to evaluate the virtual excursion.

5.1 Content

For the location setting of the excursion several factors were considered. The valley should feature a wide variety of geomorphological process units, as well being easily accessible and provide accommodation during field campaigns.
Zah et al. (2003) describe the Roseg Valley as a valley that can be seen as a product of glacier history, featuring a wide variety of geomorphological processes. As the valley fits the requirements and moreover offers an abundance of background literature (Garavaglia, 2009; Linsbauer, 2013; Oerlemans & Keller, 2022; Rothenbühler, 2006; Schollenberger, 1976; Uehlinger et al., 2003; Zah et al., 2003) it was selected as the setting of the virtual excursion. Early on in the development of the excursion, a geomorphological map was created in order to get a first overview of the valley, which served as a basis to choose appropriate topics and a route through the valley (Fig. 1).

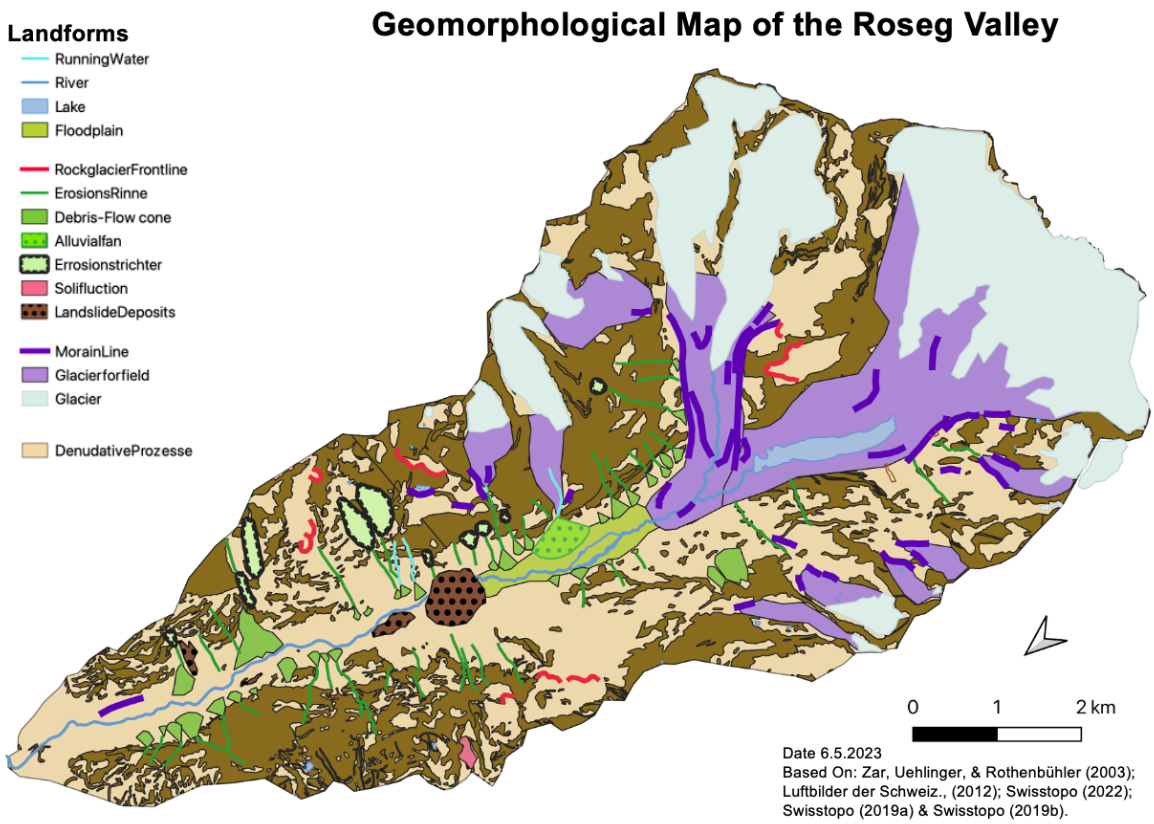

Figure 1. The geomorphological map was created to get an overview of the valley and the geomorphological landforms which should be featured in the virtual excursion.

The content of the excursion is based on a script which was written for this thesis and was detailed before the technical development of the virtual excursion. The script outlines the content and sequence of events in the virtual excursion. The contents of the UZH course GEO 231 “Physische Geografie III: Geomorphologie und Glaziologie” (Vieli & Gärtner-Roer, 2023) were considered to outline the state of knowledge of the users of the excursion. To write the content of the excursion, the two books: “Allgemeine Geologie” (Grotzinger & Jordan, 2014) and “Geografie” (Gebehardt et al., 2012) were utilized as they are recommended within several basic courses at the institute. The book “Geomorphologie” (Dikau et al., 2019) was referenced for covering the geomorphological topics explored by the excursion in more detail.
Topic specific papers provided information on focus points within the excursion, while site specific papers covering phenomena in the Roseg Valley were utilized to connect the content with the location experienced in the excursion.

5.2 Concept of the Virtual Excursion

The implementation was devised by considering already existing virtual excursions (Evelpidou et al., 2021; Stumpf et al., 2008) as well as the course content of GEO 231(Vieli & Gärtner-Roer, 2023). The goal was to create a virtual excursion as an educational supplement to the GEO 231 course (Vieli & Gärtner-Roer, 2023) which could also serve as a substitute to the field excursion in years, where the field excursion would be cancelled. A secondary goal was to introduce new features and rate their popularity along with their associated workload.

For the exploration of a 3D terrain, existing excursions (Evelpidou et al., 2021; Stumpf et al., 2008; Vieli & Gärtner-Roer, 2023) utilized a program such as Google Earth (Google, 2023a) or map.geo.admin (Swisstopo, 2023a). But according to the formulated secondary goal of this thesis, new features unique to the excursion should be provided additionally to the features provided within the mentioned software tools. As it was not within the scope of this thesis to implement the desired features within the existing programs of Google Earth (Google, 2023a) or map.geo.admin (Swisstopo, 2023a), the virtual excursion was developed in Unreal Engine 5 (UE5) (Unreal Engine 5, 2022) and the 3D terrain exploration tools were replicated there. This allowed to develop features which were uniquely tailored to support the learning goals of the excursion.

Similar to Google Earth (Google, 2023a), Google Maps (Google, 2023b) and map.geo.admin (Swisstopo, 2023a), the excursion features at its core a 3D terrain exploration tool. The 3D terrain exploration tool is accompanied by a panel that guides the user through the excursion (Guide Panel), a settings panel and icons on the 3D terrain that support the tasks completed during the excursion.
The guide panel will direct the user through the intended steps of the excursion, thus functioning additionally as a table of contents from which the activities and information sections can be easily accessed. As such, the excursion is not one linear experience, but can be easily paused, single aspects can be skipped or repeated later on.
The settings panel helps organizing the numerous possible and sometimes required interactions between the user and the application. Such as user interface (UI) settings, like text size adjustment and toggling of informative heads-up display (HUD) elements. Task specific functions which can be used during a task but should also be available for the user at their leisure during the whole excursion after they are introduced.
Interactable features in the terrain are reserved for geolocated information or imagery. To mitigate an overwhelming map, the icons can be toggled.

The virtual excursion contains the following three core features:
- A 3D terrain and a means to navigate it virtually.
- The functionality to enable the user to review 2D and 360° imagery.
- Text-based information within the virtual excursion.

Beyond these core features, as many educational valuable, innovative, and diverse features as possible were implemented, which could then be evaluated by the students to find additional beneficial features for virtual excursions in the field of geomorphology.

Table 1. Conceived and implemented features.

Feature Name	Feature Description
3D Terrain / Camera	The 3D terrain and a camera system to observe it.
Interactive Lane's Balance	A visual representation of the Lane's Balance (Lane, 1956), which can be manipulated by the user.
Profiles	Cross-sectional graphics of geomorphological phenomena integrated within the 3D model.
Integrated Image Viewer	A system where imagery is shown within the context of the 3D model.
360° Image/Video viewer	A system that allows to experience 360° imagery.
Landform Recognition Exercise	A system where landforms must be spotted and classified by the user.
Glacier Extent Exercise	An exercise where the past extent of the glacier is visualized.
Context Object Placer	A system which allows the user to place context objects within the 3D model to convey the scale of the landscape.

5.3 Imagery

Several of the features mentioned in Table 1 required imagery, which was produced in multiple field trips (1-5. July 2023; 2-6. August 23; and 22-24. October 2023). During the fieldwork conventional photos, drone footage, 360° photos and 360° videos were produced.

The conventional photos were taken with a Sony 6100 Alpha, with different lenses ranging from 10 to 210 mm focal length.

The drone footage was taken by a DJI Mavic Mini. The locations where drone images could be produced were limited by the flight restrictions (Bundesamt für Zivilluftfahrt, 2023).

The 360° Videos were taken with the Insta 360 3X, the 360° photos were taken with the google pixel 4a phone[1] (achieving a resolution of 8000 × 4000).

[1] A 360° camera such as the Insta 360 X3 consists of two wide-angle lenses mounted back-to-back with overlapping fields of view, thus a perfect stitch can be guaranteed, and a video can be produced as multiple images can be taken per second. More advanced models have more than two cameras mounted, producing a higher quality photo. However, a higher quality 360° image can also be achieved by stitching together images taken by the same camera which turns in place to take images of the whole sphere. The trade-offs are artifacts at the stitches and that no video can be produced as it is not possible to take multiple 360° images per second.

When working with 360° imagery, memory space must be considered, due to the high resolution required (here: 3830 x 1920 pixel). The collected footage for the excursion which was utilized was about 125GB (Gigabyte)[2].
As of 2024 it is not feasible to integrate the footage in the excursion which must be installed on the user's computer, however the footage can be uploaded to a cloud service and accessed via the internet. For this excursion, the footage was uploaded to YouTube and linked at the appropriate locations within the excursion (avoiding a >100 GB download by the user).

Unsteady footage may induce motion sickness and is generally unpleasant to watch. It was discovered here that smoother footage can be produced when hiking and cycling downhill while filming as it is less strenuous on the operator. However, the footage must be reversed to convey a journey uphill as desired in this excursion. This reversed movement can be noticed when moving water, vehicles or pedestrians etc. are depicted. Resulting in a trade-off between unsteady or smoother but reversed footage. The smoother, but reversed footage was selected for this excursion.
The footage was stabilized within the Insta360 software (Insta 360 STUDIO, 2023), using the option "Flow State Stabilization" and evaluated by the students. However, some students reported motion sickness and criticized the unstable footage in the evaluation. Therefore, an additional stabilization method was utilized for the submitted version, which turned off the "Direction Lock". The footage is no longer locked to the camera's frame of reference but oriented at an absolute reference system determined by the software (Insta 360 STUDIO, 2023). This resulted in smoother footage, but the viewer is no longer facing the direction of movement, which was also uncomfortable to watch. By assigning keyframes to the footage in post-production (here: DaVinci Resolve 17., 2021), controlled changes in facing direction were assigned.

5.4 Software Implementation

Moving from the conceptual, field and writing work to the software development, in the following the implementation of the features outlined in (Table 1) will be explained in more detail. This section will require the reader to have a basic knowledge of object-oriented programming, which will not be explained here [3]. Some features required a workflow utilizing multiple applications (Fig. 2). In the following the choice of Blender and Unreal Engine 5 are discussed.

[2] This amount of data and high resolution can be problematic in many process steps of production. A large enough memory card must be used to store the footage during filming. The computer for editing and rendering must have enough storage space, graphic and processing power. The 360° videos including the saved iterations and back-ups of this work take up more than a TB (Terabyte), which can be saved on a hard drive but also about 60 GB of cache data which are by default stored on the editing machine's internal drive.
[3] A brief introduction about Object Oriented Programming in the context of Unreal Engine is given in the Unreal Engine documentation (Epic Games, 2023a). Explanations will use functionalities of blender and Unreal Engine in the description of the workflow without detailed explanation as they can be looked up in the respective documentations (Blender, 2022; Epic Games, 2023).

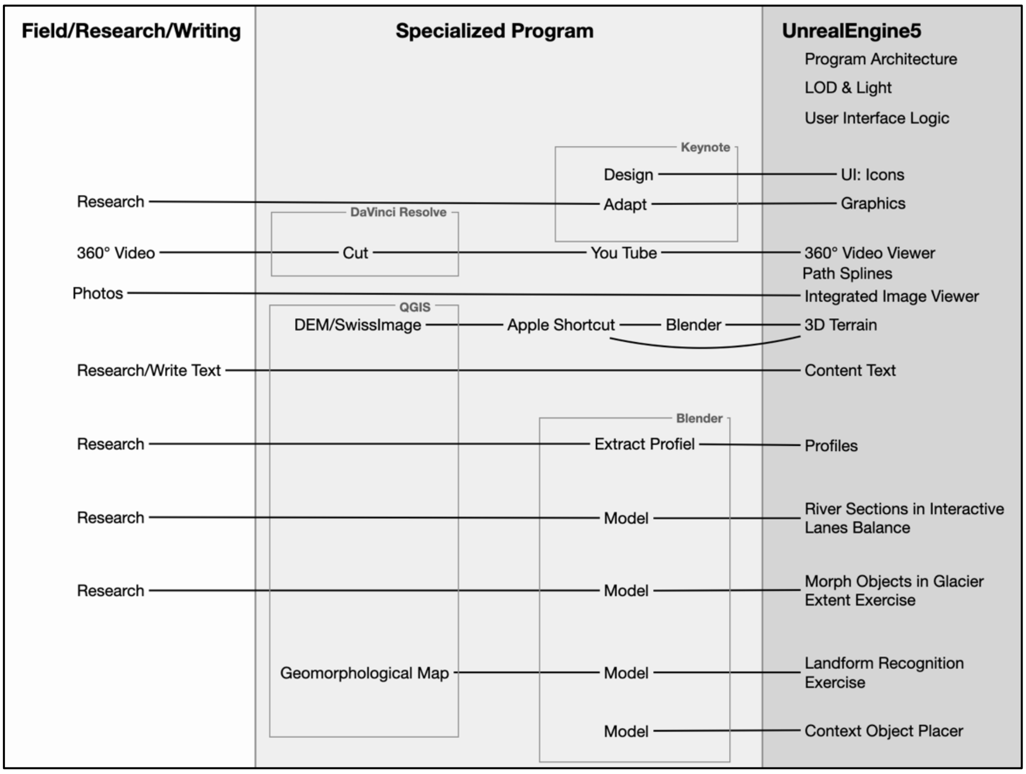

Figure 2. An overview of the simplified pipelines required to create several of the main features in the excursion. Sequence of steps from left to right.

Blender was chosen for several reasons; it is a free and open-source 3D creation suite (Blender, 2022). Blender enables 3D creation and visualizations and works cross-platform. It is well suited to individuals and small studios as it provides a unified pipeline (Blender, 2022).

Unreal Engine is an advanced real-time 3D creation tool. It is used across industries such as the film industry, architecture, automotive & transport simulation, and the gaming industry for which it was initially developed (Epic Games, 2023b). As a game engine with many prepared tools, it is ideal for the goal of exploring possibilities beyond the offered functionalities available in map.geo.admin (Swisstopo, 2023a), QGIS (Swisstopo 2023a), and Google Earth (Google, 2023a), which was one of the main reasons it was chosen for this work.

There are several base classes[4] and systems provided by UE5 which are optimized for setting up applications quickly; the virtual excursion as envisioned here could e.g. utilize the light system and level of detail system, as well as the base classes such as the game mode-, player controller-, pawn-, actors-, and mesh component- class. Furthermore, Unreal Engine provides a set of tools for developers such as the level editor and the Unreal Motion Graphics UI Designer, which were extensively used here to create the 3D environment and the UI (Epic Games, 2023b).

[4] Unreal Engine is based on C++, which is an object-oriented language. „Programming with C++ in UE is similar to standard C++, using Classes, Functions, and Variables. These are defined using standard C++ syntax. Each class defines a template for a new Object or Actor" (Epic Games, 2023a). UE5 offers blueprint visual scripting which is a „visual scripting programming tool that creates classes, functions, and variables in the Unreal Editor. These classes can then be executed by connecting various nodes together. C++ classes are used as a base for Blueprint classes, programmers can set up fundamental gameplay classes that are then sub-classed and iterated on by Designers" (Epic Games, 2023b).

5.5 Features Implementation

In the following section, the development of the different features implemented in the excursion are discussed. Noteworthy conceptual and technical challenges are mentioned at the start of each section. Followed by the most important involved classes for implementing the conceived features will be mentioned by their name given in the project file (class names in cursive).

5.5.1 Terrain

A representation of the 3D terrain of the Roseg Valley is paramount to the virtual excursion. The data to realize the terrain within UE5 was downloaded from Swisstopo (Swisstopo, 2019a; Swisstopo, 2019b).

The data provided by Swisstopo had to be processed, as it could not directly be used to create the maps and 3D terrain within the virtual excursion, due to compatibility issues between the different used programs and in order to reducing the data size and system requirements of the final application. UE5 requires the format Portable Network Graphic (.png) for textures with pixel sizes in powers of 2 to be able to run optimization processes in the background. However, Swisstopo provides data in the Tagged Image File Format (.tif) with pixel in powers of 10 (Fig. 3). To achieve these changes QGIS and apple shortcuts were utilized (Fig. 4).

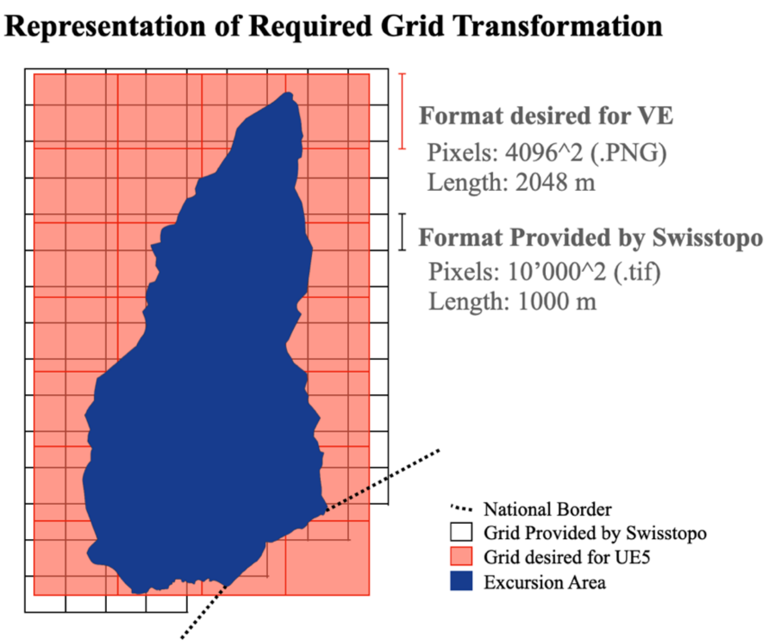

Figure 3. Simplified depiction of the grid provided grid by swisstopo, and the required grid by UE5 along with the specification of one single tile (Pixel size, Format, size in km).

UE5 provides a landscape tool, which divides the terrain in tiles and handles mesh reduction when provided with a Digital Elevation Model (DEM). However, no satisfying result could be achieved utilizing this system (visible inspection showed that landforms, such as small end moraines were no longer recognizable). Therefore, the 3D landscape tiles were created by the means of a displacement modifier within Blender and afterwards the topology was reduced with a decimate modifier, which dissolves the grid topology (and is highly customizable). The 3D landscape tiles could then be imported into UE5 (Fig. 4). The image texture and 3D mesh tiles both follow the same grid as the texture (Swisstopo, 2019b) is projected onto the 3D mesh tiles within UE5.

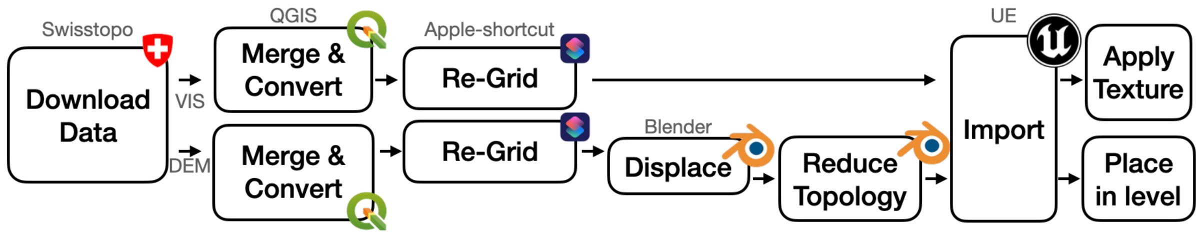

Figure 4. The simplification of the workflow to get the 3D terrain in UE5.

5.5.2 Camera Movement System

The user must be able to move around the 3D terrain within the virtual excursion. In a 3D space, there are six degrees of movement. There is no standard method of navigating a 3D space with mouse and keyboard, most 3D software tools handle this differently. The excursion is a specialized 3D application, and the movement can be simplified accordingly.

Google Earth (Google, 2023a), Google Maps (Google, 2023b) and geo.admin.ch (Swisstopo, 2023a), have some similarities in the way the digital 3D terrain is traversed. Those similarities were integrated in the camera system for this excursion as well, with the goal that the movement system would be intuitive to the user.

- The translational x and y movement is controlled by the x and y movement of the mouse and initialized by pressing a mouse button. The translation is not fixed to the reference system of the terrain but to the reference system of the camera.
- The camera moves on a spring arm (which is an actor component provided in UE5), the starting point of the arm is fixed on the terrain.
- The z movement is only indirectly controlled by "zooming" moving the camera along the spring arm.
- Yaw and pitch affect the starting point of the spring arm, resulting in an orbiting motion of the camera. Yaw is controlled by the x axis of the mouse and pitch by the y axis of the mouse. There is a keyboard input which toggles the mouse input between translation and rotation. The camera is only free to pitch in a certain range.
- Roll rotation is not possible.

The roll motion of the camera must be controlled such that the roll angle of the camera is aligned with the horizon of the terrain. Several limits must be laid out, otherwise the camera can flip over by pitching up beyond 90°, leave the terrain, or zoom beyond the base of the spring arm.
There are several problems with the movement system as described above, when navigating a 3D terrain with significant elevation. To avoid the camera overlapping with the terrain, the spring arm pitches up when the camera moves too close to the terrain. The anchor point of the spring arm must follow the terrain. However, the anchor points z-axis adjustment is implemented to transition over one second, so that translation over rugged terrain appears as a smooth motion.
The camera must be able to move to exact location on the command of other objects. This system is complicated by the fact that not only the location where the camera should move to has to be known, but also the associated location of the base of the spring arm. The logic for the camera system is set up within the *Pawn1* actor.

5.5.3 Integrated Image Viewer

Images are an integral tool to convey information and a sense of space. Thus, an accessible feature for displaying images within spatial context is a key element of the virtual excursion. It is of great benefit to have the images sorted by their location, as the user easily understands where to find which pictures. A sorting of the images by location also lends itself to the idea of the excursion already having a 3D Map at its core.
In Google Earth (Google, 2023a) and google maps (Google, 2023b) photos can be accessed through the map as well, thus it can be assumed that many users are already familiar with the concept. However, it is often unclear where to anchor the image within the map, at the location where the image was taken or at the location which is depicted. This issue is addressed in the virtual excursion developed here, by having the image icon at the object of interest and upon hovering over the image icon, a camera representation appears at the location where the picture was taken, and the picture is displayed within the 3D terrain. Additionally, the perspective changes gradually from the free roaming mode, in which the 3D map is observed, to the perspective depicted by the selected image (this addresses the concern of orientation loss upon teleportation discussed in the section on spatial cognition).

To implement this system an actor class (*PhotoObject_remastered_3*) was set up, which contains the icon, a hitbox for that icon, a camera representation (for the user to see and click on) and a mesh component displaying the associated images. The actor also contains cameras, to aid the developer while placing the images. The actor class contains the logic which requests the player pawn (*Pawn1*) to move to the corresponding location upon clicking the camera representation. The class also manages the visibility and ability to be clicked of the camara representation and corresponding image.

Instances of that actor class can be placed at any location of interest within the valley. The icons, camera, and images must be adjusted manually for each instance.

5.5.4 360° Image/Video Viewer

The paths which the user traverses in the virtual excursion are represented by a 360° video, at special viewpoints 360° photos can be viewed.

The filming and editing were discussed above in the section 5.3. The videos were uploaded to YouTube (Google, 2024) and the link can be selected within the excursion's user interface. A spline representing the path can also be displayed on the 3D map. The logic is programmed in the various widgets named *ContentGuide_[...]*.

To set up the feature to view the 360° images, the logic utilized in the Integrated Image Viewer was reused in the *360PhotoObject_3* actor. However, the functionality to display the camera representation was not needed, the process is thus modified if a 360° image is selected instead of a conventional image. In the *Pawn1* the handling of the mouse input is adjusted if the user switches from roaming the 3D terrain to looking at an image.

5.5.4 Glacier Extent Exercises

The initial idea was to animate the glacier's shape. However, it proved to be very complicated to adapt the historic map into accurate 3D models, suitable for morph animations. Prototypes were created but discarded as they were inaccurate and optimizing them to satisfying levels would have been beyond the scope of this thesis. Displaying only the front line was chosen as the next best approximation to keep a feature that allows the user of the excursion to learn about past glacier extents.

The glacier extents of the years 1895, 1910, 1920, 1930, 1950, 1957, 1971, 1979, 1985, 1991, 1998, 2003, 2006, 2009, 2012, and 2015, as mapped by Schollenberger (1976) and Swisstopo (2023b) were selected. This selection and reduction was driven by data availability as well as time constraints as the mesh representing the glacier front line had to be adjusted manually for each year. The maps (Schollenberger, 1976; Swisstopo, 2023b) were imported in Blender and a mesh representing the frontline of every chosen year was created. Utilizing morph targets the movement of the frontline was animated.
Morph targets allow modifying a mesh. The base mesh is transformed to morph into a morph target. The weight of the morph target (a value between 0 and 1) describes how far along the transformation towards a given morph target is applied (Blender, 2022). With each morph target the *GlacierFrontMesh* transforms into the position of the associated year. The preceding morph targets must be reached for the following morph targets to work properly.
In UE5 the *GlacierFrontActor* containing functions that can change the actor's morph state and the *GlacierFrontMesh* was set up and placed in the *level* which contains the morph targets.
The widget *GlacierExercise* contains the UI elements associated with the exercise, such as text and buttons to toggle the visibility of the glacier front and arrangement of the windows. As well as a further UI element, a slider which can be manipulated by the user to show the position of the frontline on the 3D map and the year on the graphic at the same time. To achieve this functionality, a blueprint logic was set up both within the *GlacierExercise* widget and the *GlacierFrontActor*.

5.5.5 Profiles

The profiles (Fig. 17) emerge from the 3D profile, so the user immediately knows which location the profile depicts. The profile hovers over the terrain so the size and position of features on the profile can be compared to the terrain.

The profiles each are an actor class (*Profile_Rockglacier, Profile_Talus* & *Profile_Glacier-Tschierva*) containing a plane displaying the graphic as a two-sided texture. The text is either contained within the texture or added as a widget component. The logic for the profile to emerge and disappear is contained in the profile actors as well. The *SettingsMenu* widget contains logic to request the profiles to be shown.

5.5.6 Landform Recognition Exercise

Inspired by the mapping task as suggested by Seckelmann & Hof (2022), a task where landforms must be discovered within the 3D terrain and if the correct location is found the landform is revealed.

A category of landform to look for is selected in the settings panel. In the 3D map the location where the landform is suspected is clicked on (a landform is guessed), subsequently the guess is verified.

The *SettingsMenu* widget, the *Pawn1*, the *PlayerController1* and the *solution_window* widget work together to realize this feature. The *SettingsMenu* widget registered which landform category is currently searched. The *Pawn1* registers the user's guess and contains the logic to compare the guess to the landform category which is currently searched. the *PlayerController1* spawns the window containing the solution. The *solution_window* widget contains the logic to verify the guess and give an appropriate list of recognition features associated with the chosen landform.

5.5.7 Context Object Placer

The user can place objects into the 3D terrain in order to compare the landforms with objects of known sizes.
The objects were modelled in Blender. The logic to determine a location where the *ContextActor*, which contains the mesh, should be spawned or to delete already existing objects is contained in the *Pawn1*. The *PopUp* widget and *SettingsMenu* widget contain the logic regarding the toggling of the context object mode.

5.5.8 User Interface

The UI was set up utilizing the standard functionality of the UE5 Unreal Motion Graphics UI Designer. The *SettingsMenu* Widget (and children) was inspired by the geo.admin.ch (Swisstopo, 2023a) toolbar which is intuitive and might be well known to geography students at the University of Zurich, which are the main target audience of the excursion. The guide panel consist of the *"ContentGuide_Main"* widget was inspired by the information panel frequently seen in public transport, which should help to understanding it intuitively. The windows containing information are oriented on standard operating systems. The logic driving the window system is contained in the *WB_windows* widget and was set up by following and modifying the code from the tutorial by Unreal Solver (2022).

The logic driving the windows, and their resizing and moving functionality, is contained in the *WB_windows* widget. The code presented in the tutorial by Unreal Solver (2022) was adapted. The widget was set up so that the window content could be defined in a separate Blueprint.

The contents of the excursion, which were written in Microsoft Word, the layout was created in the various content widgets, which can be found in the folder "Guide_Window_Content". Similar to challenges encountered in responsive web design, different screen sizes and resizing of the window had to be considered when creating the layout.

5.5.9 Lane's Balance

As the different reaches of the "Ova di Roseg" are discussed, the user is provided with markings on the map showing the extent of the river reaches along with imagery of the river, as well as an interactive version of the Lane's balance.
The logic for the interactive Lane's balance was set up in the widget *LanesBalance2*. The logic to show markings on the 3D terrain is set up in the *SelectRiverSection* widget and *RiverSelectionActor*.

5.6 Questionnaire

To evaluate the different features implemented in the virtual excursion, a questionnaire was set up. The students of the course GEO231 (Vieli & Gärtner-Roer, 2023) participated in a lecture where a person completed the excursion in the front, with student asking question and participating in discussing the answerers for the exercises. This approach was chosen as the excursion was not ready to be distributed at that point of time. The questionnaires results provide insights for the emerging field of virtual geomorphological excursions.
The questionnaire asked the students to evaluate several features in the excursion. The options were purposely chosen in an even number so no neutral stands could be taken. The answer options were:

- influencing the excursion negatively
- barely useful
- useful
- extremely useful.

The following questions were asked (in German):

- Is the function helpful that the location, where a photo was taken, is displayed beforehand, and that the camera moves to the location once a picture is selected?
- Is it helpful that profiles (Rock Glacier, Glacier thickness) are located, within the 3D model (in true scale)?
- Is it helpful that diverse geomorphological forms can be explored in an exercise?
- Is it useful that anthropological objects, such as trains and skyscrapers can be placed in the 3D model, to understand the scale of the landscape?
- Is the exercise with the past glacier extents helpful?
- Is Lane's Balance implemented as an interactive balance useful to understand the influence of different factors on rivers.
- Are the 360° photos helpful to relate the excursion to reality and to understand the geomorphological landforms and their location within the area?
- Are the 360° videos an improvement on the 360° photos?

6. Results

The following script contains the text which are used in the excursion. Text which is located within the guide panel is represented by cursive text, the rest of the text is communicated in the excursion within separate windows. Short instructions regarding interactions with the UI which can only be understood within the context of the application are not written down in the script.

6.1 Excursion Script

User Interface Tutorial

Learn how the Digital Excursion works.

In the Tool Panel you can access various submenus. The first one is all about adjusting the camera, resetting it if you get lost or if a malfunction causes you to lose control over the camera (Reset). The others will be introduced later during the excursion.

In the Guide Panel you can see your progress and your next steps. You will also be able to open Information Windows from there. Feel free to scroll back at any time and revisit parts of the excursion. Now you can start the excursion by following the first instructions in the Guide Panel.

About Virtual Excursions

Welcome to the "Virtual High Mountain Geomorphology Excursion to the Roseg Valley"! This excursion allows for a realistic exploration of a typical alpine valley with characteristic landforms and geomorphological processes, comfortably from home or from the classroom. As conventional (real) field excursions are not replaceable, the virtual excursion is meant as a supplementary tool of education, or as a replacement e.g. during a pandemic, bad weather, or lack of funding.

In this excursion you will virtually visit the Roseg Valley; 3D models and diverse image material will provide a realistic experience of the landscape, while theoretical inputs provide more detailed information about the geomorphology. In addition, short exercises will help to recapture and deepen the acquired knowledge.

About the Roseg Valley

The Roseg Valley is located in the eastern part of the Swiss Alps in the canton Graubünden. At the entrance of the valley is the village of Pontresina at an elevation of 1800 m a.s.l. and the highest elevation is Piz Bernina with 4049 m a.s.l.. The Roseg Valley includes two alpine tectonic units; the so-called Ost-Alpine and Penninicum, both of them were heavily affected by the mountain formation of the alps, which led to complicated geometries of overlaying sheets and a variety of rock types (Uehlinger et al., 2003, Weissert & Stössel, 2014). A large part of the Roseg Valley is located in the Julier/Bernina/Suvretta crystalin sheet (Uehlinger et al., 2003), which consist of granitoids such as diorites, granodiorites, syenite and alkaline granites. The bedrock of the remaining valley is mainly part of a Peninnic nappe, which consist of deformed ocean sediment and a mixture of ocean crust and various ocean sediments (Weissert & Stössel, 2014).

The Roseg Valley is a U-shaped glacial valley, the slopes are characterized by gravitational processes and the valley floor is dominated by glacio-fluvial processes (Uehlinger et al., 2003). The valley glaciers are retreating since the last glacial maximum and are currently only occupying the last kilometres of the valley (with some occasional episodes of glacial advance). They will most likely retreat back to less than a kilometre length during the coming century (Rothenbühler, 2006).

The river "Ova da Roseg" flows in different sections through the valley, starting at the glaciers, the tributaries cut through the moraines, and form a large fluvial plain. Further down, restricted by the narrower lower valley, the river flows in a more confined manner towards Pontresina, where it joins the "Ova da Bernina", which later joins the Inn (Uehlinger et al., 2003).

The climatic conditions change with elevation and different ecosystems form which are categorized as different altitudinal zones. The Roseg Valley includes the subalpine as well as alpine race and heathens and even the nival zone (Glaser & Radtke, 2012). There is also a large diversity of landforms in the Roseg Valley: several accumulation forms of different mass movements, glaciers and rock glaciers. This has made the Roseg Valley a site for several scientific research projects (Garavaglia, 2009; Linsbauer, 2013; Oerlemans & Keller, 2022; Rothenbühler, 2006; Schollenberger, 1976; Uehlinger et al., 2003; Zah et al., 2003) as well as the perfect location for this excursion.

The excursion has 4 chapters related to geomorphological process units:

Mass Movements (gravitational processes)
Glaciers (glacial processes)
Rock Glaciers (periglacial processes)
River (fluvial processes).

In these chapters you will become more familiar with the typical high mountain processes, their related landforms and spatial distribution. In each chapter, another geomorphological system will be studied. You can read up on the geomorphological systems and process units in the following section:

Geomorphological Systems and Process Units

A system is made up of components with attributes in relation to each other. In geomorphology it has also become common to use the concept of systems to understand spatio-temporal relationships (Glaser & Radtke, 2012).

A geomorphological system has two main aspects: material and energy. Materials may be for e.g. water or stone and the energy can come from different sources such as solar radiation, gravity or geothermal energy. The input to a geomorphological system comes from the environment, this input is transformed and leaves the system as output (Dikau et al., 2019) e.g. sediment which is transported by rivers is rounded. A system has a defined border, but its influence may reach across that border (Bedehaesing, 2007), e.g. a glacier's melt water regime influences the river downstream, which is no longer part of the "glacier system" itself. Landforms, processes, and their development over time are the key elements which are of interest and are studied by geomorphology (Dikau et al., 2019).

A process unit is defined when certain processes are frequent in an area e.g, in an area where a glacier has retreated, periglacial processes are abundant, thus such an area is called a periglacial process unit. In the Roseg Valley several process units can be observed: prominently glacial, periglacial, fluvial and gravitative processes units (Dikau et al., 2019).

Mass Movements

Learn more about Mass movements

What are Mass Movements

Mass Movements are the downward allocation of rock material by gravity (Dikau et al., 2019). To explain the cause for mass movements, slope stability is considered. Slope stability is determined by the balance of driving and resisting forces, when all forces balance each other out, the slope is at an equilibrium. Slope instability occurs when gravitational and shear stresses within a slope exceed the material strength of the slope (Fischer et al., 2009). There are predisposing factors such as geology, glacier retreat or topography rendering an area to be likely to become unstable at some point. Trigger factors, such as earthquakes, intense rainfall or rapid snowmelt set off a mass movement event (Fischer et al., 2009).

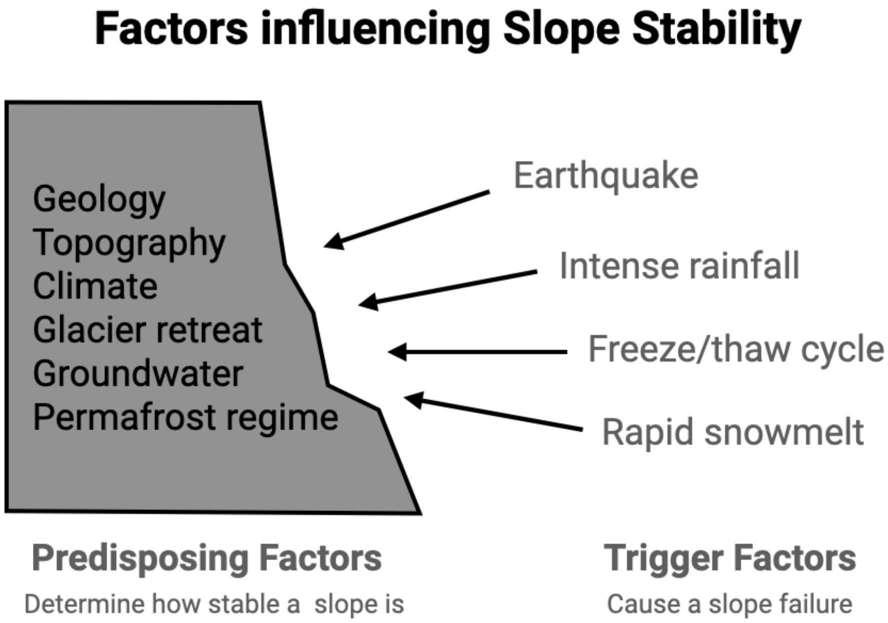

Figure 5. A slope and associated predisposing factors are displayed as well as triggering factors which might cause a slope failure. Modified after Fischer et al. (2009).

System Analysis of Mass Movements

When learning about a geomorphological phenomenon e.g. fall processes from a headwall, a variety of questions can be asked:

How steep are talus cones?
Where is the material of a talus coming from and is it transported somewhere?
How is the shape of a talus cone changing over time?

Depending on the question at hand a different system analysis approach is chosen. Let's look at a headwall and a talus by considering 3 different system analysis:

Mass movements can be analysed by describing them as a system the simplest being the form system. Where the landform is observed as a static object not changing over time (Dikau et al., 2019). The form system describes forms by the means of (morphometric) variables such as slope, size, volume, water-content etc (Glaser & Radtke, 2012).

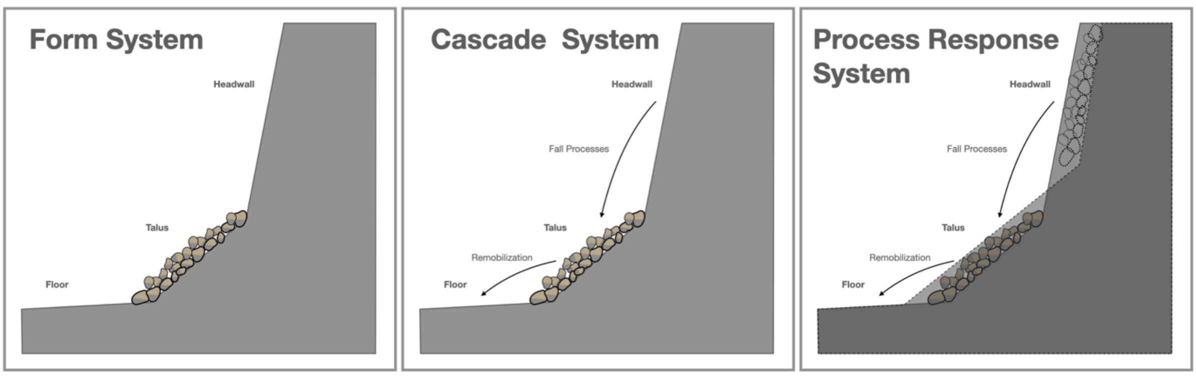

Figure 6. Depiction of a headwall and talus as different geomorphological systems. Modified after Dikau et al. (2019).

The cascade system expands on the form system by introducing the flow of material and the coupling of parts along the trajectories of the system (Glaser & Radtke, 2012). In this example, material of the headwall drops as input on the debris field which functions as a first sink. Then, the material may be remobilized and transported further to the lower slope. The material remobilized from the lower slope is the output (Dikau et al., 2019).

Process Response-Systems additionally describe feedbacks which arise from forms and processes. In this example we see that the headwall is getting smaller by the process which reduces the amount of input and leads to an eventual decline of activity, which is a negative feedback loop. This analysis helps to understand the changes to the system over time (Dikau et al., 2019; Glaser & Radtke, 2012).

In the following two examples of mass movements are discussed. Fall processes and Debris flows.

Fall processes

In fall processes the material is free falling, bouncing, or rolling, often moving as a connected mass until the movement stops and the debris rests in a so-called accumulation form. There can be secondary activations such as earthflows (Dikau et al., 2019) which transport the sediment further. Typically, different fall processes can be categorized by the volume of the mobilized material, although unfortunately the terminology is not unified (Dikau et al., 2019).

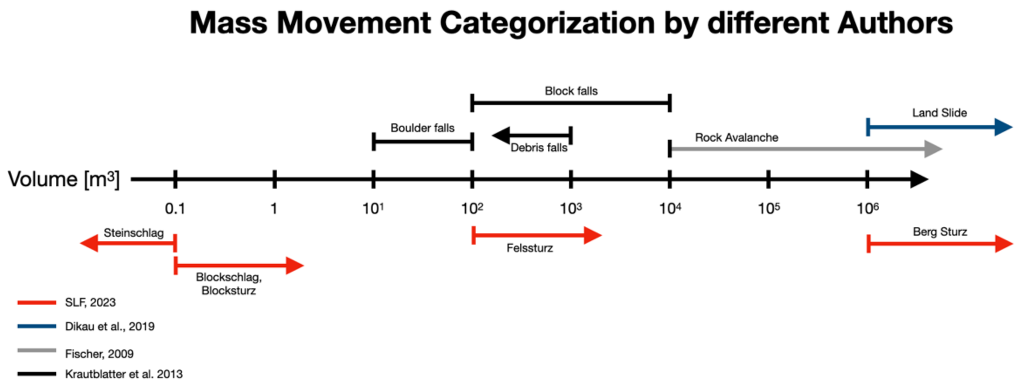

Figure 7. Terminology concerning mass movements (Dikau et al., 2013; Fischer,2009; SLF, 2023; Krautblatter et al., 2013).

Rock and cliff falls typically occur at steep walls triggered by different forms of erosion such as frost cracking or root cracking, chemical erosion, shock of earthquakes or explosions, loss of stabilizing matrix material (Dikau et al., 2019).

The typical accumulation form associated with these mass movements are talus cones, located at the bases of rock walls. Talus cones can be recognized by their high gradient slopes and smooth surfaces, while the clasts are mostly angular and barely rounded (Garavaglia et al., 2009). The superficial debris layer may be remobilized, and complicated mix forms are frequent, as talus cones often intersect each other or intersect other types of cones or talus (Garavaglia et al., 2009).

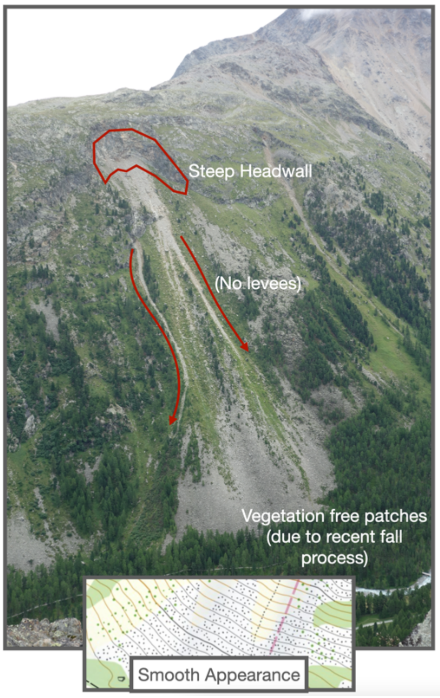

Figure 8. Talus cone in the Roseg Valley, with explanatory text and sketches. Map by Swisstopo (2023).

The debris flow dominated fan is an accumulation from just as the talus cone discussed above. The general shape is also a cone, but there are some key differences due to the difference in genesis of the two accumulation forms (Garavaglia et al., 2009). Instead of only being formed by fall processes, debris flow dominated fan are shaped by both gravitational and fluvial processes. Re-occurring debris flows are triggered during strong precipitation events (or after lake outbursts) and involve a huge volume of material, which can run over long distances at high speed (Garavaglia et al., 2009). A key characteristic of a debris flow is its behaviour as a non newtonian fluid type of the debris flow, a so-called Bingham's fluid displaying a very viscous behaviour (Dikau et al., 2019). The mixture of water and sediment can reach high speeds and a density of up to 2.6 g per cm this allows for the transportation of very large boulders (Dikau et al., 2019).

Debris flow dominated fan can be recognized by the channels which incise the cone with levees on both sides of the flow path (Procter et al., 2012). The debris flow channel as an identifying feature is not unambiguous as traces of debris flows can also be found on talus cones where flows have remobilized the debris layer leading to a complex mixed accumulation form between talus and debris flow dominated fans (Garavaglia et al., 2009).

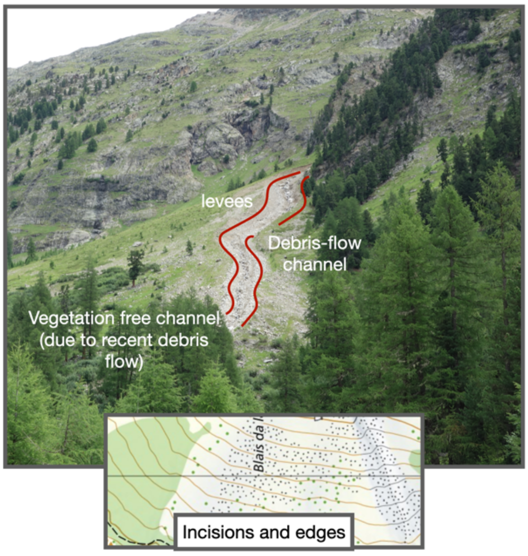

Figure 9. Debris flow cone in the Roseg Valley, with explanatory text and sketches. Map by Swisstopo (2023).

Train yourself: select the image to reveal wheatear they depict a debris flow or a talus. There are images of other landforms as well to make it more challenging.

Figure 10. Exercise to train recognition of debris flow channels and talus cones.

Categorization of Mass Movements

Dive into the discussion of mass movement categorization. Don't be frightened by the wide variety of proposed schemes. The main goal is to understand the categorization schemes and not to look at every single categorized mass movement:

There is a wide variety of different types of mass movements which can be described and categorized by geomorphology. Several categorization schemes have been proposed where different characteristics are utilized. For example: water content and velocity (Dikau et al., 2019) or the categorization by Carson & Kirkby (1972) uses the contribution of flow, creep and slide and further relates that to velocity and moisture to categorize mass movements.

The various categorization schemes have a different focus and they each are only fit to describe a subset of all the possible mass movements. Subsequently the different schemes have some overlap, and some systems are only listed in some of the categorization schemes.

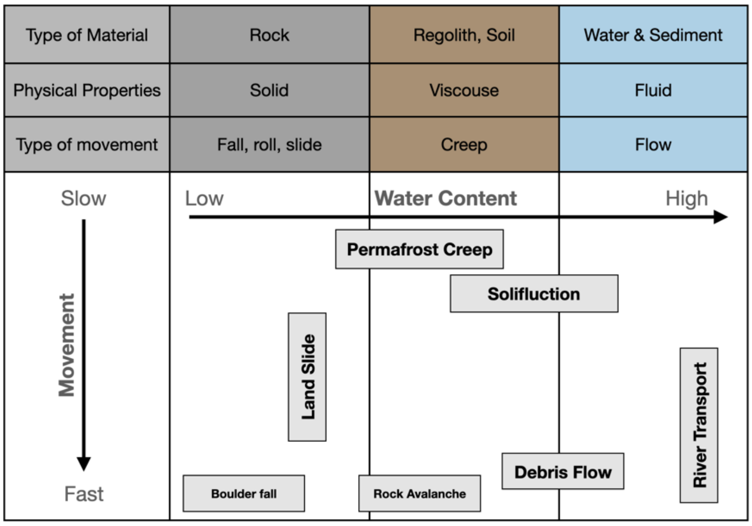

Figure 11. Mass movement categorization, by water content and movement speed as well as associated properties. Modified from Strahler & Strahler (2005).

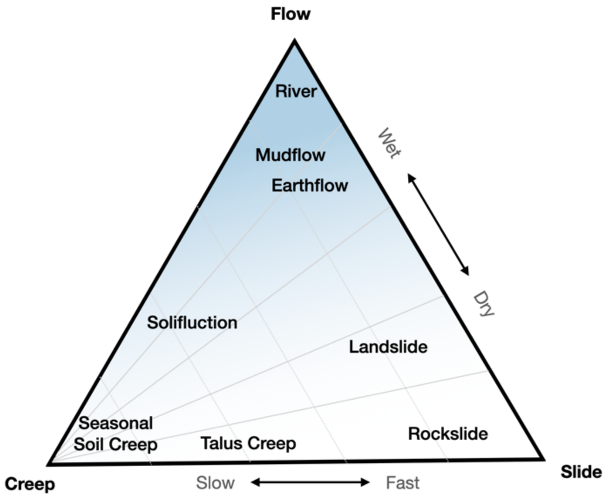

Figure 12. Mass movement categorization. Digitalized from Carson & Kirkby (1972).

Expose the hiking trail on the 3D model and watch the 360° video on YouTube.

Gravaglia et al. (2009) and Uhlinger et al. (2003) categorized many mass movement accumulation forms in the Roseg Valley into the categories:

-Talus
-Complex fans
-Debris flow dominated fan
-Landslide deposits

Glaciers

In this chapter we are looking at the glaciers in the Roseg Valley and the associated glacial and proglacial process unit.

Expose the hiking trail on the 3D model and watch the 360° video on YouTube.

Introduction

"A glacier is a body of ice that forms from the accumulation of snow on the ground and becomes thick enough to deform or flow under its own weight" (Knight, 2019).

Notably, the glacier ice stays frozen all year around. Snow and other forms of solid precipitation accumulate and become denser, if the snow does not melt over summer, it is called firn. Through snow metamorphism the firm becomes even denser and eventually turns into glacier ice, as the density increases the pressure increases as well (Dikau et al., 2019).

The viscous behaviour of ice under stress is fundamental to the behaviour of glaciers, it allows glaciers to move downhill. This viscous behaviour is also connected for example to the ice thickness (Linsbauer, 2013), as well as location of crevasses (van der Veen, 1999), and flow speeds (Millstein, 2022).

Many processes happen at timescales too long for humans to observe, but the current state and landforms that are left behind can be studied to reconstruct what happened over time (Schollenberger, 1976). One example for such landforms are the huge lateral moraines in the Roseg Valley, which accumulating at the sides of the glaciers (Schollenberger, 1976). When the glacier retreats, the moraines remain and indicate the former extent of the glacier (Dikau et al., 2019).

Accumulation and Ablation, Mass balance

The lateral moraines showed us in an impressive manner that glaciers retreat and extend but why?

In higher altitudes, where it is colder, the glacier accumulates mass all year around usually from precipitation (accumulation area see Fig. 13). In addition to snowfall, occasionally avalanches fall onto the accumulation area of glaciers, e.g. from Piz Bernina and Piz Roseg on to the Tschierva glacier (Oerlemans & Keller, 2021). As glacier ice flows slope downwards, ice thaw, sublimation, as well as ice breakoffs reduce the glaciers mass (ablation area see Fig. 13). With lower altitude the temperatures rise, and the glacier shrinks until no ice remains and the glacier ends (Dikau et al., 2019). The height at which the glacier neither gains nor loses mass is called the equilibrium line altitude (ELA).

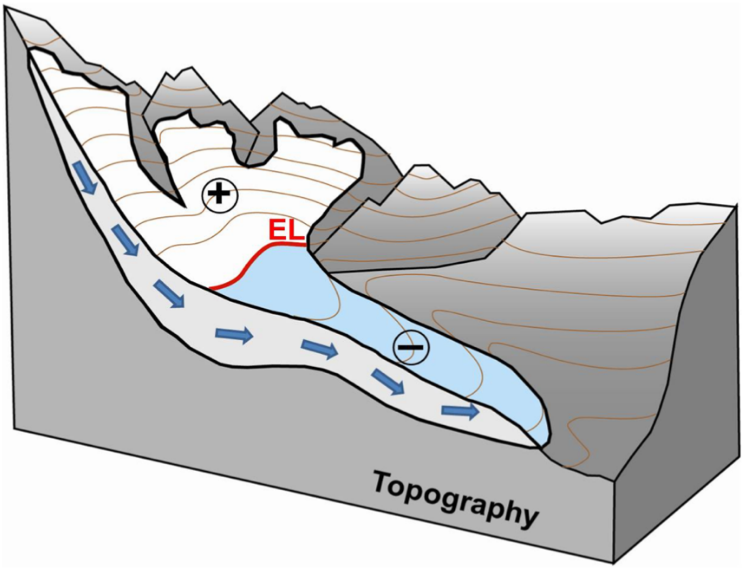

Figure 13. Simplified depiction of a glacier's accumulation area, ablation area and EL (Lindsbauer, 2013).

Adding accumulation and ablation yields the mass balance of the glacier (Fig. 14). In winter accumulation predominates, while during summer ablation processes dominate. The balance over the whole year is called the net balance (Linssbauer, 2013). A positive net balance means the glacier is gaining mass and a negative net balance means the glacier is losing mass. As climate directly influences the glaciers mass balance, observed changes in mass are a clear indicator for changing climate (Huss et al., 2009).

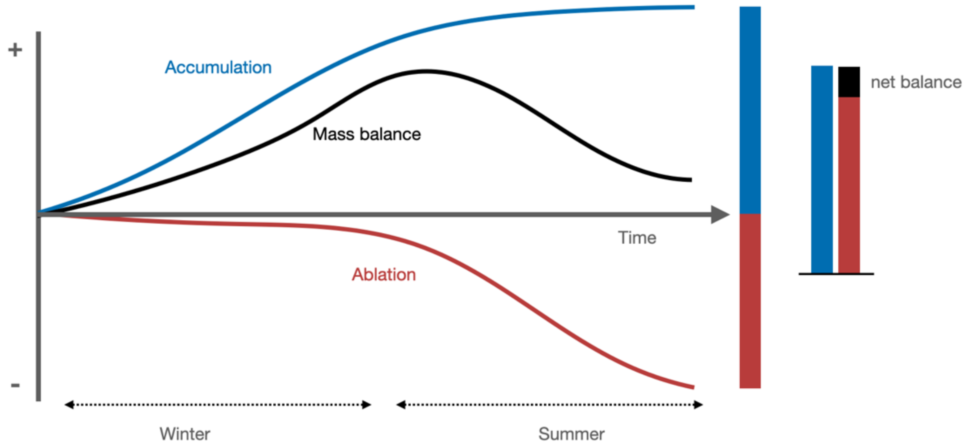

Figure 14. Depiction of mass balance terms modified after Paterson (1994).

Movement and Glacier Dynamic

The two processes, plastic deformation, and basal sliding result in glacier movement (Glaser & Radtke, 2012). Plastic deformation occurs when the ice gets so thick that the shear forces are strong enough to irreversibly deform the ice, and the ice starts to flow. Basal sliding occurs only at temperate glaciers (such as the Roseg and Tschierva glacier), where the pressure of the glacier melts ice at its base, which forms a thin layer of water that allows the glacier to slide (Dikau et al., 2019).

Ice thickness is inversely proportional to the slope angle, so a steeper slope means a thinner glacier. The ice thickness at any point of the glacier can be calculated from shear stress, slope angle, density of ice, and the gravity (Paterson, 1994), resulting in the following equation:

Equation 1. Equation for Ice thickness by slope angle, assuming perfect plasticity (Paterson, 1994).

$$h = \frac{\tau_b}{\rho_i \, g \, \sin(\alpha)}$$

h ice thickness
τ_b shear stress
ρ_i ice density
g gravitational constant
α slope

End moraines

In the following the end moraines within the glacier foreland of the Tschierva and Roseg glacier are discussed.

> The last so-called "small ice age" ended in 1850 and left behind a clearly visible end moraine constituting the border of the glacier foreland (Uhlinger et al., 2003). The Roseg & Tschierva glacier retreated ever since with occasional re-advances, which never surpassed the extent of 1850 (Uhlinger et al., 2003).
>
> The end moraine of the advance of 1889 is clearly visible, accentuated by the tree growth.
>
> The end moraine of 1920 is quite hard to spot as it is much smaller than the previously discussed moraines.
>
> From 1965 to 1985 the Tschierva glacier re-advanced (Uehlinger et al., 2003), which falls within the period of strong global dimming (Wild, 2009). Only the Tschierva glacier re-advanced, while the Roseg glacier steadily retreated (Uehlinger et al., 2003; Schollenberger, 1976).

Lateral moraine

Supraglacial debris is transported to the sides of the glacier, especially during the ablation period, where meltwater speeds up the movement. At the side it is deposited along with debris from the valley slopes (Lukas et al., 2012). Fine grained glaciofluvial and glacial debris may resurface and join the supraglacial debris, which leads to complicated mixtures and layers in lateral moraines. Contrary to end moraines, which are destroyed as the glacier extends beyond their location, lateral moraines may accumulate material with each cycle of glacial extend and retreat and thus are able to grow to impressive heights (Lukas et al., 2012).

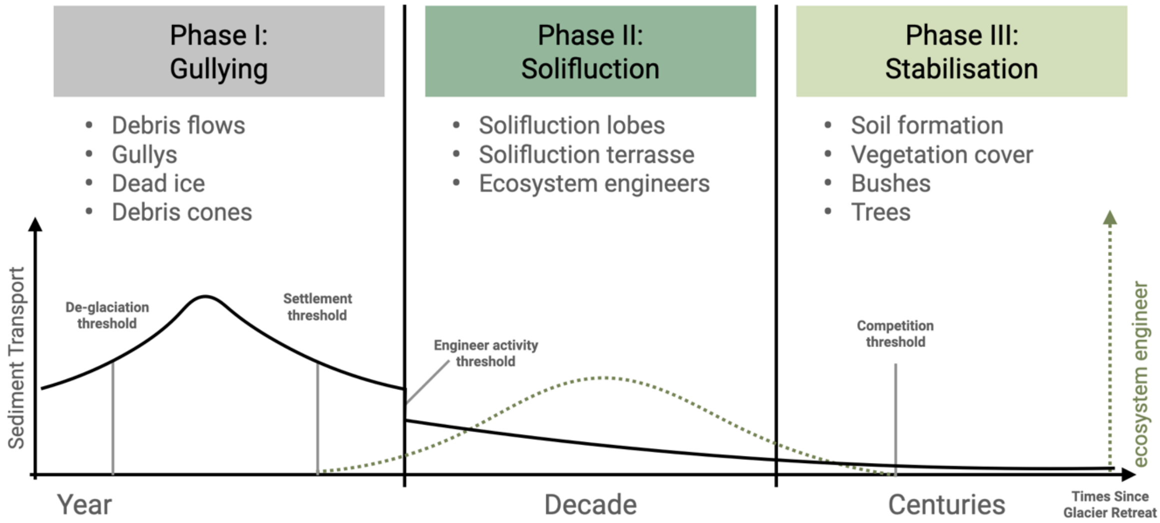

Figure 15. Phases of an exposed lateral moraine. Modified after Lukas et al. (2012).

When the glacier retreats and the moraines are exposed over centuries, they experience three phases. First, the gullying phase, where heavy erosion takes place and so-called gullies are formed. Second, solifluction the slope has already decreased, and solifluction effects start to dominate (Dikau et al., 2019). Third, stabilization the moraine is stabilized and soils form as plants populate the moraine (Dikau et al., 2019; Lukas et al., 2012).

Rock glaciers

The rock glacier might be called the flagship landform of permafrost, especially in the Engadin. We start out by learning more about permafrost and then proceed to rock glaciers themselves.

Permafrost

Permafrost is defined as ground which is consistently at sub-zero temperatures for at least two years (Dikau et al., 2019).

This definition is not tied to material or genesis, but rather to the property of temperature over time alone. This means different kinds of “grounds” may be classified as permafrost, such as solid rock, soils, or debris (Grotzinger & Jordan, 2014).

In shallow depths of the ground the temperature fluctuates with the seasonal and daily air temperature. The layer where these fluctuations is called the active layer (Dikau et al., 2019). These fluctuations lead to activity, for example erosion of headwalls, which can lead to mass movements as discussed in the chapter about mass movements (Fig. 5). On slopes, these fluctuations can lead to solifluction, where the slow creep of soil (Glaser & Radtke, 2012).

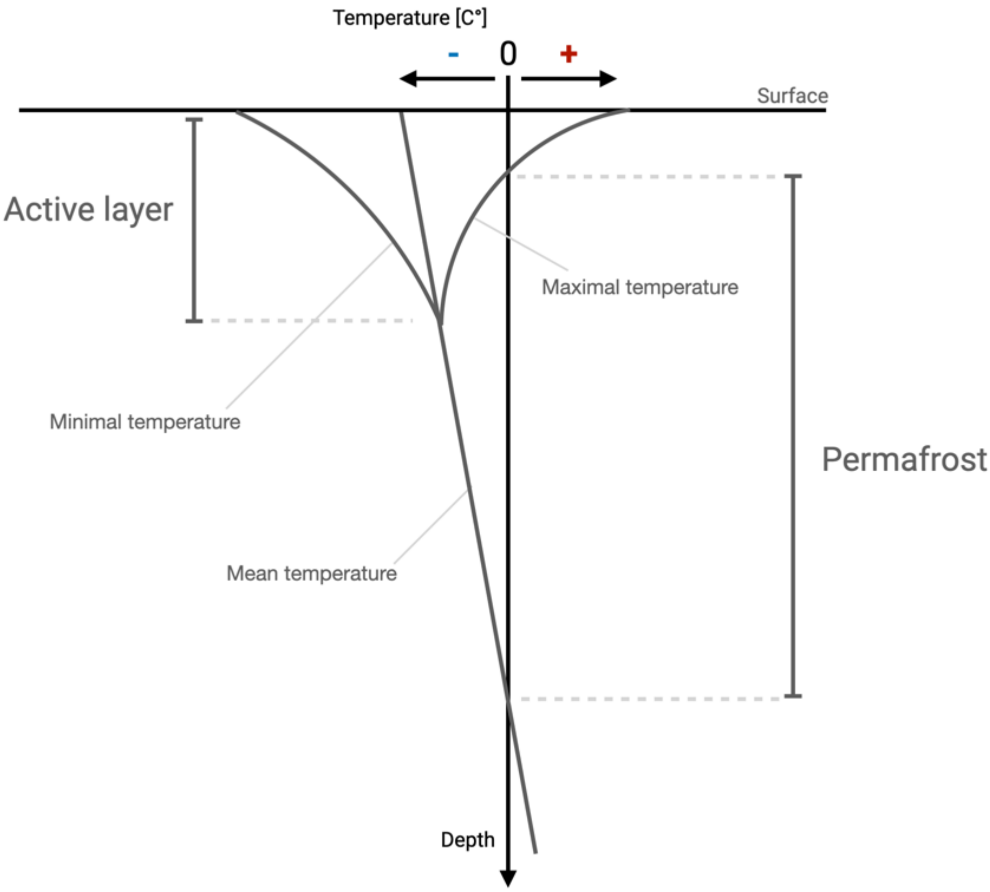

Figure 16. Permafrost temperature profile. Modified from Dikau et al. (2019).

Rock glacier

Rock glaciers consist of several layers with unique behaviours but are in essence a creeping mass of frozen debris (Cicoira et al., 2020).

Active rock glaciers often form below cirques where material accumulates and starts to creep or when moraine material begins to creep (Dikau et al., 2019). They can creep for several thousand years with top speeds of several meters per year, whereas the minimal speeds are too slow to accurately measure as of 2008 (Haeberli et al., 2006). However, with changing climatic conditions, rock glaciers may turn inactive when they lose their ice contents. This loss often causes a collapsed appearance and a termination of movement (Glaziologische Karte, 1998).

Rock glacier System

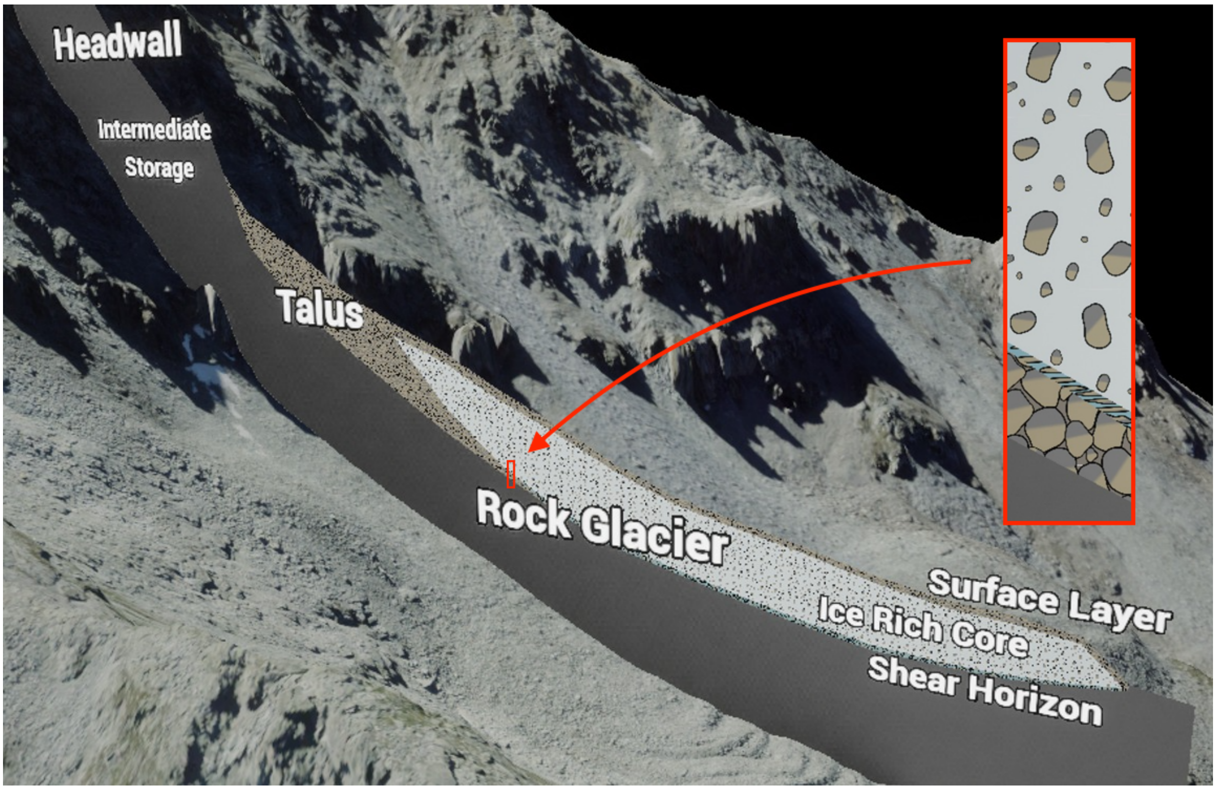

Figure 17. Profile of a rock glacier which can be viewed in the excursion. The red box displays the texture up close. Modified after Müller et al. (2014) and Cicoira (2020).

While rock glaciers are sometimes viewed in isolation it can be beneficial to take a broad look at the whole geomorphological system. Müller et al. (2014) distinguish three parts: the headwall (where the rocks originate), the talus slope, and the rock glacier.

Headwalls function as an intermediate storage. They are dominated by steep rock walls, consisting of consolidated rock and small debris storages. In these debris storages eroded material is stored for short periods of time. Remobilization events, such as avalanches or heavy precipitation, transport the debris further until it is eventually transported to the talus slope below (Müller et al., 2014).

The talus slope consists of unconsolidated material of different sizes (Müller et al., 2014). Talus slopes located in permafrost (dependent on temperatures and water content) may begin to creep and form a rock glacier (Müller et al., 2014).

The rock glacier can be further split into three units which are the active layer, the ice-rich core, and the shear horizon (Cicoira, 2020).

The surface layer consists of a few meters of seasonally frozen blocky sediments, which insulate the ice-rich permafrost beneath (Cicoira, 2020). The typically 10 to 25m thick inner core of a rock glacier is composed of ice and rocks. The water is contributed by precipitation, surface discharge, and groundwater while the rocks originate from the headwall above (Cicoira, 2020). 10-40% of the rock glaciers total displacement takes place within the ice-rich core, while the rest of the movement is mainly attributed to the processes in the shear horizon, which is only a few meters thick (Cicoira, 2020).

Movement, an open Research Question

The movement of rock glaciers is very complex and temporal, as well as spatially irregular (Cicoira et al., 2020). Haeberli et al. (2006) compared different studies but found that neither slope, thickness, temperature, or internal composition are able to explain differences in speed at individual sites completely. However, it has been found that inter-annual and seasonal variability in rock glacier movements might in large parts (60-90%) be due to pore water pressure variation within the shear horizon. The spatial variations on the other hand can in some cases be explained by slope geometry and thickness (Cicoira et al., 2020). Climatic forcings such as air and ground temperature, snow melt, and liquid precipitation may influence the movement in different ways. However, to fully explain the movement of rock glaciers remains an open research field in geomorphology.

Rivers

In 1956, Lane (1956) introduced a quantitative equilibrium equation to explain the relation of flow energy and erosion in rivers. The equation describes that the quantity and particle diameter of sediment (bed load) is in an equilibrium with the water discharge and slope of the stream. If one of the variables is changed, the short-term reaction is aggradation or degradation. In the long term, the river system will adjust one or multiple of the three remaining variables to restore balance (Lane, 1956).

$$Q_W \cdot S \propto Q_S \cdot D_S$$

Q_W Water Discharge
S Slope
Q_S Sediment Quantity
D_S Diameter

Lane's balance can be explained by visualizing the formula as a literal balance (Grotzinger & Jordan, 2014). Adding or removing sediment load or discharge and adjusting the balance by changing slope or sediment diameter changes the position of the balance in an intuitive way (Dust & Wohl, 2012).

Based on the work of Uehlinger et al. (2003), the river can be split in different morphological sections.

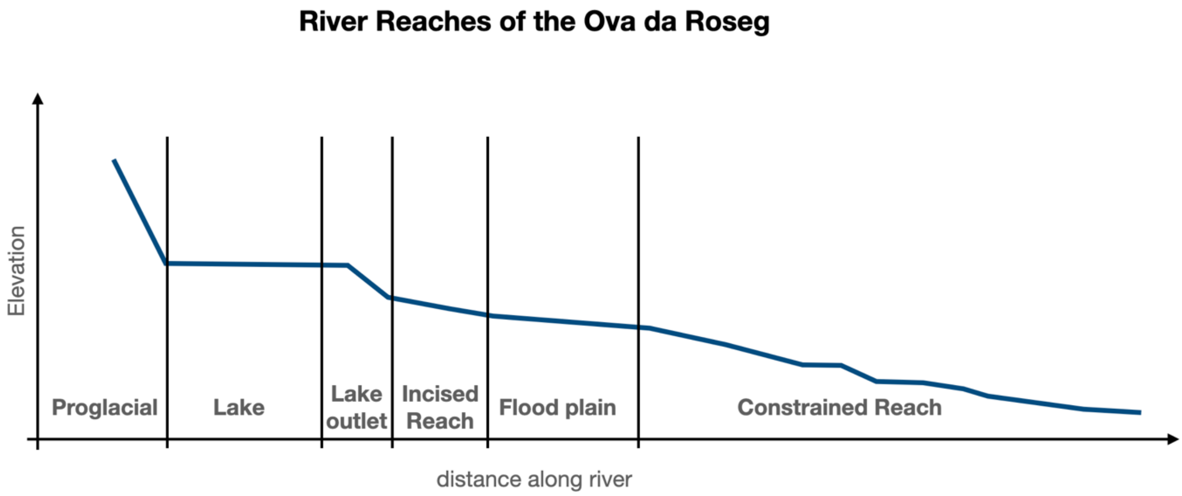

Figure 18. Profile of the Ova da Roseg displaying the different reaches and exaggerated elevation. Based on classification of Uhlinger et al. (2003) and elevation data by Swisstopo, (2019a).

Proglacial Reach

Originating at the Roseg glacier, the river exhibits a steep slope of up to 50% (Swisstopo, 2023a). As the terrain flattens near the lake and material starts accumulating, the river forms into a braided system as explained by Lane's balance (Lane, 1956; Uehlinger et al., 2003).

Lake Outlet System

The lake outlet system begins flat in the upper part until cutting through the lateral moraine of the Tschierva glacier and then steepens up to 10% (Swisstopo, 2023a). As a lot of material has sedimented in the lake, leaving less coarse material in suspension, there is little bedload transport and high channel stability (Uehlinger et al., 2003). Together with the steep slope, the Lane's balance is shifted towards degradation (Lane, 1956).

Incised Reach

Being joined by a large inflow from the Tschierva glacier, the river continues through the glacier foreland as a stable single thread channel in glacial till, with an average slope of 5% (Swisstopo, 2023a; Uehlinger et al., 2003).

Flood Plain

The Roseg flood plain covers a large area (0.67 km^2) and thus dominating the landscape in the upper valley. The plain is the flattest reach discussed here, with a 2% slope (Swisstopo, 2023a), thus tipping the Lane's balance strongly towards aggregation. 85% of the area is sparsely vegetated (Uehlinger et al., 2003). The flood plain features a heavily braided river system, resulting from the pulsed discharge regime. Extreme events, such as floods, can reroute entire channels of the braided system (Uehlinger et al., 2003).

About 7,000-10,000 years ago, a large landslide blocked off the upper part of the valley like a dam and the area above was filled with more than 30m of morainic sediment. As the river cut through these landslide deposits, the area drained again, and the flood plain formed. The area has remained ice free as the glaciers never significantly extended beyond the extent of 1850 since the last glacial maximum (Uehlinger et al., 2003).

Constrained Reach

From the flood plain to the confluence with the Bernina river, the river is constrained by the narrow lower valley. Throughout the lower valley numerous sills have been installed to control channel incision and some banks have been stabilized (Uehlinger et al., 2003). The constrained reach is on average 4% steeper (Swisstopo, 2023a), thus shifting the Lane's balance towards degradation. The river is carrying less coarse sediment as a lot has sedimented in the flat flood plain above.

6.2 Questionnaire Results

54 students participated and completed the questionnaire. An accumulated amount of about 4000 words were commented.

All features were rated on average as helpful or extremely helpful. Even the lowest rated feature was rated by 60% of the students as helpful or extremely helpful (Fig. 19).

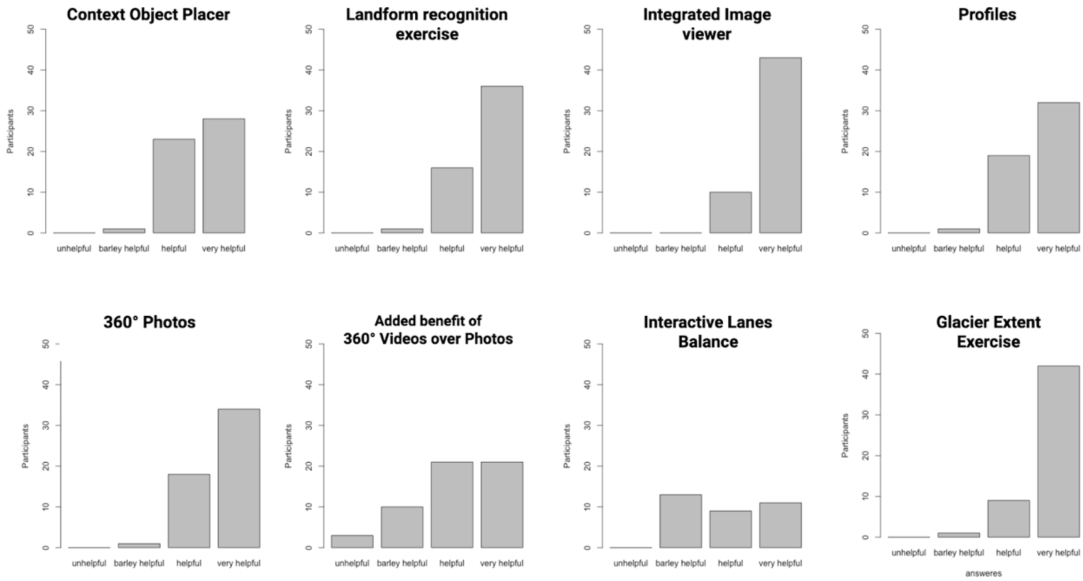

Figure 19. Results of the questionnaire as bar plots. The full questions are listed in the section 5.6, the feature names were introduced in the section 5.2 in Table 1.

Calculating the ratio of extremely helpful to other answers allows to rank the features by perceived usefulness (Fig. 20).

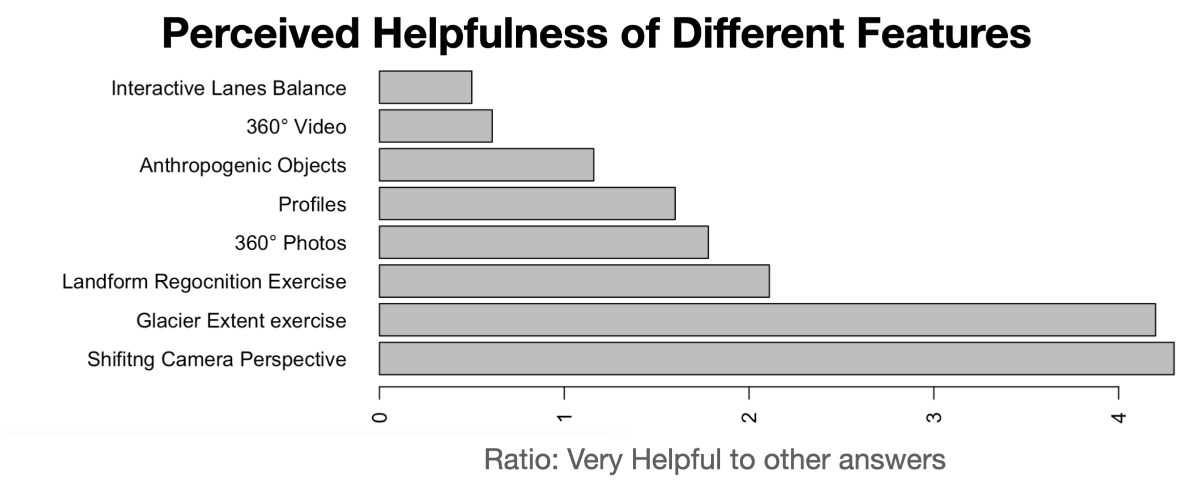

Figure 20. The features ranked by the perceived usefulness as determined by the students in the questionnaire.

In the following the comments regarding each feature and the general comments given at the end of the questionnaire are summarized.

- The shifting camera perspective feature was rated useful to understand the context of the landscape, to better estimate sizes and to learn to recognize landforms from different angels. As the 3D model is limited in resolution the photos were appreciated. However, a better tutorial and a better visible camera icon was requested. Some students wished for faster and others for slower camera movement.

- The glacier extent exercise was well received, the interactivity was valued, and it was perceived as helpful to understand the history of the glacier. The combination of diagram and graphic was especially appreciated. A play button which would let time progress automatically, was requested.

- The landform recognition exercise was for some students extremely helpful, as learning to recognize landforms is the core feature of the excursions and the course in general. It was remarked that the clear visual indication in the virtual excursion can be in some cases more helpful than the difficult situation in the field where a landform can only be pointed out by hand. The exercise was judged to be very difficult (maybe too difficult) but helpful.

- The feature displaying profiles was well received for the integration of profiles in the 3D terrain. The integration in the 3D terrain helped the students with the understanding of scale, and spatial context of the landforms. More text within the profiles was requested.

- The placement of anthropogenic objects in the 3D terrain was seen by many students as a fun feature which helps to a certain degree to convey the size of the terrain. Different objects were requested as well as better communicated sizes of the objects. Some state that a measuring tool utilizing the distance in meters or just cubes of 10, 100, 1000 cubic meters would be more useful.

- For the 360° photos and 360° videos, the comments and feedback were diverse. While some think that the conventional images are enough, there are some who think the 360° photos make a good addition. Concerning the video, the main criticism was that the 360° video is too long and there were reports of motion sickness. Parts of the video depict sections of the road where nothing of significance to a geomorphological field excursion can be seen. The students wished for the video to be sped up, or a cut of only interesting parts to be compiled.

The general comments suggest that the students appreciated that the virtual excursion helps them to learn for the exam, and that it provides an interesting new approach to complement the lecture. The guide and settings panel were commented on as being helpful to understand what to do. There were positive comments regarding the interactive exercises.

A more intriguing design, an audio version of the text was requested as well as less text in general or if not possible, at least a less daunting text box, a German translation, and more clear tutorials for the task.

7. Discussion

In this section the conceptual and technical challenges which were encountered during the development of the virtual excursion will be discussed. Furthermore, the feedback and critique which has been given by the students is discussed. Recommendations and suspended ideas which could help future virtual excursions will be presented.

7.1 Discussion of the Development

7.1.1 Choice of Location

The Roseg Valley, which was chosen as location for the excursion, proved to be a good choice due to its accessibility and the abundance of literature about the valley (Garavaglia, 2009; Linsbauer, 2013; Oerlemans & Keller, 2022; Rothenbühler, 2006; Schollenberger, 1976; Uehlinger et al., 2003; Zah et al., 2003). There are several viewpoints in the surrounding mountains (Muttas da Schlarigna & Muottas da Puntraschigna) from where pictures could be taken, which made the feature possible that shows landforms from several perspectives. The bike paths in the Roseg Valley allow for time reduction in the field work, and the videos taken on bike (when driving downhill) were of comparable quality to the videos taken on foot.

As the valley is easily accessible, many visitors had to be removed from the video material to conform to privacy regulations, which proved to be time-consuming. As a result, it is recommended to plan future video recordings regarding visitor frequency. The forest often obscures the view, therefore, to consider visibility is highly recommended as it would help orientation which is especially important in a virtual experience. The size of the excursion area must be considered as it determines the memory space required by the 3D model of the terrain and influences the distances covered by 360° videos. However, as it is a virtual excursion it is possible to cover more ground or teleport to locations which is not possible in in situ excursions. Data availability across national borders must be considered when creating the 3D model.

7.1.2 Choice of Software

There are many ways in which a virtual excursion could be implemented as a virtual excursion is only very loosely defined. Some approaches use PowerPoint presentation, a video, or a website. For the approach chosen here UE5 was utilized.

Advantages of working with UE5

- The development of specialized features was possible.
- The excursion can be done offline (once downloaded)

Downsides of working with UE5

- It is laborious to develop (compared to a video, PowerPoint, or Google Earth presentation), there will be more bugs and limited capability (less refined 3D Model) then in a big studio application.
- Functionalities must be developed, which would be already existent in other application.
- The file must be downloaded and installed on a computer.

7.1.3 Limitations

It is recommended to collaborate with software engineers to set up a virtual excursion. The project is only sparsely set up modularly which only works as it is intended as a prototype. For further implementations of virtual excursions, it is recommended to build upon the conceptual learnings of this excursion and not to reuse the project file.

7.1.4 Suspended Ideas

There are several ideas which were suspended but might be interesting for future projects.

- 360° video can be accessed by clicking on the spline in the 3D map. The location clicked would translate to the correct timestamp in the video.

- Detailed 3D scan of objects could be placed in the 3D model of the terrain.

- Boolean operation on polygons would allow to cut open "3D models" revealing the structure in three dimensions.

- 3D animation of geomorphological processes to convey the movement, sequence, and speed of processes.

- Mapping task as suggested by Seckelmann & Hof (2020)

- Bring samples from the site to the lecture.

- Video of samples on potter's wheel, the video can be played forwards and backward giving the user the impression of turning the object left and right. This might be very helpful especially when looking at minerals in rock samples.

7.2 Discussion of the Questionnaire

The features in the virtual excursion were well received, and the comments reflect a positive experience. The features developed can be recommended for future implementation.

The Integrated Image Viewer was rated the most helpful followed by the Glacier Extent Exercise. It seems that generally features which aim to convey the scale and sense of being on site (such as the anthropogenic object placer and 360 videos and photos) are less appreciated than features which focus on learning objectives. However, this evaluation might be influenced by the fact that students were entering the exam period at the time of the questionnaire.

The feature explaining Lane's balance was flawed at the time of presentation, the sign displaying the accumulation and degradation was flipped in the graphic. This leads to a confusing presentation and an overall bad experience, which is shown strongly in the rating. However, if implemented and explained correctly, the feature could have a lot of potential.

There is no control question within the questionnaire to rate the student's tendencies in answering questions. Therefore, it is hard to tell whether the overall positive response is due to an overall positive experience or due to a bias of the students to rate a peer's product positively. However, the low ratings associated with the feature which was flawed during the presentation (Interactive Lane's Balance) suggest that the students were willing to give lower ratings if they were truly unsatisfied with a feature.

8. Conclusion

In this thesis, many challenges which can be encountered when developing a virtual excursion were found, dealt with, and reported on. The developed excursion was evaluated by students and those results were presented. While the challenges encountered were often unique to the excursion at hand, various challenges described in the methods part will be of concern for all kinds of virtual excursions and the findings as documented in the discussion may help future development of virtual excursions.

For the choice of location, the topic of the excursion is the most important factor, but the choice of location also influences the possibilities to collect imagery in many ways and is limited by data availability. It is recommended to choose the location bearing these aspects in mind. It is furthermore useful if the developer is familiar with QGIS or similar software, as well as an appropriate tool to develop the excursion, for example in this thesis UE5 was used to great effect. The conceptualized features for this excursion were evaluated by 54 students and the ratings as well as comments show that many features were well received. Especially, the system which allows for photos to be viewed from the proper perspective within the 3D model. As well as the two exercises within the excursion where glacier extents can be reviewed, and landforms must be discovered within the 3D terrain.

Future virtual excursion projects might improve upon the excursion developed, pick up the suspended features, or utilize the features implemented in excursions visiting other locations or to exploring other topics.

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11. Declaration

Personal declaration: I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.

Jonas Kubik

30. January. 2024