movemont.at

ÖAW Austrian Academy of Sciences



MOVEMONT

Moving mountains
Landslides as geosystem services in Austrian geoparks

A project funded through the Earth System Sciences programme of the Austrian Academy of Sciences, 2022–2026

Martin Mergili, Jörg Robl, Oliver Gulas, Gert Furtmüller, Gerald Hartmann, Hanna Pfeffer, Andreas Kellerer-Pirklbauer, Christian Bauer, Harald Zandler, Armin Borovcnik, Thomas Hochholdt, Johannes Schuller, Dominik Wolfschwenger, Jana Petermann, Andreas Schröder, Viktor Haunsperger, Maria Frankova, Katharina Harter, Maximilian Schröcker, Eva Thiel, Horst Ibetsberger, Christian Uhlir, Walter Poltnig

doi: 10.1553/ESS-MOVEMONT

UNI GRAZ

PARIS LODRON UNIVERSITÄT SALZBURG

unesco Global Geopark

Steirische Eisenwurzen Natur- und Geopark

GeoPark ERZ der ALPEN

GEOPARK KARAWANKEN

1. Project Summary

Project Title: MOVEMONT
PI(s): Martin Mergili, Jörg Robl
Duration: 01.11.2022–30.04.2026
Total Funding (€): 507,853
Non-Academic Stakeholder(s): Steirische Eisenwurzen UNESCO Global Geopark, Erz der Alpen UNESCO Global Geopark, Karawanken–Karavanke UNESCO Global Geopark

Landslides are common processes in mountain areas, forming an integral part of their long-term destruction. To society, such phenomena may mean risks and disasters on the one hand, having triggered a huge bulk of research. However, landslides may also represent significant natural and cultural heritage and offer services to society, aspects that are yet under-researched and may be included in the rather scarcely used concept of geosystem services. In this context, landslides also help us to learn how Earth surface systems are functioning. As landslides often represent spectacular phenomena creating remarkable landforms, they are suitable for generating enthusiasm for geo-scientific topics among people, and are therefore useful for demonstrating complex geomorphological processes. UNESCO Global Geoparks (UGGps) represent ideal environments of exploring and highlighting geosystem services related to landslides, particularly in Austria where the three existing UNESCO Global Geoparks (Karawanken/Karavanke, Erz der Alpen, Steirische Eisenwurzen) are characterized by the occurrence of a broad range of landslide types and magnitudes. On this basis, the project has addressed the following topics:

1) We have developed an integrated theoretical framework considering landslide processes and their societal relevance in a comprehensive way, including chances and risks over various scales in time and space. In this context, we have picked up the concept of geosystem services, which has repeatedly appeared in the literature as a spin-off term of the more broadly employed ecosystem services, and combined it with risks as disservices, and created a conceptual framework for a more integrated consideration of landslides where education can result in a shift from disservices towards services.

2) We have mapped and characterized the landslides in each of the involved UNESCO Global Geoparks, including their distribution and characteristics, their role for biodiversity (including microbial diversity in the soils), and for the development of karst landforms and karst research.

3) We have developed and enhanced tools for the GIS-based simulation of landslide preconditioning and landslide dynamics, both in view of improved visualization and science communication, e.g., through immersive virtual reality. Thereby, we have focussed on broad-scale analysis of stress distribution in mountains and its role for slope stability, and on the dynamics of extremely rapid to slow-moving mass flows and complex deep-seated landslides and slope deformations.

4) We have developed and implemented strategies to better use landslide phenomena for science-to-public communication and transdisciplinary knowledge integration, using the involved UNESCO Global Geoparks as ambassadors. Besides various other activities, exhibitions in the museums and visitor centres of the UNESCO Global Geoparks, partly centred around virtual reality experiences, are considered the flagship initiatives for science-to-public communication. In terms of transdisciplinary knowledge integration, a citizen science initiative was launched in the Steirische Eisenwurzen UNESCO Global Geopark, where visitors can take photos through fixed frames (“Windows into the Landscape”), which can serve for long-term monitoring of geomorphological processes, but also of ecological successions and disturbances. All actions were designed in a way to generate a long-term benefit for science communication or transdisciplinary knowledge integration. Various spin-off initiatives have emerged from the MOVEMONT project.

The project was implemented by an interdisciplinary team of scientists of the University of Graz and the University of Salzburg, and specialists in science communication and transdisciplinary knowledge integration from the three involved UNESCO Global Geoparks. It was embedded into the international research and geopark landscapes through various formal and informal collaborations.

2. Key Scientific Outcomes

2.1. Initial objectives

The MOVEMONT project was guided by four objectives, formulated in the project proposal:

O 1: We will develop an integrated theoretical framework considering landslide processes and their societal relevance in a comprehensive way, including chances and risks over various scales in time and space. In this context, we will pick up the concept of geosystem services, which has repeatedly appeared in the literature as a spin-off term of the more widely used ecosystem services, but not yet come into more widespread use.

O 2: We will map and characterize the landslides in each of the involved UGGps, using a common methodology and exploiting existing databases, as a basis for the further steps. We will investigate the importance of landslides with regard to biodiversity, including their role for hosting rare or endangered plant and animal species, but also for microbial diversity in the soils. We will further investigate the role landslides play for the development of karst landforms and their investigation: large landslides reset surficial karstification in the affected area and can therefore be used to analyze rates of karren formation, given that the landslide age is known.

O 3: We will develop an integrated tool set for the GIS-based modelling of landslide preconditioning and dynamics, considering a broad range of process types, temporal and spatial scales. Thereby, we focus on broad-scale analysis of stress distribution in mountains and its role for slope stability, and on the simulation of the dynamics of slow-moving mass flows and complex deep-seated landslides and slope deformations. The models and tools to be developed - along with existing models and tools - will be coupled to visualization interfaces tailored for environmental education, e.g., enabling immersive virtual reality (VR) experiences.

O 4: We will merge all the research outcomes to develop and implement strategies to better use landslide phenomena for environmental education, employing the involved UNESCO Global Geoparks as pilot areas. Feedback loops between scientists, geopark managers, and the public will ensure a well-concerted and targeted research and transdisciplinary knowledge integration. The latter will include exhibitions with physical (e.g., 3D models) and virtual (e.g., immersive VR) elements, guided tours, workshops with schools, and the installation of monitoring systems for demonstration purposes. As landslides often represent spectacular phenomena creating remarkable landforms, we consider them suitable for generating enthusiasm for geo-scientific topics among people of different ages and social backgrounds, and therefore useful for demonstrating complex geomorphological systems and their interaction with biological and societal systems.

Each of the objectives was translated into a work package (WP1–WP4), with specific tasks assigned to each work package. Sections 2.2–2.4 will be structured according to the work packages and tasks, considering WP1–WP3. WP4 will be covered in detail in Section 3.

Adjustments to the Workplan and Methodological Advancements

A further study area was selected at the lower part of the Wildalpen rock avalanche deposits in the so-called Hopfgarten Basin, with the aim of investigating so-called toma hills, mounds occurring in the deposition area of large rock avalanches, which are of high significance in terms of geomorphological heritage and, potentially, biodiversity. These investigations are described as **Task 2.A**.

An additional study area within the Steirische Eisenwurzen UGGp was selected at the Hinterwildalpen Basin slightly west of the Wildalpen rock avalanche area. The reason for this area of investigation lies in a landslide

event that occurred on 18 September 2024 in Hinterwildalpen. It was triggered by extreme precipitation from 12 to 16 September and has been included as **Task 2.B**.

Beyond fulfilling our objectives, a breakthrough was achieved with the development of the higher-order numerical framework DEM-FCM, enabling highly efficient 3D stress computations across entire mountain ranges without complex boundary-conforming remeshing. This efficiency allowed us to couple the landscape evolution model OpenLEM with 3D stress calculations to simulate how the transition from fluvial to glacial topography reorganizes subsurface stresses. To evaluate rock slope stability during this progressive relief decay (applied to the Hochkönig Massif), we replaced basic stress limits with a minimum cohesion formulation. Based on the Mohr-Coulomb criterion, this metric quantifies the rock-mass cohesion required to resist local topographic shear stresses. Our coupled models demonstrated that while individual landslides locally reduce stress, they laterally redistribute it to adjacent slopes, driving short-term cascading instabilities. Furthermore, the OpenLEM-FCM simulations successfully quantified how glacial valley steepening drastically increases the required minimum cohesion on flanks, providing crucial insights into long-term landscape resilience.

In regard to the objective O3, the task T3.4 was merged into tasks T3.2 and T3.3, and is therefore not separately considered in Sections 2.2–2.4. We finally decided not to merge the tools for stress redistribution (T3.2, targeting landslide susceptibility) and for landslide dynamics (T3.3) into one integrated tool, since the two toolsets developed are quite comprehensive by themselves, but with different scopes, and after rediscussing the original concept, we did not see a lot of added value in merging the two tool sets into one. Instead, we invested more resources in optimizing the toolsets resulting from T3.2 and T3.3 for themselves (Section 2.7).

Various spin-off activities have developed from the work on the virtual reality (VR) visualization of the landslide simulation results, pushing forward the gamification of such simulations. These activities were partly carried out within the MOVEMONT project, but are continued afterwards. As they aim at improved science communication rather than scientific advance, they are described in some more detail in Section 3.5.

2.2. Methods used/developed

WP1 Landslides as Geosystem Services

Methods were centred around literature research, the systematic analysis of science databases (SCOPUS, Web of Science, Google Scholar), and the development of a theoretical concept and a visual representation to integrate the role of landslides as geosystem services and as hazards and risks (geosystem disservices).

WP2 Landslide Characterization and Mapping

T2.1 Landslide Inventory: an integrated concept for the analysis of remote sensing data and fieldwork was developed. The following criteria for landslide documentation were defined at the start of the fieldwork. Due to the limited availability of specialized literature, fieldwork for all regions was prepared using high-resolution digital terrain models (DTM) with a resolution of 0.5 m (Erz der Alpen) and 1 m (Eisenwurzen and Karawanken). Field assessments were carried out to evaluate landslide activity. Various landforms and landslides were pre-identified and subsequently evaluated during field assessments to determine their activity levels. Full-scale mapping of landslides throughout the UGGps was not feasible within the project's framework. In the Erz der Alpen and Karawanken-Karavanke UGGps, focus was placed on landslides situated along or visible from key trails (such as the "Erzweg" or other advertised paths). In the Steirische Eisenwurzen UGGp, mapping focused primarily on areas with the Gosau formation as base rock, as existing literature was largely limited to the large Wildalpen rock avalanche. The field evaluations were supplemented by InSAR data analysis for the period of 2016 to 2020.

T2.2 Landslides and Karst: As indicated in the project proposal, one of our main research tasks in the Wildalpen rock avalanche area of the Steirische Eisenwurzen UGGp was the analysis of small-scale karst features which evolved after the landslide event which took place about 5900-5700 years ago. Particularly, we focused on karren features that evolved in the area of release. On the one hand, distinct bare rock slopes which formed during the event and which are considered as the sliding plane of the uppermost part of the landslide were studied. On the other hand, we investigated karren features at selected allochthonous boulders, which were displaced during the event. The three rock slope sites are characterized by smooth surfaces with distinct almost linear karren features which extend over the entire length of the rock surfaces. At the allochthonous boulder site it was more difficult to clearly delineate and map well-developed karren features. Therefore, we further focused on the three rock slope sites. Field trips to the area of release of the Wildalpen landslide have been carried out on four different dates between September 2023 and November 2025 (21.09.2023, 20.10.2023, 8.11.2024, 7.11.2025). During these field trips four suitable surfaces for karren analyses have been selected. These were three rock slope sites and one allochthonous boulder site. The following methods have been applied: Uncrewed Aerial Vehicle (UAV)-based data acquisition for subsequent structure-from-motion (SfM) analysis using a DJI Matrice 300 RTK. This UAV is a quadcopter category C3/C4 and consists of a Global Navigation Satellite System (GNSS) antenna, a Real Time Kinematic (RTK) module, a gimbal to which various systems can be attached (including RGB camera) and a remote control. For SfM smartphone data generation we used a standard mobile phone camera. For smartphone laser scanning (SLS), the 3D Scanner app of the iPhone 12 Pro has been applied which uses the device-own laser module. GNSS measurements have been accomplished for GCP measurements as well as for profiling specific karren features using a Emlid Reach RS2. The latter application has been done to verify the digital elevation model computed from the other methods. Finally, at some selected karren features we did additional manual measurements.

T2.3 Landslides as Ecological Niches: based on project requirements: highly active landslides were chosen for biodiversity research. We surveyed ecological communities (plants and arthropods) as well as ecosystem functions on landslides and controls in the Karawanken-Karavanke UGGp and the Erz der Alpen UGGp in 2023 and on toma hills formed by the Wildalpen rock avalanche (Steirische Eisenwurzen UGGp) in 2024. We used established methods such as area vegetation surveys, pitfall traps, and insect netting. The ecosystem functions primary productivity, herbivory and predation were measured using biomass samples, visual assessment and artificial caterpillars, respectively. We measured several abiotic parameters such as soil temperature, soil moisture and pH, to assess the variation of environmental variables that may drive community composition.

T2.A Toma Hills: Field trips to the study area have been carried out on six different dates between July 2023 and November 2025 (18.07.2023, 20.09.2023, 18.-19.10.2023, 04.-05.06.2024, 08.05.2025, 06.-07.11.2025). This field of research was incorporated into a master's thesis carried out by Armin Borovcnik (Borovcnik 2024) and supervised by Andreas Kellerer-Pirklbauer, Harald Zandler and Christian Bauer. This research deals with the geophysical analysis and 3D-visualisation of the toma landscape of Hopfgarten, a special depositional form of the Wildalpen rock avalanche. Previously, little was known about the internal structure of toma hills, with existing outcrops being the main source of interpretation. The aim of this work was therefore to use the geophysical method of direct current geoelectrics to obtain information about the internal structure of selected toma hills in the Hopfgarten study area. For this purpose, a total of three toma hills of different sizes at two different sites in the study area were investigated in more detail with 14 to 18 parallel geoelectric profiles. Furthermore, an approach for the delineation and mapping of toma mounds based on ALS data from the province of Styria was applied. In addition, digital surface models from high-resolution UAV images were created for the morphometric analysis of selected toma hills in order to determine the effects of geometric resolution on mapping and volume calculation.

T2.B Hinterwildalpen Landslide: in Zandler et al. (2025) we describe and quantitatively capture the landslide and discuss its respective origin. Methodologically, a field survey (08.11.2024 and 08.05.2025), a UAV survey and an analysis of the height differences compared to an ALS-based elevation model from 2011 in addition to meteorological data of four meteorological stations have been used.

WP 3 Landslide Simulation

The methodological framework developed within Work Package 3 represents a significant advancement in the simulation of alpine landscape evolution, topographic stress, and landslide dynamics. A core achievement was overcoming the computational limitations of traditional modelling approaches, enabling high-resolution, three-dimensional simulations across entire mountain massifs and simulations of a broad variety of landside processes, from extremely rapid to slow, and from slide-type to flow-type movements.

T3.1 From Landscape Geometry to Landslides: to quantify the geomorphological preconditioning of mountain landscapes within the three Austrian UGGps, we implemented an automated analytical framework in MATLAB utilizing TopoToolbox. This framework allowed for the highly efficient extraction and analysis of the landscape geometry, including local relief, channel profiles, and normalized steepness indices across multiple catchments in all three geoparks. To identify potential landslide release areas in over-steepened topography, we applied a probabilistic rockfall model. This model identifies contiguous unstable rock masses, allowing us to estimate detachment volumes realistically without the computational burden of tracking material deposition (Haunsperger et al., 2026). Due to the progressive removal of excess relief, the topography evolves with each event. These topographic snapshots served as input data for computing 3D stresses within the mountain massif (see T3.2).

T3.2 From Topographic Stresses to Landslides: A major methodological breakthrough was the development of a novel higher-order numerical framework, termed DEM-FCM for computing three-dimensional linear elastic stress fields (Haunsperger et al., 2026). Traditional 3D stress modelling relies on the Finite Element Method (FEM), which requires complex, boundary-conforming meshes that are computationally expensive for rugged alpine terrains. The DEM-FCM bypasses this by utilizing a fictitious domain approach that embeds the mountain topography into a structured integration grid. To accurately capture the complex surface geometry without remeshing, the framework incorporates the Marching Volume Polytopes (MVP) algorithm (Haunsperger et al., 2026). This direct DEM-to-mesh workflow drastically reduces pre-processing overhead and degrees of freedom, enabling highly efficient dead-load stress computations directly from matrix-oriented elevation grids (Zenodo repository: Haunsperger, 2026). 3D stress calculations were carried out for all three UGGPs, visualized as flyovers across the landscape, and prepared for Kitware Glance. Versions of these in reduced resolution are available for viewing at www.geodynamics.at.

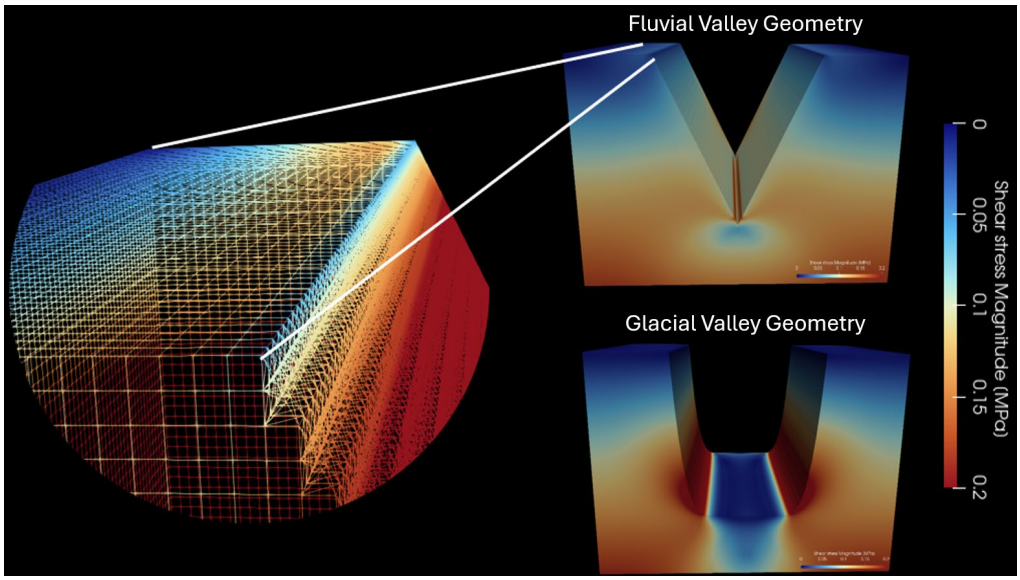


Figure 1: Shear stresses for simplified valley geometries (fluvial vs. glacial) as a result of the DEM-FCM software developed during the research project. The detailed view on the right shows the setup of the computational grid, color-coded for shear stress as well. Driven by the high computational performance of this method, high-resolution simulations with over 1 billion cells are achievable.

The exceptional computational efficiency of the FCM approach allowed for coupling with a probabilistic rockfall model to simulate the progressive decay of alpine relief (Haunsperger et al., 2026). By sequentially removing unstable rock masses and recalculating 3D stress tensors, we demonstrate how landslides fundamentally reorganize subsurface stress fields in mountain massifs. This mechanism is particularly pronounced in the decaying, over-steepened topographies that characterized the glaciated Alps during the Last Glacial Maximum (LGM). To evaluate rock slope stability during this evolution, we utilise a stress-based stability metric: a minimum cohesion formulation based on the Mohr-Coulomb failure criterion (Haunsperger et al., 2026; Robl et al., 2026). This metric calculates the rock-mass cohesion required to resist local topographic shear stresses, providing a spatially explicit measure of failure proximity.

The latest development involves coupling the OpenLEM model with DEM-FCM to quantify stress changes and sites of rock failure during glacial advances and retreats. This accounts for both topographic changes driven by glacial and fluvial erosion, and varying ice loads as a function of climate.

T3.3 From Rapid to Slow Flows and Slides: the GIS-based open-source mass flow simulation tool has been developed and continuously enhanced since 2014. Within the MOVEMONT project, enhancements were centred around functionalities extending the applicability of the model for science communication and transdisciplinary knowledge integration. Some of the enhancements were elaborated in collaboration with Shiva Pudasaini (TU Munich), the co-developer of r.avaflow. He developed some of the physically based model equations (e.g., earth flow model, rock avalanche fragmentation, energy loss through internal shearing) which were then implemented in the C code of the r.avaflow core module and tested on real and synthetic topographies. Further, a web interface was developed (using HTML, PHP, CSS and JavaScript) to facilitate the use of the software and make it accessible to a broader audience (before, it was mainly operated through a scripting interface and only worked on LINUX systems). Python scripts were developed to ensure smooth transfer of the model results to the 3D animation software Blender (versions 4 and 5) and the game engine Unreal Engine 5.

2.3. Achievements and new insights

WP1 Landslides as Geosystem Services

Our results show that well-established concepts of biodiversity and ecosystem services are by far prevailing the younger concepts of geodiversity and geosystem services in all three publication databases. While the amount of geodiversity papers represents < 1% compared to the amount of biodiversity papers, the amount of geosystem services papers represents < 0.1% compared to ecosystem services papers. This can be explained by the fact that geodiversity and geosystem services concepts are much younger, with first publications in the databases going back to late 1990s and 2000s, respectively. The share of papers addressing both concepts of biodiversity and geodiversity among the geodiversity papers varies from about 30% (WOS and Scopus databases) to nearly 50% (GS). Similarly, the share of papers addressing both concepts of ecosystem and geosystem services among the geosystem services papers varies from about 30% (Scopus) to two thirds (GS). However, the increased share among the results of the GS database is attributed to its full text search, compared to abstract and titles search in WOS and Scopus databases.

WP2 Landslide Characterization and Mapping

T2.1 Landslide Inventory: The results of the mapping campaigns for each of the UGGps are described in detail in Uhlir (2024a, 2024b, 2025). A notable result was that InSAR data analysis for the period of 2016 to 2020 yielded varying results across the different UGGps. In the Erz der Alpen UGGp, the analysis revealed significant subsidence on the level area south of the Bischofshofen ski jumping hill's take-off table. In the Steirische Eisenwurzen UGGp, significant subsidence was identified on top of the Dörfelstein, whereas no significant subsidence was detected for the Karawanken-Karavanke UGGp.

T2.2 Landslides and Karst: Figure 2 shows some exemplary results from the study sites in the former area of release. In **Figure 2a**, the live view from the SLS is visible on the mobile phone's display. This allows the

user to monitor the scan progress and the detection of unscanned areas. A result based on this approach is depicted in **Figure 2b**. For the same area, the results of SfM-smartphone are presented in **Figure 2c**. Finally, **Figure 2d and e** give some impressions from the GNSS-based profiling of karren features and the related results. The latter measurements have been an important basis for the subsequent methodological tests outlined in the following section.



Figure 2: Field impressions form the selected study sites in the uppermost part of the Wildalpen landslide: (a) bedrock area with distinct karren features; the surface is cleared from branches and other organic material before the remote sensed-based data acquisition; (b) allochthonous boulder with some karren features; (c) bedrock area: ground control point (GCP); (d) bedrock area: GNSS measurements of a GCP; (e) bedrock area: manual mapping of a 8 cm wide and 11 cm deep karren feature. Photographs by authors.

T2.3 Landslides as Ecological Niches: Analyses are currently in progress (M.Sc. theses Schröcker and Harter, BSc thesis Thiel) or were completed in 2024 (MSc thesis Frankova). We found that a number of plant species were present only on landslides in our study, confirming the geodiversity-biodiversity link. Landslides and other geological processes thus increase the diversity of ecological communities likely via an increase in landscape heterogeneity and the generation of new niches for additional species. However, some of these plant species were neophytes, demonstrating that disturbances such as mass movements may facilitate the spread of invasive species. Contrary to our expectations, we found few red-listed plant species in our study. Ecosystem functions so far did not show much response to the geo-features we investigated. Further

analyses will include community assessments of arthropods as well as analyses at different spatial scales (landscape scale for Karawanken and Ore of the Alps, small scale (m2) for Eisenwurzen) to explore the increased heterogeneity at these scales and the resulting potential increase in niche space.

T2.A Toma Hills: Results of the geoelectrical measurements showed that the investigated toma hills are composed of high-resistivity, less fractured landslide material with a higher proportion of pores, which thus form the core of the toma hills and are embedded in fine landslide material (**Figure 3**). This largely confirms assumptions from earlier studies on the structure of toma hills. The comparison of the morphometric results based on the ALS-DGM used (1x1m grid) and high-resolution UAV surface models (4x4cm grid) showed some significant differences in the derived volumes of the toma hills and thus also showed the advantages and disadvantages of the different data sets. Since the internal structure has hardly been investigated in such detail so far, this work provides a valuable basis for further investigations in the field of toma hill research (for details refer to Borovcnik 2024).

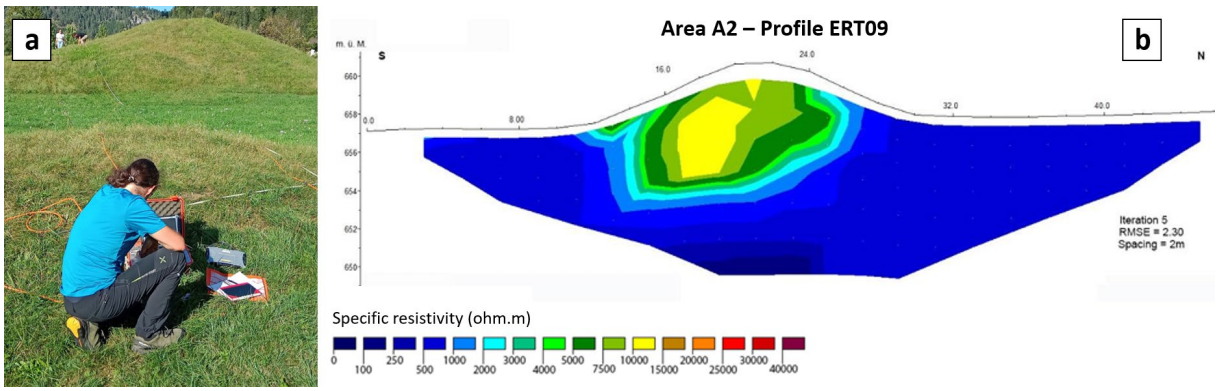


Figure 3: ERT measurements (a) and selected results (b) at the Hopfgarten Basin focusing on a Toma hill landform. For details refer to text. Figure modified after Borovcnik (2024); Photograph by authors.

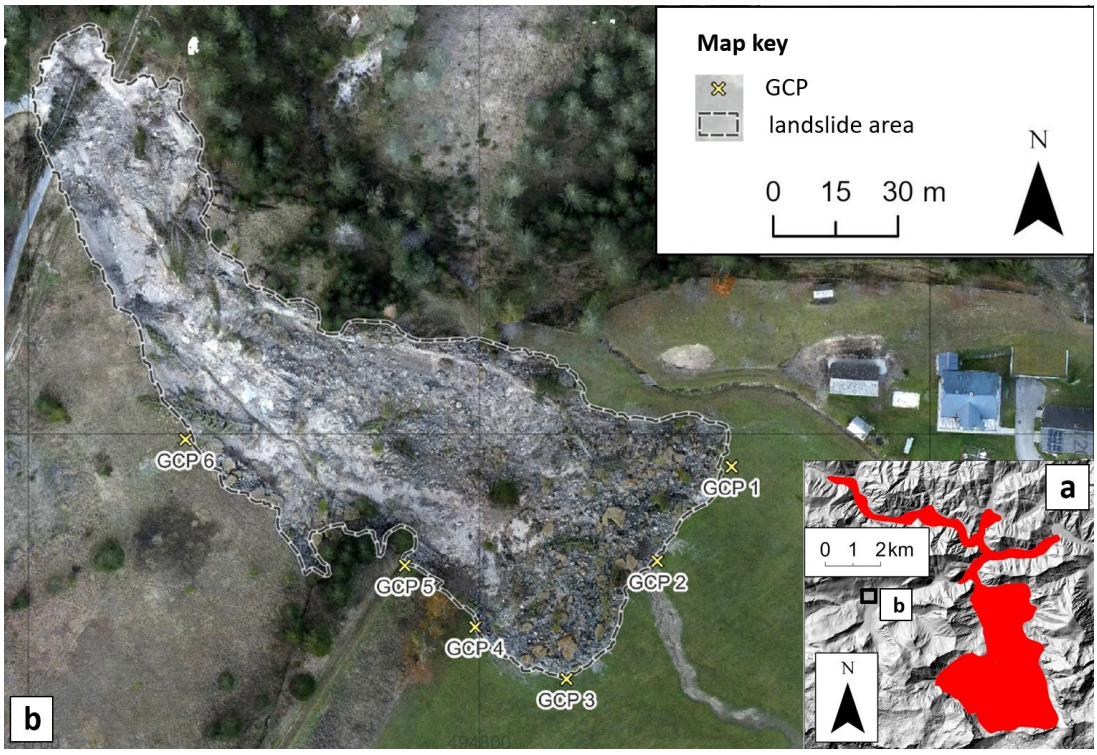


Figure 4: Recent landslide Hinterwildalpen: (a) overview map; (b) orthoimage from the UAV survey on November 8, 2024. The starting zone with the destroyed road infrastructure and the deposition zone on top of the agricultural area are clearly visible.

T2.B Hinterwildalpen Landslide: This landslide (**Figure 4**) affected an area of 7,600 m² and moved 5,500 m³ of material. The process was triggered after 258 mm of precipitation within a period of five days. This amount of precipitation within such a short period of time was the highest value since measurement started in 1901. The precipitation event led to oversaturation of fine sediment and started the landslide. The high precision survey connected with meteorological data of high temporal resolution led to good quality of the results (for details refer to Zandler et al. 2025).

WP3 Landslide Simulation

Work Package 3 of the MOVEMONT project yielded several methodological breakthroughs and new insights into alpine landscape evolution and landslide dynamics.

T3.1 From Landscape Geometry to Landslides: Topographic metrics offer crucial insights into the vulnerability of the landscape to mass wasting. The analyses were carried out for the entire area of the respective UGGPs and at a higher spatial resolution for specific catchments. For instance, detailed morphometric analyses were conducted for 11 catchments in the UGGp Ore of the Alps, 121 catchments in the UGGp Steirische Eisenwurzen, and 34 catchments in the UGGp Karawanken (see www.geodynamics.at). Besides enabling the correlation of topographic metrics (principally geophysical relief) with the landscape's state of topographic stress.
4K fly-out visualization movies were created for the three geoparks and are displayed on large screens in the exhibition centres. Among other elements, the topography, geophysical relief, and—at the request of the UGGp Ore of the Alps—the geological map were overlaid onto the perspective view movies. To facilitate the understanding of glacial overprinting, ice flow modelling and visualizations of glacial advance and retreat during the ice ages were created for the Salzach catchment (UGGp Ore of the Alps) as well as for the Hochschwab (UGGp Steirische Eisenwurzen). To provide interactivity, selected datasets were prepared for the web-browser-based tool Kitware Glance. This allows users to explore the topography by rotating, zooming, and tilting the landscape within the areas of the three geoparks. Versions of these visualisations in reduced resolution are available for viewing at www.geodynamics.at.

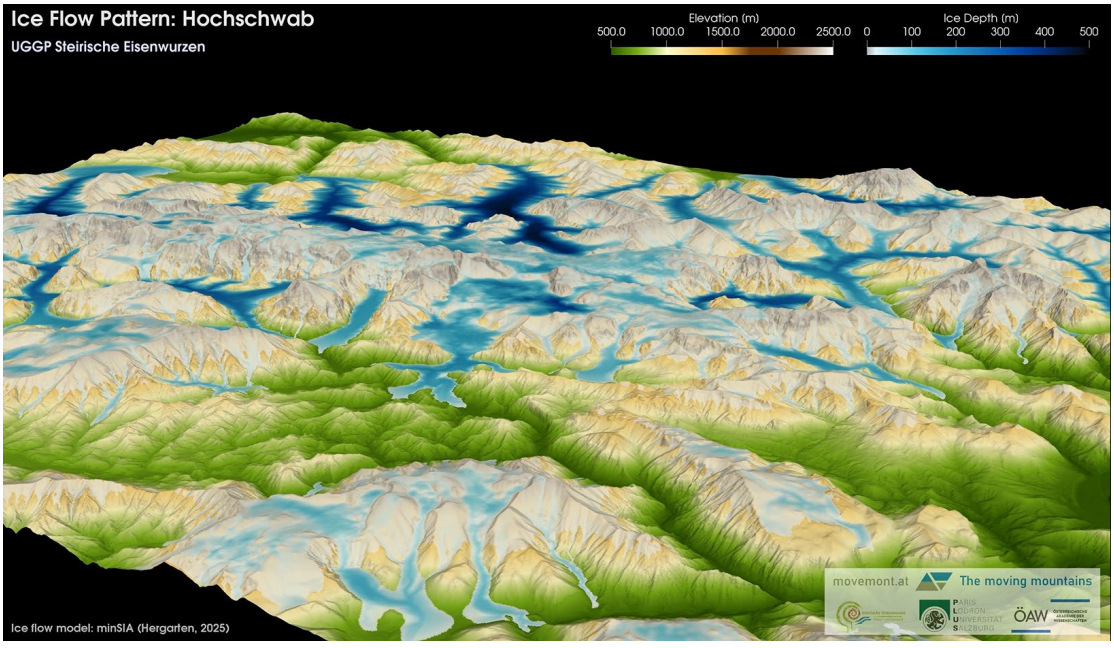


Figure 5: Fly-over animations simulating glacial advance and retreat driven by climate cooling and warming were computed and provided to the UGGPs Eisenwurzen and Ore of the Alps for exhibition presentations.

T3.2 From Topographic Stresses to Landslides: A core achievement was overcoming the severe computational limitations traditionally associated with modelling 3D stresses in complex alpine terrain. Instead of using complex boundary-conforming meshes, a novel, higher-order numerical framework called

the Finite Cell Method for Digital Elevation Models (DEM-FCM) was developed (Haunsperger et al., 2026). This approach embeds the topography directly into a structured integration grid and uses a Marching Volume Polytopes algorithm to accurately capture the exact surface geometry. This enabled high-resolution 3D linear elastic stress computations across entire mountain massifs at a significantly reduced computational cost (Haunsperger et al., 2024; Haunsperger et al., 2026). Parallel to publishing the article of the higher-order version of DEM-FCM, the source code will be provided via a public Zenodo repository (Haunsperger, 2026: https://doi.org/10.5281/zenodo.20794091). The models revealed a highly complex spatial distribution of shear stresses. Beyond the expected maxima on over-steepened glacial flanks, massive stress concentrations also manifest at valley floors and converging valleys. Since zones of high shear stress are preferred sites for fracturing, this yields a series of implications. These include enhanced groundwater flow permeability in bedrock aquifers beneath valley floors and accelerated mechanical and chemical weathering rates. Ultimately, this initiates a positive feedback loop: erosive valley incision amplifies stresses within the valley floor, driving further fracturing and thereby reducing bedrock resistance to erosive processes, which in turn accelerates incision. This opens up a series of new research avenues for future projects. Furthermore, the models quantified how lithological contrasts govern landscape geometry: strong Dachstein limestone in the Hochkönig Massif sustains extreme near-surface shear stresses, whereas the weaker Greywacke Zone flattens much more rapidly through slope deformations (Haunsperger et al., 2026). Since mass movements occur across all lithological units of the Alps, this approach allows for the quantification of rock mass strength at the mountain scale including structural elements such as bedding or faults planes and its comparison against values for rocks at laboratory-scale (in general without discontinuities). By coupling the DEM-FCM stress model with a probabilistic rockfall simulation, the progressive decay of a typical mountain massif of the Northern Calcareous Alps (i.e., Hochkönig Massif, UGGP Ore of the Alps) was modelled. The simulations revealed a surprising pattern of stress redistribution: while individual rockfalls locally reduce maximum shear stresses at the failure site, gravitational loads are laterally redistributed to adjacent inner slopes, locally increasing shear stresses. This mechanism provides a mechanical explanation for cascading, secondary rock instabilities (Haunsperger et al., 2026). Over the long term, repeated mass removals truncate extreme localized stresses, evolving the terrain into a mechanically more resilient landscape. Another breakthrough was modelling the transition from fluvially to glacially conditioned landscapes and related stress changes. Glacial erosion drastically steepens valley flanks—as observed across major parts of the Eastern Alps and exemplified by the three Austrian UNESCO Global Geoparks (UGGs)—thereby increasing shear stresses in the bedrock (Robl et al., 2026). Because glacial ice buttresses these over-steepened flanks during glaciations, rapid ice retreat (deglaciation) removes this support, exposing the landscape to sudden extreme stress peaks, which acts as a primary trigger for massive post-glacial landsliding (Robl et al., 2026). Due to climate change, the rapid glacier retreat in high-alpine regions necessitates models for calculating topographic stresses to protect alpine infrastructure and communities. To evaluate rock slope stability, we computed the minimum cohesion required to resist localized shear stresses to predict sites prone to rock failure. The results demonstrated that localized stress maxima depend heavily on 3D landscape geometry and lateral confinement, confirming that full 3D elastic stress modelling and stress-based stability metrics are necessary for assessing potential landslide release areas (Haunsperger et al., 2026).

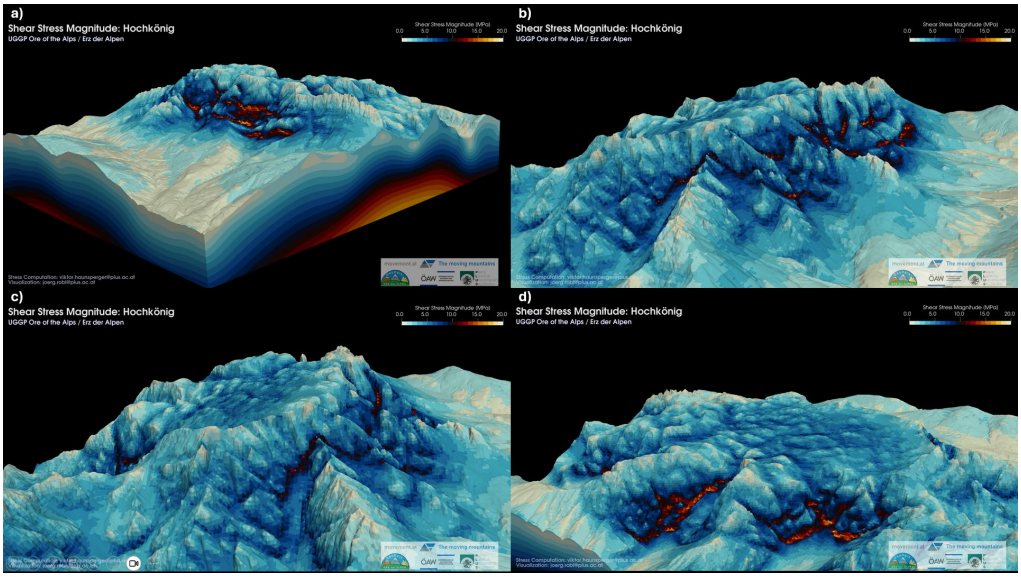


Figure 6: The shear stress magnitude for the Hochkönig Massif (Erz der Alpen UGGp) viewed from different perspectives. High-resolution 3D solutions from DEM-FCM enable the analysis of the near-surface stress state, as well as the far-field effects of varying topographic loads on stress distribution at depth. For the visitor centres across the three UGGPs, fly-over videos and cross-sectional animations through the mountains were produced for the respective geopark mountain massifs, making them available for display in the exhibition centres.

T3.3 From Rapid to Slow Flows and Slides: within the MOVEMONT project, r.avaflow was equipped with the following additional functionalities (some of them were already available before and were improved during the project.

- A web interface for the operation of the software, including a detailed documentation of the parameters and requirements: https://www.landslidemodels.org/r.avaflow/direct.php
- CSV files tailored for 3D animations in Blender or Unreal Engine. They are automatically produced in each simulation, along with a script for the generation of 3D models and animations in the Blender software.
- Models for rock avalanche fragmentation (Pudasaini et al., 2024) and for the effects of internal shearing (Pudasaini and Mergili, 2025b), included directly in the r.avaflow C code.
- Two models for slower landslide processes, among them one earth flow model (Pudasaini and Mergili, 2025a) and one equilibrium-of-motion model (Mergili et al., 2025), both included directly in the C code of r.avaflow.
- A model for controlled landslide deformation, allowing the simulation of landslides within the full range between flow-type and slide-type movements (Pudasaini and Mergili, 2024), included directly in the C code.
- A model for layered movements (useful for deep-seated gravitational slope deformations and for the impact of landslides into water bodies), also included directly in the C code.

All the details of the enhancements of r.avaflow are provided in Mergili et al. (2025), which is considered one of the key publications of the MOVEMONT project.

2.4. Discussion of Findings in Relation to Recent Scientific Discourse

WP1 Landslides as Geosystem Services

Fig. 3 illustrates an idealized concept of how effective geo-education can unlock cultural GSS and gESS by generating interest and awareness for landslide processes and their consequences. The graphics has been

designed for landslide processes, but is essentially valid for all earth surface processes. In **Figure 7a**, effects of geo-education are excluded, and the disservices clearly dominate over the services. Successful geo-education can represent an important contribution to risk management, and thereby expand services – also to be understood as a general contribution to geo-knowledge as an important prerequisite to preservation of geodiversity – at the cost of disservices (**Figure 7b**). **Figure 7** has to be interpreted in a qualitative way, and the fractions between services and dis-services are indicative only.

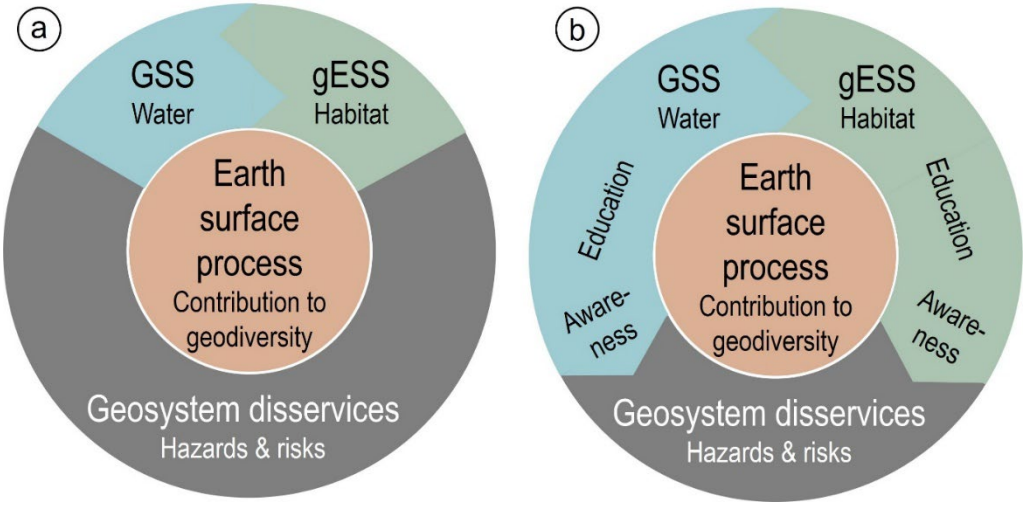


Figure 7. Optimized concept of geodiversity, gESS and GSS, and the related disservices. Water and habitat are given as examples for regulatory and provisional GSS and gESS. (a) Effects of geo-education are excluded; (b) effects of geo-education are included.

By now, the concept depicted represents a theoretical model which is subject to empirical evaluation. Such evaluation is out of scope of this work, which is rather understood as an effort to highlight the relationship between geodiversity, geosystem services, and geosystem disservices at a conceptual level. Empirical evaluation may rely on the analysis of well-documented previous efforts of geo-education (references), but will also build on the analysis of the effects of exposing visitors of the Steirische Eisenwurzen UNESCO Global Geopark to virtual landslide experiences.

WP2 Landslide Characterization and Mapping

T2.2 Landslides and Karst: We investigated the suitability of various remote sensing methods for detecting the karren features based on high-resolution 3D models. This field of research was incorporated into a master's thesis carried out by Thomas Hochholdt (Hochholdt 2024) and supervised by Andreas Kellerer-Pirklbauer, Harald Zandler and Christian Bauer. The methods applied included terrestrial laser scanning (TLS), airborne laser scanning (ALS), smartphone laser scanning (SLS) and structure-from-motion approaches based on optical data recorded by an unmanned aerial vehicle (SfM UAV) and a smartphone (SfM smartphone). These methods were tested under different conditions, in particular regarding the inclination angle of the surface to the sensor (25°, 40°, 55° and 70°). To compare the remote sensing methods, an artificial reference model was created that represented the typical karren features as explained above. Our results revealed that the choice of the optimal remote sensing method for creating 3D models of karren features depends on the specific requirements of the respective object of investigation. While the SfM methods deliver the most promising results overall, TLS and SLS have their specific strengths in certain surface structures and application cases (triangular geometries and flat slopes). The good performance of the SLS method with mobile devices was surprising, whereas the ALS method was not convincing (for details refer to Hochholdt 2024).

WP3 Landslide Simulation

T3.1 From Landscape Geometry to Landslides: Morphometric analyses reveal how mountain landscapes and their characteristic topographic signatures evolve through the interplay of tectonic uplift and climate-controlled fluvial and glacial erosion. Our findings indicate that while this type of quantitative landscape analysis provides valuable insights into the 3D state of stress and hence landslide activity within mountain massifs, it can only partially explain the actual 3D stress distribution. This confirms our initial hypothesis that due to complex topographic features—such as ridge lines, deeply incised valleys, and glacial cirques—morphometric analyses cannot substitute for full 3D stress computations as developed within this research project. However, our morphometric analysis revealed new findings related to uplift and exhumation of the Karawanken – Pohorje region. These novel insights have resulted in a 4-year doctoral project funded by the University of Salzburg, which commenced in March 2026 and continues the research within the area of the UGGp Karawanken.

T3.2 From Topographic Stresses to Landslides: Advancing the field and breaking computational barriers, our findings represent a fundamental shift in evaluating topographic preconditioning and landslide susceptibility. Historically, computing three-dimensional linear elastic stress fields across rugged mountain topography has been severely limited by computational costs, as traditional Finite Element Methods (FEM) require complex, boundary-conforming meshes (Haunsperger et al., 2026). The development of the DEM-FCM (Finite Cell Method for Digital Elevation Models) framework bypasses this bottleneck utilizing a fictitious domain approach (Haunsperger et al., 2026). This novel framework accurately captures complex surface geometries directly from digital elevation models without remeshing (Haunsperger et al., 2026). This provides the scientific community with an efficient tool to compute 3D stresses for entire mountain massifs, an achievement that was previously computationally prohibitive (Haunsperger et al., 2026). From static snapshots to dynamic landscape evolution, prior research predominantly treated landscapes and their stresses as static entities. A major conceptual leap in our project was coupling the DEM-FCM stress model with probabilistic rockfall simulations and the OpenLEM landscape evolution model (Haunsperger et al., 2026; Robl et al., 2026). This allowed us to simulate stress redistribution during the progressive decay of alpine relief (Haunsperger et al., 2026). By quantifying the transition from fluvially valleys (conditioned valleys (V-shaped) to glacial troughs (U-shaped), our models demonstrated how glacial erosion concentrates gravitational shear stresses in the bedrock (Robl et al., 2026). Crucially, the models confirmed that glacial ice provides a lateral buttressing effect that suppresses failure; rapid deglaciation removes this confinement, exposing bedrock to sudden extreme shear stresses and providing a mechanical explanation for massive post-glacial landsliding (Robl et al., 2026). Progressive rock mass weakening driven by permafrost degradation, hydraulic fracturing, or thermal stress fracturing causes topographic stress to exceed the decreasing rock mass strength, making climate change a major trigger of rock slope failure. For this purpose, the ability to compute the 3D stress state of mountain massifs with high spatial resolution is crucial. A significant refinement in stability assessment is driven by our results, which demonstrate that broad-scale slope stability cannot be accurately predicted using empirical 2D geometric metrics, such as hillslope steepness or geophysical relief (Haunsperger et al., 2026). Maximum shear stresses, which govern catastrophic rock slope failures, rely heavily on 3D landscape geometry, slope curvature, and lateral confinement. By formulating a novel 3D stress-based stability criterion based on the minimum cohesion required to resist localized shear stresses, we highlighted the necessity of 3D modelling for reliable hazard evaluations (Haunsperger et al., 2026). Unexpected stress redistribution and cascading instabilities were revealed when analyzing the cumulative decay of the Hochkönig Massif, as simulations showed that individual failures do not simply stabilize a slope (Haunsperger et al., 2026). Instead, while maximum shear stresses decline at the immediate failure site, gravitational loads are laterally redistributed to adjacent inner slopes, where shear stresses locally increase (Haunsperger et al., 2026). This finding provides a physical mechanism for the positive path dependency of landslides, explaining how an initial failure can drive adjacent slopes past critical limits and trigger cascading secondary instabilities (Haunsperger et al., 2026).

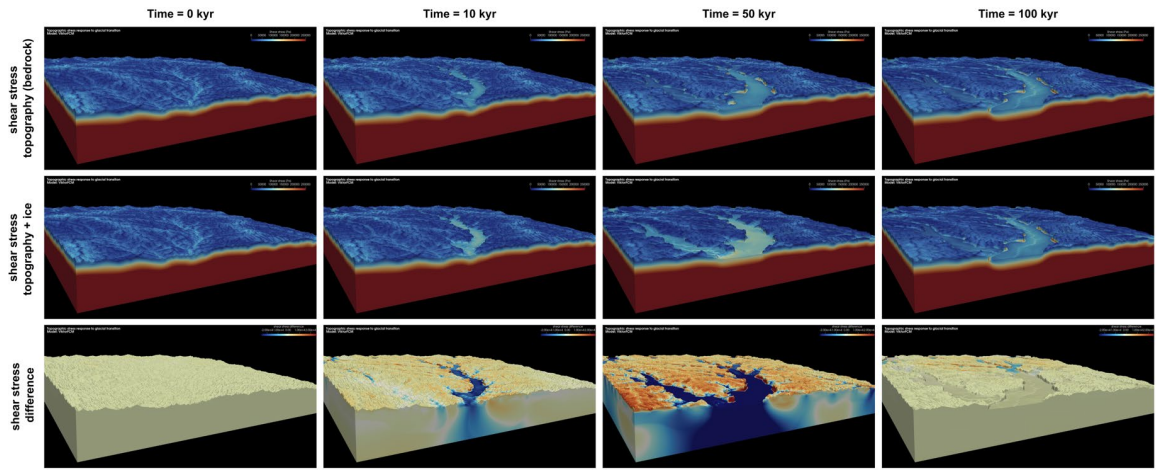


Figure 8: Changes in the 3D stress distribution during the transformation of a fluvial into a glacial landscape, accounting for topographic and ice loads. The results are based on coupling OpenLEM with the 3D stress computation code (DEM-FCM) developed within this project.

T3.3 From Rapid to Slow Flows and Slides: The simulation framework r.avaflow v4, developed and finalized during the MOVEMONT project based on earlier versions of r.avaflow, includes a variety of functionalities making it more flexible than most comparable tool sets. We did not perform a systematic comparison between r.avaflow v4 and other simulation frameworks, but there has been a large number of requests for (i) international (and also some national) collaboration and support with r.avaflow v4; (ii) co-authorship in scientific papers using r.avaflow v4; and (iii) review of scientific papers using r.avaflow v4. Based on that, we conclude that our software has a significant impact within the landslide modelling community and beyond.

2.5. Connection to International Programs (UNESCO, UN, Future Earth, LTER, EU, etc.)

The entire project is closely aligned with the objectives of the International Geoscience and Geoparks Programme (IGGP) of UNESCO and was presented at both European and global UNESCO Global Geopark conferences. Landslides represent an important topic within the networks of UNESCO Global Geoparks, and the project has already inspired new project ideas, particularly through the cooperation of Alpine UNESCO Global Geoparks. In the context of the upcoming European programming period 2027–2034, several new project concepts and ideas are already being prepared, building on the experiences and results of this initiative.

2.6. Publications

2.6.1 Peer-Reviewed

Peer-Reviewed Publications, published or accepted

- Frankova, M., Schröcker, M., Petermann, J. S. (2024): Slightly sliding communities: How plants and insects respond to landslides. Acta ZooBot Austria 160: 219-220. https://www.zoobot.org/wp-content/uploads/2024/08/13g_Acta-160_Abstract_Frankova.pdf
- Haunsperger, V., Robl, J., Argentin, A.-L., Hergarten, S., Mergili, M., Schröder, A. (accepted): Stress redistribution following landslides: Insights from 3D stress modeling of mountain topography: Earth Surface Processes and Landforms.
- Haunsperger, V., Robl, J., Schröder, A. (2026): A finite cell method for digital elevation models and its application to geology: Finite Elements in Analysis and Design 259: 104572.
- Mergili, M., Pfeffer, H., Kellerer-Pirklbauer, A., Zangerl, C., Pudasaini, S. P. (2025): r.avaflow v4, a multi-purpose landslide simulation framework. Geoscientific Model Development 18: 9879-9896. https://doi.org/10.5194/gmd-18-9879-2025

- Osmers, A., Rademacher, A., Schröder, A. (2025): Goal-Oriented Adaptive Finite Cell Methods. Proceedings Numerical Mathematics and Advanced Applications ENUMATH 2023, Volume 2, Springer Nature Switzerland: 223–232.
- Pudasaini, S. P., Mergili, M. (2024): Mechanically controlled landslide deformation. Journal of Geophysical Research: Earth Surface 129(5): e2023JF007466. https://doi.org/10.1029/2023JF007466
- Pudasaini, S. P., Mergili, M. (2025a): A dynamic earthflow model. Engineering Geology 350: 107959. https://doi.org/10.1016/j.enggeo.2025.107959
- Pudasaini, S. P., Mergili, M. (2025b): Landslide dynamics with energy loss in internal shearing. Landslides 22: 1491-1507. https://doi.org/10.1007/s10346-024-02424-4
- Pudasaini, S. P., Mergili, M., Lin, Q., Wang, Y. (2024): Dynamic simulation of rock-avalanche fragmentation. Journal of Geophysical Research: Earth Surface 129(9): e2024JF007689. https://doi.org/10.1029/2024JF007689

Peer-reviewed publications in preparation

- Haunsperger, V., Robl, J., Schröder, A. (in prep.): A higher-order finite cell method for digital elevation models with moment fitting.
- Mergili, M., Pfeffer, H., Emmer, A., Bauer, C. (in prep.): Geosystem services and disservices – two sides of the same medal?
- Pfeffer, H., Mergili, M. (in prep.): Bridging the Gap Between Scientific Simulation and Public Imagination by Using Digital Tools for Landslide Communication.
- Pfeffer, H.; Schuller, J.; Reifberger, W.; Mergili, M. (in prep.): Landslide Lab – A 3D Application for the Interactive Exploration of Landslide Classifications.
- Pfeffer, H.; Wolfschwenger, D.; Schuller, J.; Reifberger, W., Mergili, M. (in prep.): MassMoVR – A Game Engine Framework for the Creation of Virtual Reality Experiences from Landslide Simulations.
- Robl, J., Haunsperger, V., Argentin, A.-L., Hergarten, S., Schröder, A. (in prep.): Stress State Evolution in Glacially Imprinted Landscapes.
- Schuller, J.; Mergili, M., Pfeffer, H. (in prep.): (Un)RealRocks – A Reproducible Approach to Modeling Rockfall Processes in Unreal Engine.
- Zandler H., Kellerer-Pirklbauer A., Bauer C., Kain H., Lieb G. K. (2025): Quantifizierung eines Erdstroms in Hinterwildalpen im September 2024 aufgrund eines extremen Niederschlagsereignisses. Natura Styriaca 01: 101-111. https://www.zobodat.at/pdf/NatStyriaca_01_0101-0111.pdf

Conference Contributions

- Haunsperger, V., Robl, J. C., Schröder, A., Hergarten, S. (2024): 3D modeling of topographic stress in alpine landscapes: the competition between relief formation and destruction. Proceedings Pangeo-Deuqua 2024.
- Haunsperger, V., Robl, J., Argentin, A.-L., Hergarten, S., Schröder, A. (2025): Computing the state of stress in mountain massifs undergoing topographic decay. EGU General Assembly: EGU25–1292.
- Haunsperger, V., Robl, J., Hergarten, S., Argentin, A.-L., Wilks-Stebbings, H., Schröder, A. (2026): Towards a stress-based stability criterion for rock slopes from 3D stress modeling of entire mountain massifs. EGU 2026.
- Haunsperger, V., Robl, J., Schröder, A., Hergarten, S. (2024): Three-Dimensional Stress Analysis of Mountain Ranges: A Novel Approach Using Marching Volume Polytopes Algorithm and Finite Cell Method: European Geosciences Union General Assembly 2024 (EGU24): 6250.
- Haunsperger, V., Schröder, A., Robl, J. (2026): A finite cell method for digital elevation models and its application to geology. HofEIM 2026.

- Kmetyko, S., Mergili, M. (2026): Moving Mountains: A Board Game to Communicate the Risks of Landslides in High Mountain Terrain. EGU 2026.
- Mergili, M. (2025): Simulation of alpine natural hazards in the years 2000, 2025, and 2050. AK Naturgefahren Workshop, Innsbruck.
- Mergili, M., Bauer, C., Kellerer-Pirklbauer-Eulenstein, A., Petermann, J., Pfeffer, H., Robl, J., Schröder, A. (2024): Can landslides provide geosystem services? EGU General Assembly, Vienna, Austria, 14–19 April 2024, EGU24-8075. https://doi.org/10.5194/egusphere-egu24-8075
- Mergili, M., Pfeffer, H. (2025): A comprehensive physical geography game for virtual reality. EGU25-10446. https://doi.org/10.5194/egusphere-egu25-10446
- Mergili, M., Pfeffer, H. (2025): A synthetic world for virtual field trips and serious gaming. Regional Conference on Geomorphology, Timisoara.
- Mergili, M., Pfeffer, H., Köstner, J., Gosch, L., Kellerer-Pirklbauer, A., Eulenstein, J., Gulas, O. (2023): Immersive virtual reality gaming for geoeducation: proof-of-concept for the prehistoric Wildalpen Rock Avalanche, Austria. EGU General Assembly, Vienna, Austria, 23–28 April 2023, EGU23-2743. https://doi.org/10.5194/egusphere-egu23-2743
- Mergili, M., Pfeffer, H., Pudasaini, S. P. (2024): Layered slides, slow flows, and virtual reality: recent enhancements of the r.avaflow mass flow simulation tool. 15th Congress INTERPRAEVENT, Vienna, Austria, 10-13 June 2024.
- Mergili, M., Schuller, J., Wolfschwenger, D., Pfeffer, H. (2026): Geogames and geohazards. EGU 2026.
- Pfeffer, H., Gulas, O., Mergili, M. (2025): Developing Engaging Virtual Reality Landslide Experiences for Museum Audiences: Lessons from a Case Study for the Wildalpen Landslide (Austria). Regional Conference on Geomorphology, Timisoara.
- Pfeffer, H., Mergili, M. (2023): Geomorphology is a game: Investigating the applicability of Game Engine capabilities for experiencing landslides. WLF6, Florence, Italy, 14-17 November 2023.
- Pfeffer, H., Mergili, M. (2024): Level Up Learning: A User-Friendly Game Engine Template for Virtual Reality Landslide Experiences. EGU General Assembly, Vienna, Austria, 14–19 April 2024, EGU24-1785. https://doi.org/10.5194/egusphere-egu24-1785
- Pfeffer, H., Mergili, M. (2026): Landslide Lab: A 3D Application for the Interactive Exploration of Landslide Classifications. International Conference on Geomorphology, Christchurch, New Zealand.
- Pfeffer, H., Schuller, J., Wolfschwenger, D., Mergili, M. (2026): (Un)Real Landslides: Game Engine Technologies for Process Simulation and Communication. EGU 2026.
- Robl, J., Haunsperger, V., Hergarten, S., and Schröder, A. (2026): Stress State Evolution in Glacially Imprinted Landscapes. EGU 2026.

2.6.2 Academic Theses, Other Publications, and Public Contributions

PhD Theses (in preparation)

- Haunsperger, V (in prep.): Finite Cell Methods for Efficient Simulation of Stress Distributions in Landform Evolution Modeling.
- Pfeffer, H. (in prep.): Geomorphology is a Game: Potentials of Game Engines and immersive virtual reality for transdisciplinary communication of landslide processes and hazards.

Master and Bachelor theses

- Borovcnik, A. (2024): Bergsturz Wildalpen – Geophysikalische Analyse und 3D Visualisierung der Tomalandschaft von Hopfgarten. MSc thesis, Graz University of Technology.
- Frankova, M.: (2024): Sliding Communities – Alpine Plant Communities on Landslides in Two UNESCO Global Geoparks in Austria. MSc thesis University of Salzburg, https://eplus.uni-salzburg.at/download/pdf/10568423.pdf

- Harter, K. (in prep.): Geosphere-biosphere interactions: how a landslide shapes plant communities and ecosystem functions. MSc thesis, University of Salzburg.
- Hochholdt, T. (2024): Vergleich verschiedener Fernerkundungsmethoden zur Quantifizierung mikroskaliger Karstverwitterungsformen auf Basis hochauflösender 3D-Modelle. MSc thesis, Graz University of Technology.
- Schröcker, M. (in prep.): Alpine mass movements and their impact on arthropod communities. MSc thesis, University of Salzburg.
- Schuller, J. (in prep.): Simulation von Steinschlägen mittels Unreal Engine: Ein reproduzierbarer Ansatz zur Modellierung geomorphologischer Prozesse. MSc thesis, University of Graz.
- Thiel, E. (in prep.): Effects of Toma hills on arthropod communities. BSc thesis, University of Salzburg.

Reports

- Uhlir, C. (2024a): Bericht zur Aufnahme von Massenbewegungen im UNESCO Geopark Erz der Alpen.
- Uhlir, C. (2024b): Bericht zur Aufnahme von Massenbewegungen im UNESCO Geopark Eisenwurzen.
- Uhlir, C. (2025): Vorläufiger Bericht zur Aufnahme von Massenbewegungen im
- UNESCO Geopark Karawanken.

Models and tools

- Haunsperger, V. (2026): FCM-Geomechanics. Zenodo. https://doi.org/10.5281/zenodo.20794091

2.7. Generated Data-Sets/Models/Tools

Generated Models and Tools

- **DEM-FCM Framework:** A major computational tool developed during the project is the novel Finite Cell Method for Digital Elevation Models. This higher-order numerical framework calculates three-dimensional linear elastic stress fields directly from matrix-oriented elevation grids. By utilizing a fictitious domain approach and a Marching Volume Polytopes algorithm, the tool bypasses the need for computationally expensive boundary-conforming meshes. This makes it possible to efficiently compute high-resolution 3D dead-load stresses across entire mountain massifs (Haunsperger et al., 2026).
- **Coupled Topographic Decay Model**: We developed a dynamic modelling framework that couples a probabilistic rockfall algorithm with the DEM-FCM stress computations. This tool iteratively identifies and removes unstable rock masses, recalculating the full 3D stress tensor for the modified topography at each step to simulate the redistribution of topographic stresses during the progressive decay of over-steepened alpine relief (Haunsperger et al., 2026).
- **OpenLEM Landscape Evolution Model:** The open-source landscape evolution model OpenLEM was utilized and coupled with stress calculations to simulate long-term climatic preconditioning of topography and related topographic stress changes. This tool successfully modelled the topographic and mechanical transition from fluvial to glacial topography over 100,000-year glacial cycles (Robl et al., 2026).
- **Automated Morphometry Toolbox:** An automated analytical framework, built in MATLAB using TopoToolbox, rapidly extracts and quantifies landscape metrics (e.g., geophysical relief, channel steepness, and river profiles) across large catchments in the Austrian UGGPs, successfully bridging the gap between geometric landscape analysis and stress modelling.
- **r.avaflow v4:** A multi-purpose, GIS-based Open-Source simulation framework for flow- and slide-type landslide processes and related cascading effects, from extremely rapid to extremely slow. r.avaflow v4 builds on previous versions of r.avaflow and includes interfaces with the 3D animation software Blender and the game development software Unreal Engine. It is described in detail in

Mergili et al. (2025). The codes as well as a web-based user interface with integrated manual, along with some tutorial videos, are available at https:/www.avaflow.org.

Generated Data-Sets

- **Hochkönig Massif Decay Dataset (UGGP Ore of the Alps):** The project generated a comprehensive synthetic dataset simulating the progressive decay of the Hochkönig Massif. This dataset includes a sequential series of modified digital elevation models representing topographic unloading, alongside their corresponding 3D stress tensors. It encompasses approximately 470,000 simulated rockfall events accumulating roughly 1.8 km^3 of eroded volume, providing a unique dataset for studying lateral stress redistribution and cascading instabilities (Haunsperger et al., 2026).
- **Paraglacial Stress Evolution Datasets:** We produced high-resolution datasets computing the spatial and temporal evolution of topographic stresses during the transition from fluvially conditioned to glacially over-steepened topography, quantifying the shear stress peaks associated with glacial debuttressing (Robl et al., 2026).
- **3D Stress-Based Stability Maps:** Using a newly formulated minimum cohesion metric based on the Mohr-Coulomb criterion, we started generating spatially explicit stability maps for the investigated Austrian UNESCO Global Geoparks. These datasets quantify the critical rock-mass cohesion required to resist localized 3D topographic shear stresses at any given point in the landscape and in depth of the investigated mountain massifs (Haunsperger et al., 2026).

2.8. Limitations and Uncertainties

Methodological Limitations

The DEM-FCM framework isolates topographic controls by assuming a homogeneous, linear-elastic rock mass, which simplifies natural lithological variations and structural discontinuities (Haunsperger et al., 2026). Combined with the probabilistic rockfall model, the numerical framework evaluates instantaneous elastic responses to unloading under static conditions, neglecting tectonics stresses, transient dynamic processes like sliding momentum, fluid pressure fluctuations, or progressive rock-mass fatigue (Haunsperger et al., in revision). Additionally, the probabilistic rockfall model estimates detachment volumes based entirely on geometry, disregarding the runout and deposition of unconsolidated debris (Haunsperger et al., in revision).

Uncertainties in Data

Geomorphometric analyses are highly sensitive to Digital Elevation Model (DEM) resolution. Coarse grids act as low-pass filters that smooth rugged terrain. This smoothing complicates both the accurate extraction of low-order channel networks and the representation of small-scale local relief, while also affecting stress computations. To mitigate these limitations, we employed LiDAR data with a 10 m grid spacing.

Transferability of Results

Despite these limitations, the developed methods are highly transferable. The DEM-FCM bypasses boundary-conforming meshes, allowing 3D stress modelling to be directly applied to virtually any rugged mountain topography globally (Haunsperger et al., 2026). Additionally, automated geomorphometric frameworks for extracting relief and channel matrix remain statistically robust at grid sizes up to 30 meters where larger landforms and in turn landslides are of interest. This proves that the techniques to assess topographic transience and stability are not restricted to regions where high-resolution LiDAR DEMs are available. They can be successfully transferred to remote mountain ranges worldwide using widely available, coarser digital elevation models such as SRTM1 or TanDEM-X.

3. Transdisciplinary Process Reflection and Social Impact

3.1. Concept and Goals of Initial Co-Design

The project idea was co-developed by the Steirische Eisenwurzen UGGp, seeking scientific partners for enhancing its science-to-public dialogue and transdisciplinary engagement, and the University of Graz, who was developing landslide visualization approaches targeting science communication. Out of the initial discussions, the idea emerged of a more comprehensive initiative involving all three Austrian UGGps, using landslides in combination with state-of-the-art digital methods to draw public interest to earth surface processes and to increase awareness of the related chances and risks. The initial idea had a strong focus on the installation of VR experiences in the visitor centres and museums of the UGGps, but was quickly extended with additional aspects such as the role of landslides for biodiversity, karst processes, and landscape evolution.

3.2. Ongoing Integration and/or Capacity Building

UNESCO Global Geoparks (UGGps) are unique areas of international geological significance where landscape features and cultural heritage are closely interconnected, influencing one another and forming a unity appreciated by visitors from all over the world. Their main goals are to strengthen the resilience of unique cultural landscapes in the Alps by fostering dialogue with the local population and promoting sustainable tourism.

The project represents a successful co-creation process between science and practice. UGGP Steirische Eisenwurzen acted as a central bridging institution linking research and regional implementation. Scientific findings (geomorphologic and ecological field investigations as well as computer simulations of mountain systems and landslide processes) were translated into physical exhibition elements, digital VR applications, and educational narratives. Regional partners contributed with local knowledge, infrastructure, and outreach channels.

Based on the experiences made up to now, we are confident that, due to the MOVEMONT project, awareness of scientific topics in the field of sustainable tourism development has increased and will further increase within the three Austrian UGGps. New tools were developed to explain complex scientific content in an attractive and accessible way, while also strengthening the integration of science into tourism activities.

One of the core actions within the MOVEMONT project was the enrichment of the visitor centres of the UGGPs with new and innovative knowledge, methods, and technologies generated and developed during the project. Simulations of landscape decay and 3D stress distributions were optimized and visualised as movies and interactive browser-based applications (i.e., Kitware Glance) in all three UGGps. These visualisations successfully support environmental education and raise public awareness about alpine natural hazards. Further, the presentation of the prehistoric Wildalpen rock avalanche in the Water Museum Wildalpen was mentioned in the proposal as a pilot action and is considered a flagship among various other exhibition elements in all three UGGPs. The following exhibitions were implemented in the visitor centres and museums, as **science-to-public communication actions**:

- **Steirische Eisenwurzen UGGp**: the special exhibition “Wild Alps – Portrait of a Natural Force”, opened on 8 May 2025 at the Museum HochQuellenWasser in Wildalpen. The exhibition communicates scientific findings on large landslides to a broad public audience, focusing on the large prehistoric Wildalpen rock avalanche. The centrepiece of the exhibition is a VR station where visitors (one at a time) can experience the rock avalanche, whereas other visitors can watch on a big screen. The remaining part of the exhibition is built around the VR experience, providing various pieces of information on different aspects of the rock avalanche, ranging from biodiversity aspects to karst processes. For example, the results from the ecological analyses as well as a number of specimens (insects) from our field collections were prepared and used for the exhibition in

Wildalpen. The information provided largely translates the scientific knowledge generated withing the MOVEMONT project to information targeting a broader audience.

- **Erz der Alpen UGGp**: Nine A1-sized posters were printed for the Geopark centre and museums in German and English and are available online. Videos depicting the topography, geological map, and glaciation of the UGGp are available in the visitor centre in Bischofshofen, the Knappenheim Mühlbach, Museum Hüttau and in the Seelackenmuseum in St. Veit.
- **Karawanken-Karavanke UGGp**: The outcomes of WP2 and WP3 were used to develop a public-friendly educational tool explaining landslides. In cooperation with the scientific partners, especially KFUG and PLUS, the possibilities for landslide simulations based on the outcomes of WP3 were prepared and discussed. The Karawanken-Karavanke UGGp focused on the development and implementation of VR–based simulations that could be used in the info/visitor centres and interpretation points throughout the Geopark area. The core result was the finalized simulation of the complex Topitza landslide integrated into the Geopark presentation using VR at the main visitor centre of the Geopark, the Geo.Dom on Petzen Mountain. To make the topic of landslides more attractive and accessible, it was integrated into the overall Geopark presentation through VR experiences. The main innovation was the integration of scientifically based landslide simulations into the Geopark's tourism offers, thereby increasing awareness of landslides among a broader target audience. The project was implemented in close collaboration with the UGGp Steirische Eisenwurzen, regional stakeholders, and specialized project partners. The central innovation, i.e., the chance to experience a rock avalanche in an immersive way, significantly enhances science communication by translating complex geomorphological processes into accessible, experiential learning formats. Apart from the VR experience, the exhibition addresses some further key research topics:

    - Geology: Exceptional landslide processes
    - Biology: Ecological impacts of landslides on flora and fauna
    - Geomorphology (Karst systems)

    The exhibition further acts as a bridge to the regional water exhibition, highlighting the interconnectedness of geological hazards, hydrology, and landscape development. Furthermore, the installations along the long-distance hiking route "Seven Elements Trail" (siebenelemente-derweg.at), where geological processes are communicated within a broader landscape interpretation framework, contributes to regional tourism and education.

Transdisciplinary knowledge integration action was implemented through a Citizen Science programme piloted during the final stage of the MOVEMONT project: *Fenster in der Landschaft* ("Windows into the Landscape") (**Figure 9**). Wooden frames, serving as fixed viewpoints, were installed at selected locations within the Steirische Eisenwurzen UGGp. Visitors take standardized photographs through the frames and upload to a central database for long-term monitoring. Monitoring Sites: river landscape Salza, River landscape Enns, montane forest ecosystem, and rock avalanche site Wildalpen. The expected impact consists in long-term monitoring of landscape and environmental change, promotion of participatory environmental observation (Citizen Science), increased public awareness of climate and geomorphological processes, and strengthening geoparks as education and sustainable tourism hubs.

The project was further based on strong involvement of stakeholders within both the project partnership and the UGGPs. New collaborations emerged and several cross-border initiatives were established within the Karawanken-Karavanke UGGp. The understanding of landslide impacts and the monitoring of active landslides were further developed, and the implementation of related monitoring activities has already begun.

3.3. Outreach/Social and/or Policy Impact

Based on the experiences made, we are confident that awareness of landslides and interest in understanding their causes and impacts have increased significantly as a result of the MOVEMONT project. The project also enabled the involvement of a wide range of stakeholders and contributed to the development of new activities related to landslide research, monitoring, and public education.



Figure 9: The three “Windows into the Landscape” installed in the Steirische Eisenwurzen UGGp. Photos: Oliver Gulas

A key event of the project was the opening ceremony of the special exhibition “Wild Alps – Portrait of a Natural Force” on 8 May 2025 at the Museum HochQuellenWasser in Wildalpen With approximately 75 attendees, including representatives from municipalities, Wiener Wasser (City of Vienna), and national scientific institutions, this event demonstrated strong stakeholder engagement and public interest. Keynote talks were given by both PIs of the MOVEMONT project.

Within the course of the project, several more talks have been given by project members in front of different audiences. Another oral presentation was given by Andreas Kellerer-Pirklbauer on 18 July 2023 during the UNESCO Geopark evaluation procedure (evaluators: Jutta Weber (Germany) and Jack Matthews (GB) with the title “Research in the Styrian Eisenwurzen UNESCO Global Geopark (Austria) by the University of Graz: recent and ongoing activities”. A further talk was presented by the same person for the public focusing on alpine hazards and the Wildalpen landslide entitled *Projekt "Bergsturz Wildalpen" und Naturgefahren im alpinen Raum*. The University of Graz carried out one university course for master students in the Hopfgarten Basin where various aspects on Toma hills were studied.

We now summarize the activities within the international and regional geopark networks, public events, outreach activities for schools, and science-to-public presentations.

Dissemination in the international and regional geopark community

The project achieved strong visibility through international and regional geopark networks:

- Presentation at the Global Geoparks Conference (Morocco, 2023)
- Contribution during the UNESCO Global Geopark revalidation mission in Styrian Eisenwurzen (2023)
- Presentation at the European Geoparks Conference (Iceland, 2024)
- Presentation performed at the Global Geoparks Conference (Chile, 2025)
- Contribution to the publication Digital GeoHazards Book on Global Geoparks Network level
- Annual contributions to the regional nature park magazine (distribution: approx. 1,500 households)
- Continuous social media communication
- Public lectures and guided interpretation formats (Organization of a public stakeholder event in Wildalpen (2023)

Public events (general target audience)

- Gulas, O., Mergili, M., Robl, J., Pfeffer, H., Kellerer-Pirklbauer, A., Bauer, C., Zandler, H., Weissinger, A. (2025): Eröffnung der Sonderausstellung Wilde Alpen – Portrait einer Naturgewalt" im Museum HochQuellenWasser Wildalpen. Museumsverein - Museum HochQuellenWasser Wildalpen. 08.05.2025.
- Kmetyko, S., Gössler, K., Mergili, M. (2024): Präsentation der Virtual Reality bei der Langen Nacht der Museen. Universitätsbibliothek Uni Graz. 05.10.2024.
- Mergili, M., Pfeffer, H., Breitler, J., Kmetyko, S. (2025): biblioNight. Universitätsbibliothek Uni Graz. 14.05.2025.
- Mergili, M., Gössler K., Breitler, J., Schuller, J., Pfeffer, H. (2025): Lange Nacht der Museen. Universitätsbibliothek Uni Graz. 04.10.2025.
- Mergili, M., Herler, D., Jacobsohn, F. J., Pfeffer, H. (2023): Vorstellung des Digitalen Globus und der Virtual Reality bei der BiblioNight 2023. Universitätsbibliothek Uni Graz. 13.06.2023.
- Mergili, M., Kmetyko, S., Jacobsohn, F. J. (2023): Vorstellung des Digitalen Globus und der Virtual Reality bei der Langen Nacht der Museen 2023. ORF, Universitätsbibliothek Uni Graz. 07.10.2023.
- Pfeffer, H., Kmetyko, S., Breitler, J., Mergili, M. (2025): Unsere Berge bewegen sich und du bist mittendrin. Lange Nacht der Forschung 2024. Universitätsbibliothek Uni Graz. 24.05.2024.
- Schröcker, M. (2026): Was passiert heute in Extremlebensräumen der Alpen? Wenn der Hang ins Rutschen kommt. Lange Nacht der Forschung. Salzburg. 24.04.2026.

Public events (target audience: school children and high school students)

- Pfeffer, H., Mergili, M. (2024): Unsere Berge bewegen sich – und du bist mittendrin! Virtual reality gaming in der Geographie, Vorführung beim Tag der Offenen Tür der Universität Graz. 04.04.2024.
- Robl, J. (2026): Bewegte Alpen: Zwischen Gletschereis und Katastrophenschutz, Vortrag beim Tag der offenen Tür der Universität Salzburg.
- Schröcker, M. (2024–2025): Moving Mountains - Gebirge im Wandel und deren Auswirkung auf Biodiversität. Schnuppertage am Fachbereich Umwelt & Biodiversität der Universität Salzburg, 04.11. and 09.12. 2024, 08.01.2026.
- Schröcker, M., Götz, A. (2023): Moving Mountain: Wie verändert das Klima das Gebirge? Schüler Uni. Salzburg. 22.11.2023.

Outreach activities for schools

- Breitler, J., Jacobsohn, F. J., Kmetyko, S., Mergili, M. (2023): Vorstellung des Digitalen Globus und der Virtual Reality beim GIS-Tag 2023. Institut für Geographie und Raumforschung der Universität Graz / Umweltbildungszentrum Steiermark. 15.11.2023.
- Doric, A., Mergili, M. (2025): geo.gespottet. Dein Geographie-Tag am Campus. Universität Graz. 05.02.2025.
- Gössler, K., Breitler, J., Seyerlehner, S., Reisinger, V., Mergili, M. (2024): VR-Brille – Unsere Berge bewegen sich und du bist mittendrin. Präsentation beim GIS-Tag. Institut für Geographie und Raumforschung der Universität Graz / Umweltbildungszentrum Steiermark. 20.11.2024.
- Jacobsohn, F., Pfeffer, H., Mergili, M. (2023): Geographie für Schüler*innen – Vorführung von Virtual Reality und Digitalem Globus. Universität Graz. 01.12.2023.
- Kmetyko, S., Jacobsohn, F. J., Mergili, M. (2023): Geographie für Schüler*innen – Vorführung von Virtual Reality und Digitalem Globus. Universität Graz. 15.12.2023.
- Mergili, M., Doric, A., Kmetyko, S., Pfeffer, H. (2025): Besuch der Volksschule Vasoldsberg am Institut für Geographie und Raumforschung der Uni Graz. 10.03.2025.

- Mergili, M., Kmetyko, S., Pfeffer, H., Breitler, J., Gössler, K., Doric, A. (2025): Besuche des Gymnasiums Petersgasse am Institut für Geographie und Raumforschung der Uni Graz. 06.03.2025–14.03.2025.
- Pfeffer, H., Herler, D., Mergili, M. (2023): Interaktives Bergsturzerlebnis - Präsentation eines Virtual Reality Erlebnisses des Wildalpen Bergsturzes im Rahmen einer Schulexkursion. Museum HochQuellenWasser, Wildalpen. 03.05.2023.
- Pfeffer, H., Mergili, M. (2023): Geographie für Schüler*innen – Vorführung von Virtual Reality und Digitalem Globus. Universität Graz. 24.11.2023.

Science-to-public presentations

- Kellerer-Pirklbauer-Eulenstein, A., Mergili, M., Pfeffer, H., Köstner, J., Gosch, L., Eulenstein, J., Bauer, C., Gulas, O. (2023): Das Projekt „Bergsturz Wildalpen“ und Naturgefahren im alpinen Raum. Wildalpen. 20.09.2023.
- Kellerer-Pirklbauer-Eulenstein, A.;,Mergili, M., Pfeffer, H., Köstner, J., Gosch, L., Eulenstein, J., Bauer, C., Gulas, O. (2023): Research in the Styrian Eisenwurzen UNESCO Global Geopark (Austria) by the University of Graz: Recent and ongoing activities. Wildalpen. 18.07.2023.
- Mergili, M. (2024): Gebirge in Bewegung: Gefahrenprozesse erkennen, verstehen und kommunizieren. IGG Vortrag, Innsbruck. 04.06.2024.
- Mergili, M. (2024): Geosystemdienstleistungen versus Geogefahren: Geomorphologie geht uns alle an! ÖGG Vortrag, Wien. 10.06.2024.
- Mergili, M. (2025). Unsere Berge bewegen sich. Und du bist mittendrin! Vortrag im Rahmen der Ausstellungseröffnung „Wilde Alpen – Portrait einer Naturgewalt“. Wildalpen. 08.05.2025.
- Mergili, M. (2025): Turning the view: Landslides as geosystem services. Online presentation for the British Geomorphological Society. 03.12.2025.
- Robl, J. (2024): Klima im Wandel: Globale Zusammenhänge - lokale Auswirkungen. Vortrag beim Rotary Club Bischofshofen.
- Robl, J. (2024): Von einer Schwemmebene zum alpinen Siedlungsraum – Wie Klima und Tektonik die Landschaft formen. Vortrag bei den Geotagen Bischofshofen.
- Robl, J. (2025): Kalkalpen unter Spannung: Aufstieg und Zerfall eines Gebirges. Vortrag im Rahmen der Ausstellungseröffnung „Wilde Alpen – Portrait einer Naturgewalt“. Wildalpen. 08.05.2025.
- Robl, J. (2025): Klima im Wandel, Vortrag und Diskussion am Gymnasium St. Rupert, Bischofshofen.
- Robl, J. (2025): Lebensraum Alpen – Aufstieg und Zerfall eines Gebirges. Vortrag bei der Naturschutz Akademie Steiermark.
- Schröcker, M., Frankova, M., Petermann, J. (2023): Slightly sliding communities: how plants and insects respond to landslides. Tage der Biodiversität. Wien. 8 11.–10.11.2023.

3.4. Challenges, Lessons Learned and Reflection

One of the main challenges emerging during the project were different approaches among the three UGGPs how to reach the project goals. Whilst the Steirische Eisenwurzen UGGP and the Karawanken-Karavanke UGGP preferred to implement virtual reality experiences in their visitor centres and museums, the Erz der Alpen UGGP preferred more traditional means of science communication and transdisciplinary knowledge integration, such as posters or guided tours within the UGGP. This, however, was seen as a chance rather than a problem, since it ensured a higher diversity of approaches, varying among the individual UGGPs. At the end, each UGGP has enhanced its transdisciplinary efforts, based on the knowledge generation withing the project, and serving as anchor points for future initiatives. Time since implementation is too short to provide a tangible assessment of the outcome of the initiatives.

Unexpected findings revealed that VR glasses were already being used in many different information centres throughout the Geopark, as well as in several elementary and middle schools within the region. Based on these experiences, the idea emerged to further develop the simulations for use with outdoor

virtual reality glasses. This could represent the next step in making landslide education and explanations even more engaging, attractive and accessible to visitors.

3.5. Continuation and Long-Term Impact

All science-to-public communication and transdisciplinary knowledge integration actions taken within the MOVEMONT project were implemented in view of their long-term impacts (Section 3.2). The exhibitions established at the Museum HochQuellenWasser in Wildalpen and the visitor centres of the Erz der Alpen UGGp and the Karawanken-Karavanke UGGp, ranking among the main outcomes of the project, are foreseen as mid-to-long-term installations, outlasting the project durations by several years and, in the ideal case, decades.

This section focuses on follow-up initiatives that have emerged out of the project. First to mention, a major follow-up initiative will be the extension of the *Fenster in der Landschaft* initiative, which should be installed also in the other Austrian UGGPs.

Uni Graz and Uni Salzburg have established programmes to be used during Science-to-Public events such as *Lange Nacht der Forschung*, *Lange Nacht der Museen*, or *KinderUni*, which will be used also in the future to generate interest and enthusiasm for earth surface processes.

The development of info boards for the most important landslides in the Karawanken Geopark are the subject of planned funding through a LEADER project. These boards are based on full-scale mapping of landslides in the Karawanken Geopark over two years by Christian Uhlir. This project addresses the fact that current printed and digital geological maps are largely inadequate or erroneous. Funding is planned through ongoing and submitted EU projects.

Furthermore, an ongoing development process and joint initiative addresses the challenges caused by landslides in the Alps was initiated within the European Geopark Network. (long-term impacts, continuation strategies, institutional embedding, follow-up funding.)

In addition, new projects have already emerged out of the MOVEMONT project, such as the INTERREG SI–AT project KaraMon, within which the monitoring of landslides will be further implemented and expanded and INTERREG Alpine Space project which focuses on enhancing the resilience of alpine headwaters, groundwaters and other water resources against climate change. Climate change increases the risk of compound disasters in the Alps, including also landslides. Understanding how hydrological changes impact slope stability is crucial for long-term climate risk management in mountain communities.

The development of the VR gaming experiences for the exhibitions served as a boost for further, ongoing gamification initiatives in regard to landslide processes which were not initially foreseen, aiming to (i) advance the interfaces between conventional GIS techniques and technologies used by the video game industry and (ii) enhancing capabilities to enhance the understanding of earth surface processes in general and landslides in particular among a broader public. Such initiatives are mainly pursued at Uni Graz and include:

- **MassMoVR**: a template for Unreal Engine (a game development software) to generate landslide experiences more easily (target group: university teachers)
- **LandslideLab**: realistic visualization of the most important types of landslides, with Unreal Engine and the visualization software Houdini (target group: students)
- **(Un)RealRocks**: creating an operational rock fall model directly in Unreal Engine, building on the physics used directly in this software (target group: scientists and risk management professionals)
- **GeoGame**: a comprehensive physical geography video game, based on a synthetic virtual world (target group: students and broader public)

- **A landslide board game**, named “Moving Mountains”, is being developed, with the aim to convey a better understanding of relations and trade-offs between the use of resources and landslide hazards and risks in certain geographic settings.

Building on the general findings for the Austrian UGGps, our international project partner, Université de Clermont-Auvergne, was piloting a study on the global role of landslides in the context of geoheritage and geotourism. A review and systematization of scientific information related to landslides around the world and their value as geoheritage elements was carried out. The work included the analysis of concepts associated with geodiversity, geoheritage, and the main types and mechanisms of landslides in different geological settings. In addition, a conceptual framework for the identification and assessment of landslide-related geosites was developed, considering scientific, educational, landscape, and social criteria. Factors such as representativeness, uniqueness, magnitude, historical significance, educational value, state of conservation, and hazard potential were evaluated. To make a foundation for this, a database of representative landslide case studies from around the world was compiled, including information on their location, typology, origin, and scientific relevance. The results provide a foundation for future applications in research, geoeducation, geotourism, geoconservation, and geological risk management. This study provides a valuable inventory for the recognition of globally significant landslides for inscription on Global Geoheritage lists, such as the IUGS Global Geological Sites, IUCN Key Geoheritage Areas, and UNESCO designations. The result will be submitted as a paper to the journal Episodes.