LaRiMiT: A knowledge-based landslide risk mitigation portal

User's Guide

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EXECUTIVE SUMMARY

The mitigation of landslide risk to human-valued physical and non-physical assets is a fundamental component in the disaster risk management cycle. The reduction of risk can be pursued through the selection, planning and implementation of suitable mitigation measures and/or actions. The selection of the most appropriate mitigation measures is a complex process which depends on both the characteristics of the expected landslide event and the potential impacts on the physical, economic, environmental, cultural and societal human-valued assets. Each risk mitigation effort is thus markedly case- and site-specific.

The web-based portal LaRiMiT (**La**ndslide **Ri**sk **Mi**tigation **T**oolbox) aims at reducing the risks associated with +climate changes and enhanced precipitation and flood water exposure within the built environment.

LaRiMiT implements an analytic hierarchy process (AHP) to select the most appropriate landslide risk mitigation measures based on user inputs and expert rating of a set of candidate mitigation measures.

User inputs include case-specific information regarding the type of movement and relevant physical conditions at the site, the user's quantitative rating of the relevance of the technical, economic and environmental suitability of the mitigation measures as well as the relevance of the rapidity of implementation in situations of urgency.

Expert inputs to LaRiMiT underlie the expertise on the different mitigation measures provided by the toolbox, regarding both the physical interactions between landslides and mitigation measures and other factors related to the required time for implementation as well as economic and environmental impact of the measures.

LaRiMiT provides quantitative ranked lists of mitigation measures for given in situ conditions. The user can influence the ranking by setting priorities on the relative importance of the effectivity of the mitigation measure, its environmental impact(s), the time required for implementation and the costs.

1 Introduction

Risk mitigation is a fundamental step in the disaster management cycle. Risk mitigation provides the transition between a post-event reconstruction phase and the building of adequate capacity in view of possible future hazardous events (Fig. 1). A quantitative approach to risk mitigation entails an assessment of the estimated risk through for example, the comparison of the estimated risk with acceptable and/or tolerable risk. Risk (*R*) is often estimated with the following risk model:

$$R = H \cdot C = H \cdot V \cdot E \quad (1)$$

where *H*= is the hazard, or the likelihood of occurrence of a damaging event over a period of time; and *C* is the consequence. The magnitude of the consequences are a function of the vulnerability V, or the expected degree of damage and loss for one or several vulnerable assets under the hazardous event, and the exposure *E*, which parameterizes the quantity, value or degree of presence of the same vulnerable assets in the same period of time in a given reference area. The consequence describes the expected impact of the hazardous event, given that the event occurs.

In practice, risk mitigation entails the identification and implementation of suitable risk mitigation measures, actions and/or policies to reduce risk to acceptable/tolerable levels. In a best-practice perspective, the suitability criterion is thus related to the potential reduction of the hazard or reduction of the consequence(s) or both, and includes an assessment of attributes such as technical effectivity and suitability, functional pertinence, reliability of design and technology, feasibility and manageability, time required for implementation, affordability, and compatibility with environmental and sustainability-related goals at the site of interest.

1.1 Historical background

In the EC FP7 landslide risk project SafeLand (www. safeland.no), a work package on risk management included an activity identifying cost-effective structural and non-structural landslide risk mitigation options. The activity also included development of an innovative web-based "toolbox" of technically appropriate risk prevention and mitigation measures, based on technology, experience and expert judgment in Europe and abroad. The toolbox's aim documented structural and non-structural, including risk-transfer, measures applicable to all countries in Europe. The SafeLand toolbox included technical specifications or policy prescriptions (how to), and documented, with hindsight, the experience and effectiveness of the approach (do's and don'ts), and estimated costs, benefits, hazards and vulnerability associated with each measure, including uncertainties. At the end of the SafeLand project in 2012, the toolbox was operative, but not sufficiently validated, nor sufficiently user-friendly.

1.2 The Klima 2050 project

Klima 2050 is a Centre for Research-based Innovation (CRI) funded by the Research Council of Norway (RCN) and public and private partners from the building and construction and infrastructure sectors. The project aimed at reducing the societal risks associated with climate change and enhanced precipitation and flood water exposure within the built environment. Producing innovative measures for prevention of water-triggered landslides is one of the activities in the centre. The Norwegian Geotechnical Institute, as coordinator of the SafeLand project and responsible for the SafeLand toolbox, as well as responsible for the Klima 2050 landslide work package, developed further the mitigation toolbox in 2015 by implementing new web-based software, validating the methodology and extending the capability of the software. In 2019 an extensive

Figure 1. The disaster management cycle

2 Purposes of LaRiMiT

LaRiMiT is a knowledge-based landslide risk mitigation web portal. The purpose of LaRiMiT is to provide an expert-assisted tool for the case- and site-specific ranking and best-practice selection of landslide risk mitigation measures. LaRiMiT aims to become a reference knowledge-based hub on landslide risk mitigation through the future inclusion of a Wiki, links to cutting-edge research and regulations, a repository of technical tools, a catalogue of best-practice case studies, etc.

3 Technological and programming aspects

To achieve its purposes and wide diffusion worldwide, LaRiMiT is designed as a web-based application. The risk mitigation algorithm is based on the Analytic Hierarchy Process (AHP) using the Python-based Django web framework. Such choice entails the following benefits:

- Ease of remote access by the experts' panel and users
- Accessibility through mobile devices
- No software installation required
- Online availability of the most recent version
- Possibility for users to improve their knowledge of candidate mitigation measures through hyperlinks to technical information, case studies

4 Database of mitigation measures

The mitigation measures are divided into two main groups: <u>reduction of landslide hazards</u> (active measures), and <u>reduction of landslide consequences</u> (passive measures (Table 1). The 80 mitigation measures are arranged into 11 categories, describing the reduction of predisposing factors or the improvement of physical processes. Table 2 lists all the mitigation measures included int the 11 different categories.

Table 1. Categories of landslide risk mitigation measures in LaRiMiT database

Risk = Hazard x Consequences
Risk = Hazard x Vulnerability x Elements at risk

Measures reducing the Hazard (preventing triggering of the landslide)		Measures reducing the Consequences (limiting the runout)	
1	NBS for erosion control – living approach		
2	NBS for erosion control – living/not living approach		
3	Modifying slope geometry or mass distribution	9	Deviating the path of landslides
4	Modifying surface water regime – drainage	10	Dissipating the energy of landslides
5	Modifying groundwater regime – deep drainage	11	Arresting and containing landslides
6	Modifying mechanical charact. of the unstable mass		
7	Transfer of loads to more competent strata		
8	Retaining structures to improve the slope stability		

The mitigation measures listed in Table 2, classify the measures into "grey" (i.e., traditional engineering measures), "green" (i.e., Nature-Based Solutions), and "hybrid" (i.e., a combination of grey and green solutions), following the recent innovations in LaRiMiT by Capobianco et al., (2022).

The database of mitigation measures with a technical explanation of the measures can be accessed from the top menu on the LaRiMiT homepage. For each measure, the user can find:

- Description of the measure, including advantages and disadvantages
- Design methods

- Expert ratings
- References in the literature
- Links to best-practice information

New mitigation measures will be included in the database as part of future developments of LaRiMiT.

Table 2. LaRiMiT database of landslide risk mitigation measures (Capobianco et al,. 2022)

Measure	No.	Category	ID	Mitigation Measure	Type
Reduction of landslide hazard	1	NBS for erosion control; living approach	1.1	Hydroseeding	NBS
			1.2	Turfing	NBS
			1.3	Tree bushes direct/pit planting	NBS
			1.4	Live/inert fascines and straw wattles	NBS
			1.5	Brush mattresses	NBS
			1.6	Brush layering	NBS
			1.7	Live stakes (live poles)	NBS
			1.8	Live smiles	NBS
	2	NBS for erosion control, living/not living approach	2.1	Geotextiles (Rolled Erosion Control Products)	NBS
			2.2	Drainage Blankets	NBS
			2.3	Beach replenishment/nourishment	NBS
			2.4	Rip-rap	NBS
			2.5	Rock dentition	Gray
	3	Modifying slope geometry or mass distribution	3.1	Removal of unstable soil/rock mass	Gray
			3.2	Removal of loose/unstable blocks/boulders	Gray
			3.3	Removal of material from driving area	Gray
			3.4	Substitution of material with lightweight fill	Gray
			3.5	Material addition to maintain (increase) stability	Gray
			3.6	Terracing (NBS)	NBS
	4	Modifying surface water regime, drainage	4.1	Surface drainage works (ditches, channels, pipes)	Gray
			4.2	Local regrading to facilitate run-off	Gray
			4.3	Sealing tension cracks	Gray
			4.4	Impermeabilization (geomembranes, facing)	Gray
			4.5	Vegetation -hydrological effects	NBS
			4.6	Hydraulic control work (channel lining /checkdams)	Gray
			4.7	Diversion channels	Gray
	5	Modifying groundwater, deep drainage	5.1	Shallow trenches filled with free-draining material	Gray
			5.2	Deep trenches filled with free-draining material	Gray
			5.3	Sub-horizontal drains (conventional drilling)	Gray
			5.4	Sub-horizontal drains (directional drilling)	Gray
			5.5	Wells*	Gray
			5.6	Vertical small dia (<800 mm) wells – Siphoning	Gray
	6	Modifying mechanical characteristics of the unstable mass	6.1	Vegetation - mechanical effects	NBS
			6.2	Substitution	Gray
			6.3	Compaction from surface	Gray
			6.4	Deep compaction	Gray
			6.5	Mechanical deep mixing with lime and/or cement	Gray
			6.6	Low pressure grouting with cements/chemical s	Gray
			6.7	Jet grouting	Gray

Measure	No.	Category	ID	Mitigation Measure	Type
			6.8	Modification of groundwater chemistry (lime piles)	Gray
	7	Transfer of loads to more competent strata	7.1	Counterfort drains (intersecting trench drains)	Gray
			7.2	Piles	Gray
			7.3	Barrettes (diaphragm walls)	Gray
			7.4	Caissons - mechanical effects	Gray
			7.5	Soil nailing	Gray
			7.6	Dowels and harnessing	Gray
			7.7	Rock bolting	Gray
			7.8	Strand anchors	Gray
			7.9	Soil nail and root technology – SNART	Hybrid
	8	Retaining structures to improve the slope stability	8.1	Reinforced soil structure	Gray
			8.2	Gabion walls	Gray
			8.3	Crib walls	Gray
			8.4	Drystack masonry walls	Gray
			8.5	Mass concrete or masonry walls	Gray
			8.6	Reinforced concrete stem walls	Gray
			8.7	Vegetated gabions	Hybrid
			8.8	Live crib walls	NBS
			8.9	Vegetated slope gratings	Hybrid
Reduction of landslide conse-quences	9	Deviating the path of landslides	9.1	Deflection structures (berms)	Gray
			9.2	Rock sheds	Gray
			9.3	Channelization structures (lateral walls)	Gray
	10	Dissipating the energy of landslides	10.1	Debris racks	Gray
			10.2	Baffles (Impediments)	Gray
			10.3	Check dams	Gray
			10.4	Attenuator system	Gray
			10.5	Afforestation	NBS
			10.6	Live gully breaks	NBS
	11	Arresting/ containing landslides	11.1	Rigid barriers	Gray
			11.2	Flexible barriers	Gray
			11.3	Ditch and embankment	Gray
			11.4	Debris retention basin	Gray

5 Specification of movements and materials involved in landslide

5.1 Slope movements

The LaRiMiT toolbox addresses the following types of movement, using the classification of slope movements by Varnes (1978) in the red rectangle in Figure 2: Fall, Topple, Slide, Spread and Flow.

5.2 Type of materials

The materials considered are classified according to the guidelines proposed by Hungr et al. (2013) and shown in Table 3.

5.3 Depth of movement

The depth of movement is to be specified by the user according to Table 4.

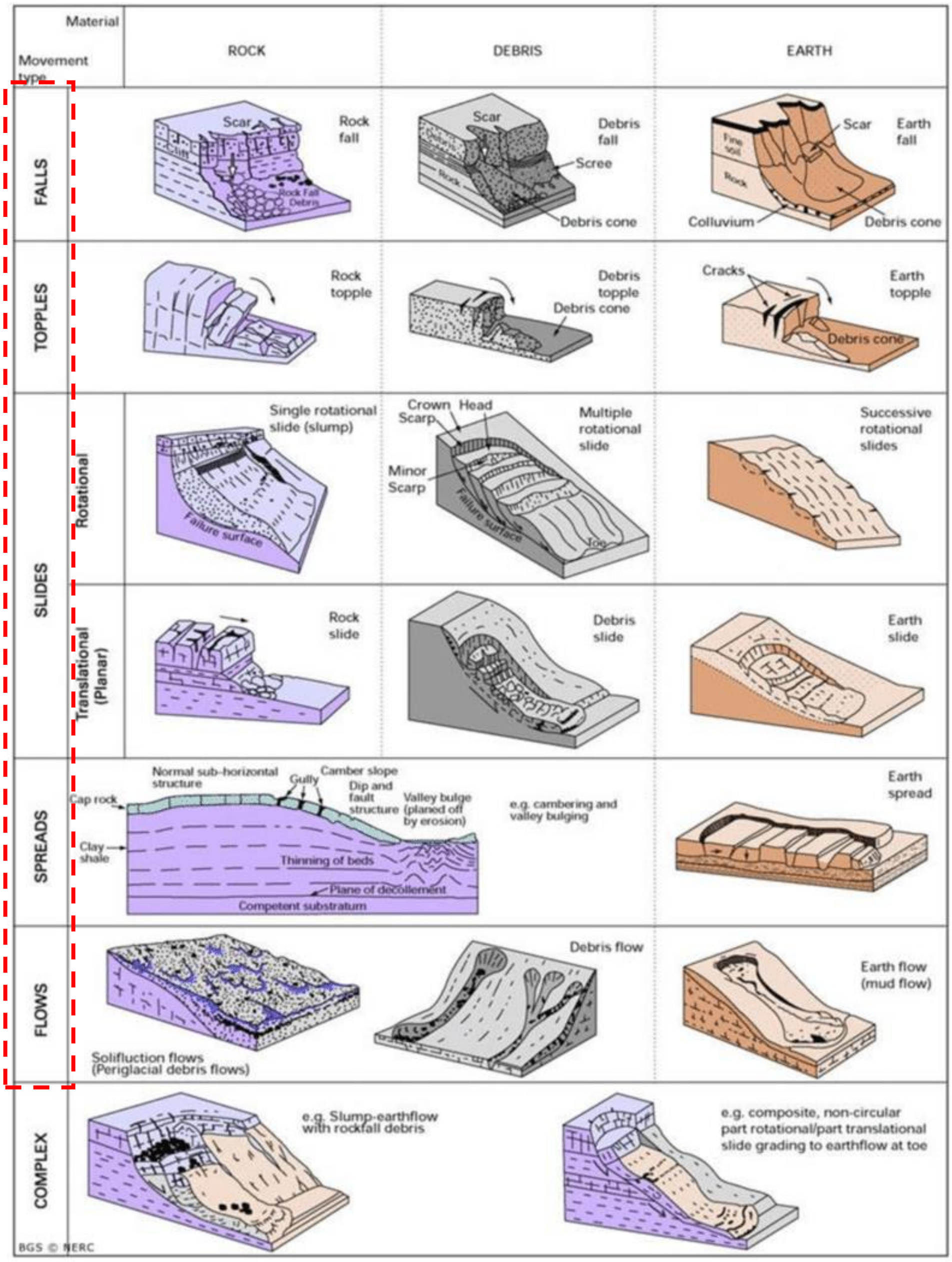

Figure2. Classification of slope movements (Varnes 1978)

Table 3. Landslide-forming material types (Hungr et al., 2013)

LaRiMiT category	Material type*	Character descriptors	Simplified field description for the purposes of classification	Corresponding USCS classification **	Laboratory indices ***
Rock	Rock	Strong	Broken with a hammer	-	UCS>25 MPa
		Weak	Peeled with a knife	-	2<UCS<25 MPa
Soil	Clay	Stiff	Plastic, can be modelled into standard thread when moist, has dry strength	GC, SC, CL, MH, CH, OL, OH	I_P>0.05
		Soft	-	-	-
		Sensitive	-	-	-
	Mud	Liquid	Plastic, unsorted remolded, and close to Liquid Limit	CL, CH, CM	I_P>0.05, I_L>0.50
	Silt, sand, gravel and boulders	Dry	Non-plastic (or very low plasticity), granular, sorted. Silt particles cannot be seen by eye.	ML	I_P<0.05
		Saturated	-	SW, SP, SM	-
		Partially saturated	-	GW, GP, GM	-
Debris	Debris	Dry	Low plasticity, unsorted and mixed	SW-GW	I_P<0.05
		Saturated	-	SM-GM	-
		Partially saturated	-	CL, CH, CM	-

* Hungr et al. (2013)

** USCS: Unified soil classification system

*** UCS: Unconfined compression strength; I_p: Plasticity index; I_l: Liquidity index

Table 4. LaRiMiT classification of depth of movement

Class description	Depth below ground surface (m)
Surficial	<0.5 m
Shallow	0.5 — 3.0 m
Medium	3.0 — 8.0 m
Deep	8.0 — 15.0 m
Very deep	>15 m

5.4 Rate of movement

The user needs to specify the expected rate of movement using the categorization given in Table 5. The categorization of the rate of movement is based on Cruden and Varnes (1996). In LaRiMiT, Cruden and Varnes' velocity classes 4-7 are merged into a single class called "moderate to fast".

Table 5. Landslide velocity scale (Cruden & Varnes 1996)

LaRiMiT category	Velocity class	Description	Velocity (mm/s)	Typical velocity	Response
Moderate to fast	7	Extremely rapid	$5 \cdot 10^{3}$	5 m/s	Nil
	6	Very rapid	$5 \cdot 10^{1}$	3 m/min	Nil
	5	Rapid	$5 \cdot 10^{-1}$	1.8 m/h	Evacuation
	4	Moderate	$5 \cdot 10^{-3}$	13 m/month	Evacuation
Slow	3	Slow	$5 \cdot 10^{-5}$	1.6 m/year	Maintenance
Very slow	2	Very slow	$5 \cdot 10^{-7}$	16 mm/year	Maintenance
Extremely slow	1	Extremely slow			Nil

5.5 Ground water conditions

The groundwater conditions listed below are considered:

- Artesian (pressurised zone)
- High hydrostatic water level
- Low hydrostatic water level
- Absent (no water table)

5.6 Surface water conditions

The user also specifies the surface water condition at the site:

- Rain
- Snowmelt
- Localized
- Stream
- Torrent
- River

6 Suitability criteria for landslide risk mitigation

The suitability criteria for each mitigation measure play a fundamental role in the LaRiMiT web tool evaluation as they reflect both the user's requirements and expert knowledge. Suitability criteria for landslide risk mitigation measures considered both hazard and consequence mitigation. In the context of LaRiMiT, three suitability macro-criteria have been identified: likelihood mitigation suitability, consequence mitigation suitability and time required for implementation. Table 6 summarizes the criteria for suitability assessment and impact that were considered.

Table 6. Criteria for suitability assessment

Criterion	Sub-criteria	Impact
Functional suitability	Suitability for type of movement	Likelihood
	Suitability for material type	Likelihood
	Suitability for depth of movement	Likelihood
	Suitability for rate of movement	Likelihood
	Suitability for groundwater conditions	Likelihood
	Suitability for surface water conditions	Likelihood
Reliability	-	Likelihood
Feasibility and manageability	-	Likelihood
Economic suitability	-	Consequence
Environmental suitability	-	Consequence
Time required for implementation	-	Likelihood and consequence

The likelihood mitigation suitability characterizes how effective a mitigation measure is expected to be in terms of reducing the likelihood of triggering a landslide and/or limiting the runout of a landslide for given the type of movement and site conditions. The criteria related to likelihood mitigation suitability are functional suitability, technical reliability and feasibility and manageability. Functional suitability describes a measure's inherent effectiveness in performing its likelihood mitigation function with respect to a specific set of attributes of the slope movement (type of movement, material type, depth of movement, rate of movement, groundwater conditions and surface water conditions). Technical reliability describes the confidence with which a given mitigation measure can be designed and how reliable it can be expected to perform in terms of experience and the knowledge about the construction technology. Feasibility and manageability jointly describe the ease of construction and maintenance of a given measure, as well as the degree of safety for workers and persons in general during the construction process.

Consequence mitigation suitability describes a measure's impact on the community and site where it is to be implemented. The criteria related to consequence mitigation are economic suitability and environmental suitability. Economic suitability describes the affordability of the measure, in terms of design costs, construction costs, maintenance costs, management costs, etc. Environmental suitability describes the measure's level of impact on the community and site in terms of sustainability, ecological footprint, environmental impact, adaptability to climate change, aesthetic quality, etc.

The time required for implementation criterion describes a measure's suitability in terms of the time required for its planning, design, construction and implementation.

In summary, the suitability concept looks a the reliability and feasibility of the measure:

- Reliability: maturity of technology, reliability of design, Reliability of performance
- Feasibility and manageability: ease of construction, public safety, durability, ease of maintenance

and the urgency and consequence suitability of the measure:

- Time required for implementation
- Environmental suitability: ecological footprint, environmental impact, adaptability to climate change, aesthetic quality
- Economic suitability: cost of design, construction, maintenance and management.

7 LaRiMiT's interactive system

LaRiMiT is a collaborative system which involves three main categories of actors; namely: users, experts and administrators. Figure 3 illustrates the synergy between administrators, experts and users in the compilation of the expert scores and the utilization of the LaRiMiT toolbox, and Figure 4 summarizes the structure and solution function of LaRiMiT.

Through forms on the LaRiMiT portal, the user inputs the required information for the case study. The experts' scoring on the suitability of each mitigation measure is stored in the database (Capobianco et al., 2022). The scores will be adjusted as more experts are consulted and as experience is gained. It should be stressed that user inputs are case- and site-specific while expert inputs are not. Administrators are responsible for the coding of the software and the coordination and management of the portal.

7.1 Role of user

The role of user is to input case-specific information on the description of the movement and the relevant physical conditions at the site (se details in Section 5):

- mode of analysis (triggering/runout)
- type of movement
- material type
- depth of movement
- rate of movement
- ground water condition
- surface water conditions

The user also prioritises on a relative scale 0-10 (with 0: not relevant and 10: extremely relevant) four variables to account for in the analyses of the suitability of the mitigation measures, expressed in terms of relative Importance (Figure 5):

- Effectivity of the mitigation measure (effectivity being the degree to which the measure is successful in producing the desired result)
- Environmental impact

– Duration of construction time
– Costs

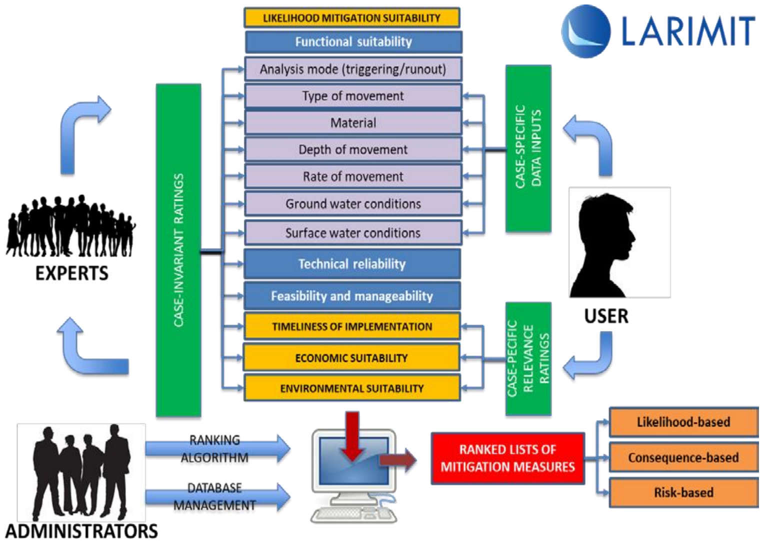

Figure 3. Synergy between LaRiMiT administrators, experts and users

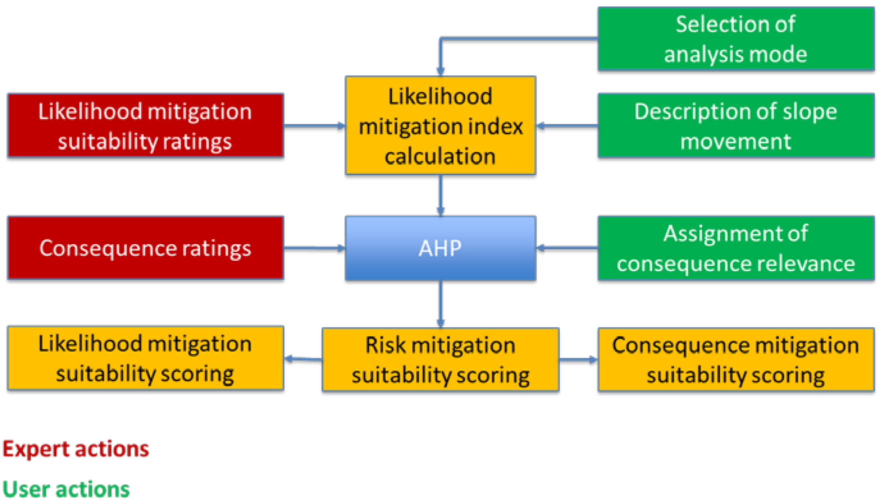

Figure 4. Structure and solution in LaRiMiT (AHP: Analytic Hierarchy Process)

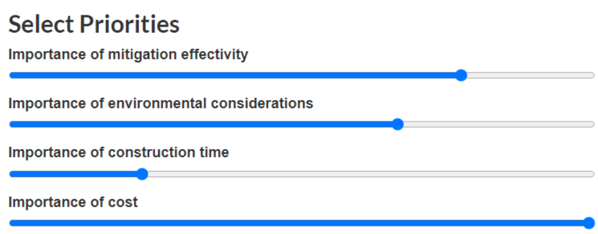

Figure 5. Priorities set up by User for determining the most suitable mitigation measures

7.2 Role of expert

Experts are asked by the administrator (see 7.3) to impart their technical knowledge and experience to evaluate the physical interactions between landslides and mitigation measures, their feasibility and their suitability, as described in Section 6. For each mitigation measure in the toolbox, the experts are/were asked to set the following scores:

– score on a scale 0-10 (with 0: not suitable and 10: fully suitable) to express the quantitative relevance of each suitability factor, as described in Section 6.

– core on a scale 0-10 (with 0: not suitable and 10: fully suitable) to express the quantitative suitability of each measure in terms of its likelihood to mitigate hazard or consequence, and the required tie for implementation.

LaRiMiT is planned as a dynamic system where experts can provide new mitigation measures and/or update previously assigned ratings to mitigation measures. Figure 6 illustrates the dynamic expert score updating process. The expert ratings were treated statistically and fed to the ranking algorithm. For instance, if 20 experts will have provided their ratings for a given candidate measure, the mean value (or another quantile) may be taken as singleton input to the compilation of option scoring matrices. Details about the dynamic and iterative methodology for implementing expert scoring can be found in Capobianco et al. (2022).

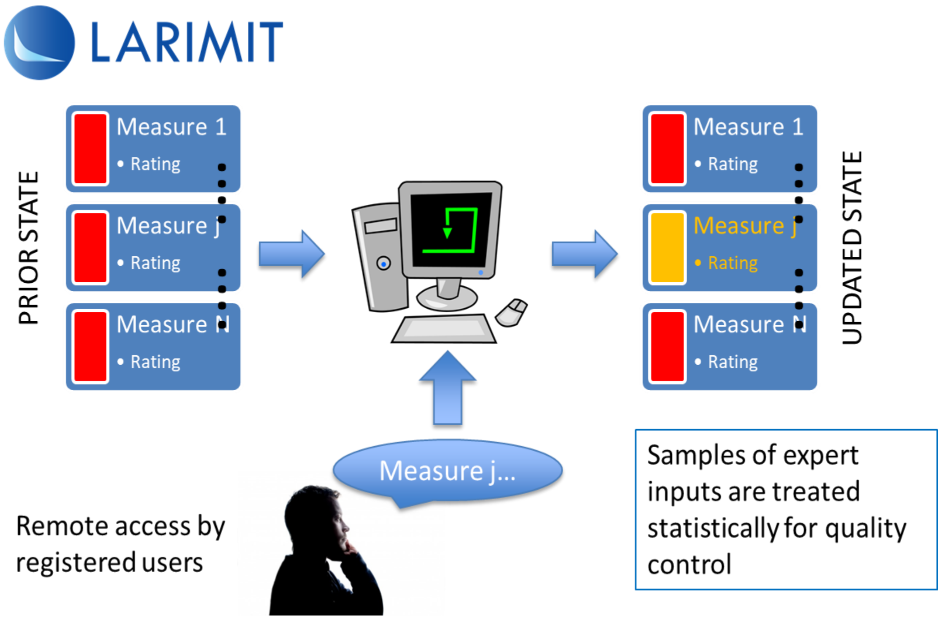

Figure 6. Dynamic updating of expert ratings

7.3 Role of administrator

LaRiMiT administrators act as facilitators for experts and users. Their main tasks are:

– Coordination of the development of the toolbox
– Software coding
– Management of the software platform
– Coordination of the compilation of the landslide risk mitigation measures database
– Improvement and refinement of the statistical management of expert ratings
– Requesting experts for input

8 Ranking algorithm: The Analytic Hierarchy Process

Once suitability criteria are available, a quantitative ranking algorithm is required to obtain a ranked list of suitability for a specific case under investigation. The LaRiMiT toolbox makes use of the analytic hierarchy process (AHP). The method is described in Uzielli et al. (2017).

8.1 Conceptual and functional description of the AHP

The AHP is a structured technique for organizing and analysing complex decisions, based on mathematics and subjective assessment. It was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then. The AHP allows decision-making through a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative options based on a set of criteria, of weights defining the importance of each criterion in the overall decision and on scores for each candidate mitigation measure.

Operationally, the AHP is structured into the following sequential macro-phases; namely: (1) definition of goals, criteria and options; (2) computation of the vector of criteria weights; (3) computation of the matrix of option scores; and (4) calculation of the output ranking scores.

In the computation of criteria weights, criteria are compared pairwise in terms of subjectively assigned relative importance values (i.e., how relevant is criterion A with respect to criterion B for all possible couples of criteria A,B). A matrix is then computed using matrix algebra. Scores parameterize the suitability of the different options with respect to the different criteria.

The computation of option scores entails the scoring of each option (i.e., each candidate mitigation measure) with respect to each criterion. A set of matrices, equal in number to the number of criteria and of (square) size equal to the number of available options are formed again using matrix algebra. Final ranking scores are then calculated by implementing the criteria weight matrix and the option scores matrices in a dedicated algorithm.

The output of the AHP is thus a ranked set of suitability scores for all candidate options. The quantitative scores reflect the input relevance weights and option scores. The AHP also contains an internal check for the consistency of criteria weightings and prevents inconsistent subjective assignment of relative relevance scores for the set of criteria. Formal mathematical aspects of the AHP are not provided here; readers are referred to Saaty (2008).

8.2 Implementation of the AHP for landslide risk mitigation

In the LaRiMiT toolbox, the goal is the optimization of landslide risk mitigation in terms of suitability and cost-benefit. Criteria and sub-criteria reflect the categorization of suitability criteria as described in Sections 6 and 7. Options are the different mitigation actions and measures. Figure 7 illustrates the design of the system in terms of the AHP glossary (goal, criteria, sub-criteria and options) and method of implementation.

The consequence-related suitability indices (economic suitability index, environmental suitability index, time required for implementation index) are assigned as single parameters by the experts. The mitigation measure effectivity index is described below.

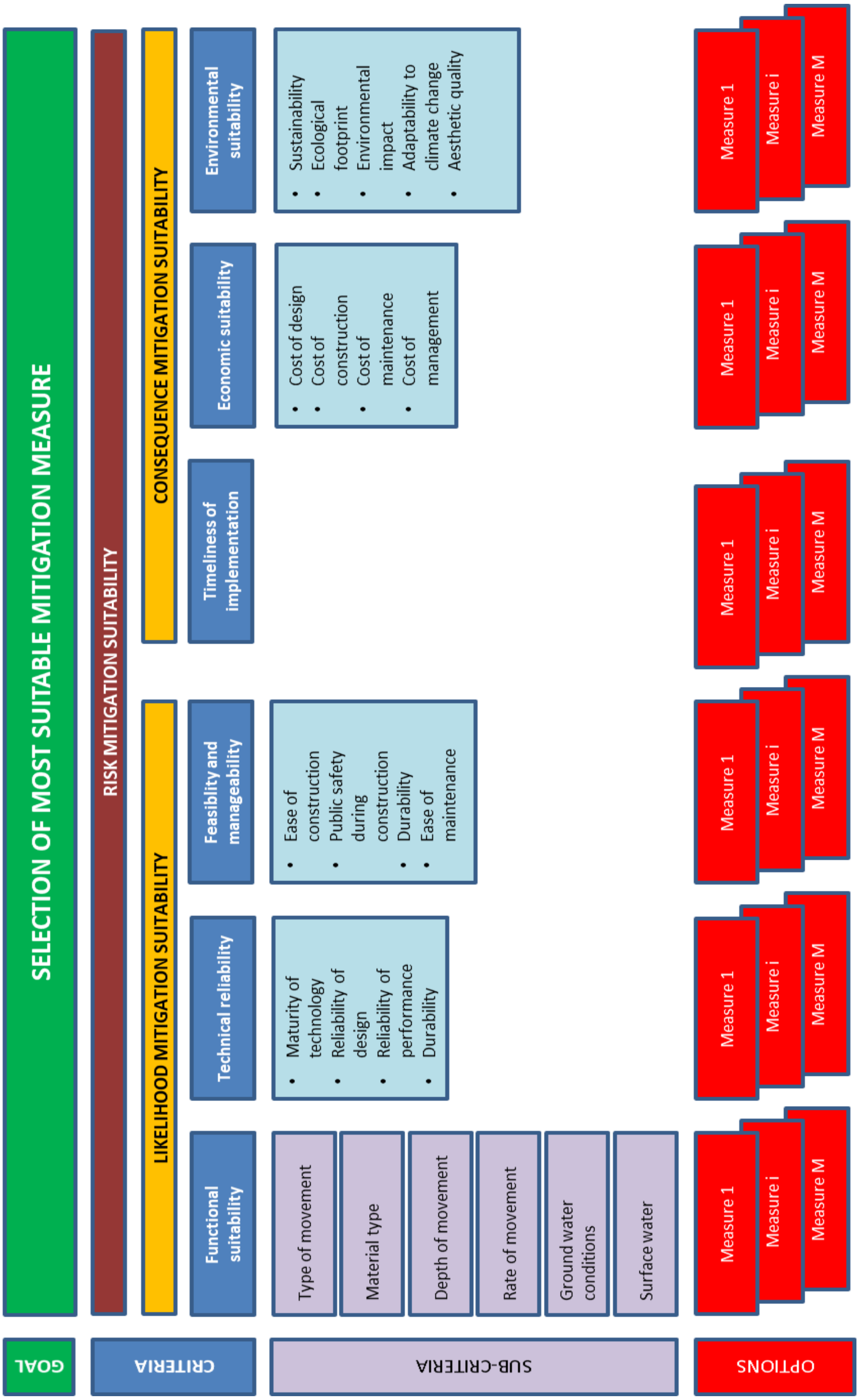

Figure 7. Goal, criteria, sub-criteria and options for the AHP algorithm

8.3 Calculation of mitigation effectivity index

The likelihood mitigation suitability index LMI is given by

$$\mathrm{LMI} = \frac{2\mathrm{FSI} + F\mathrm{MI} + T\mathrm{RI}}{4} \tag{2}$$

in which:

Symbol	Likelihood mitigation suitability factor index description
$F\mathrm{SI}$	functional suitability index
$F\mathrm{MI}$	feasibility and manageability index
$T\mathrm{RI}$	technical reliability index

The feasibility and manageability index and the technical reliability index are assigned directly by experts on a scale of 0 to 10 (0: not suitable; 10: fully suitable).

8.4 Calculation of the functional suitability index

The functional suitability index is required for the calculation of the likelihood mitigation suitability index as given in Section 6. The functional suitability index FSI is given by

$$\mathrm{FSI} = \frac{\mathrm{TMR} + \mathrm{MTR} + \mathrm{DMR} + R\mathrm{MR} + G\mathrm{WR} + \mathrm{SWR}}{6} \tag{3}$$

where the following functional suitability factor ratings are assigned by experts on a scale 0-10 (0: not suitable; 10: fully suitable):

Symbol	Functional suitability factor score description
TMR	functional suitability rating for type of movement
MTR	functional suitability rating for material type
DMR	functional suitability rating for depth of movement
RMR	functional suitability rating for rate of movement
GWR	functional suitability rating for groundwater conditions
SWR	functional suitability rating for surface water conditions

Using the formulation given in Eq. (3), FSI also ranges between 0 and 10.

If one or more of the expert-assigned functional suitability factor ratings is zero, then $F\mathrm{SI}$ is set to zero by means of a filtering procedure which identifies and excludes unsuitable options.

Referring to Figures 5 and 7, the priorities set by the user are handled as indicated in Figure 8.

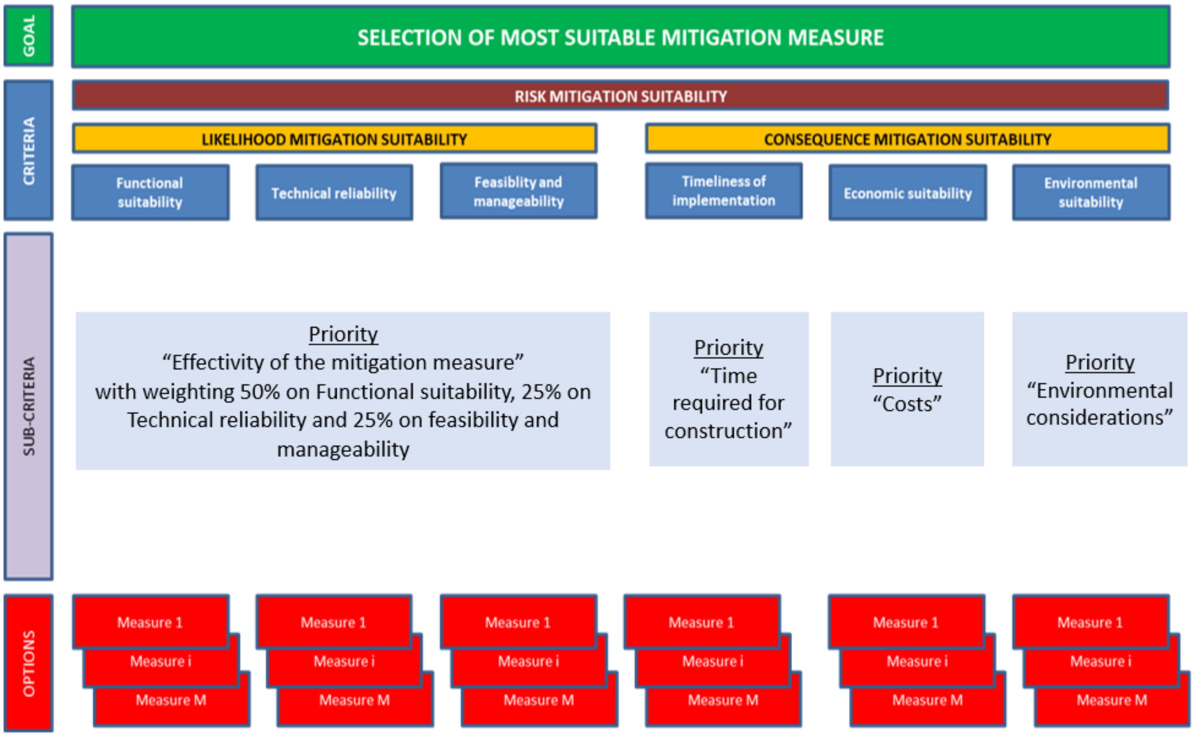

Figure 8. Weighting of suitability criteria in LaRiMiT

9 Outputs of LaRiMiT

LaRiMiT provides individual suitability scores for each mitigation measure and an overall score based on the priorities selected by the user. The analytical hierarchy process ranks the measures according to the priorities set by the user for effectivity of the mitigation measure, environmental impact, time required for implementation and cost. Scores are between 0 and 1. A higher score indicates (for each priority and for the overall score) a preferable measure. The overall score is a combination of the score weighted according to the priorities specified by the user.

The mitigation effectivity ranking informs on the suitability of the measures in terms of their inherent effectivity to reduce landslide hazard, i.e., to reduce the likelihood of occurrence of a landslide and/or a landslide causing a runout characterized by user inputs. The mitigation effectivity refers to the user-defined movement characteristics (type of movement, material, depth of movement, rate of movement, groundwater conditions and surface water conditions). It depends solely on likelihood mitigation suitability criteria and does not account for site-specific impact criteria (economic suitability, environmental suitability and time required for implementation).

10 Future developments

LaRiMiT is under constant development. Possible future improvements include:

- Extension of the database of mitigation measures.
- Further validation and possible refinement of the ranking algorithm.
- Integration with geospatial databases (e.g., Skrednett, National Road Databank, among others) to the purpose of automating the assignment of site conditions (e.g. type of slope, land use, geology, topography, etc.).
- Compilation of a Wiki or other knowledge-based best-practice compendium

- Links to leading contributions to landslide risk management literature
- Integration with risk analysis tools
- Integration with tools for risk treatment and cost estimation
- Links to databases of national regulations
- Smart management of expert ratings, including the clustering of ratings according to soil and movement type, geographical location and other relevant factors.

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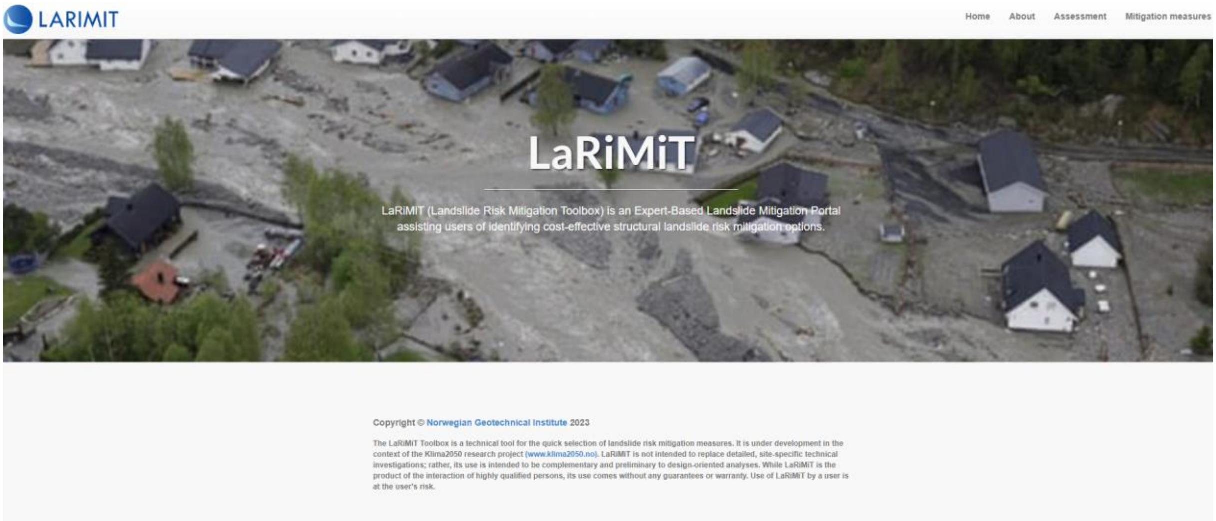
APPENDIX A – DETAILED PROCEDURE FOR USERS

In Appendix A, the user can find all the information regards the application of the web toolbox. This section presents screen dumps of the portal and an overview of the responses required by the user, as well as a few examples. Each step contains a description and images from the website per November 2023.

STEP 1 – CONNECTION TO THE WEBSITE

The site is accessed with www.larimit.com



To be completed in November 2023.