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An expert-based landslide risk mitigation web portal

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	cannot give an information to the readers. Please improve the figure to be comprehensive. THE FIGURE HAS BEEN ENLARGED. SOME TEXT HAS BEEN ADDED TO EXPLAIN THE VARIOUS PARTS OF THE SCREENSHOT Table 4 and Figure 6: Please put them in the right position in the text before References and Affiliations. DUE TO THE ABOVE MODIFICATIONS, TABLE 4 AND FIGURE HAVE BEEN MOVED.

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A web-based landslide risk mitigation portal

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Abstract

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. A web-based portal is in course of development within the Norwegian research project Klima2050. The project is aimed at reducing the risks associated with climate changes and enhanced precipitation and flood water exposure within the built environment. The portal implements the analytic hierarchy process (AHP) for the purpose of selecting the most appropriate landslide risk mitigation measures based on user inputs and dynamic expert scoring of an extensive set of candidate mitigation measures. This paper outlines the conceptual standpoints and the present and foreseeable future structure of the portal.

Keywords

Risk, mitigation, toolbox, Analytic Hierarchy Process, web portal

Introduction

Risk mitigation is a fundamental module in the disaster management cycle. As shown in Fig. 1, mitigation provides the transition between a post-event reconstruction phase and the building of adequate capacity in view of possible future hazardous events. A quantitative approach to risk mitigation entails the quantitative estimation of risk and the assessment of the estimated risk through the comparison with acceptable and/or tolerable risk. Risk estimation can be pursued in a quantitative mode through the following risk model:

$$R = H \cdot V \cdot E = H \cdot C \qquad [1]$$

in which H=hazard is the likelihood of occurrence of a damaging event of a given magnitude in a given period of time; V=vulnerability is the expected degree of damage and loss to one or more vulnerable assets from the same hazardous event, and E=exposure parameterizes the quantity, value or degree of presence of the same vulnerable assets in the same period of time in a given reference area. Consequence [C] is the product of vulnerability and exposure, and describes the impact of the hazardous event. Operationally, 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 possible mitigation of hazard, consequence or both, and includes an assessment of attributes and constraints such as affordability, feasibility, reliability and adaptability to natural and man-induced changes at the site of interest.

In the EC FP7 landslide risk project SafeLand, 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 a web-based "toolbox" of

Figure 1. The disaster management cycle

innovative and technically appropriate prevention and mitigation measures, based on technology, experience and expert judgment in Europe and abroad. The toolbox's aim was to document structural, non-structural, including risk-transfer, measures applicable to all countries in Europe. The SafeLand toolbox included technical specifications or policy prescriptions (how to), document, with hindsight, the experience and effectiveness of the approach (do's and don'ts), and estimated the 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.

Klima 2050 is a Centre for Research-based Innovation (CRI) funded by the Norwegian Research Council (NRC) and public and private partners, with the aim of 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 center. The Norwegian Geotechnical Institute, as coordinator of SafeLand project and main responsible for the SafeLand toolbox, as well as responsible for the Klima 2050 landslide work package, saw the potential for further development of the mitigation toolbox. A main activity in the Klima 2050 landslide work package has therefore since its start in 2015 been to develop the applications of the toolbox, by use of new software and validation methodology and through the extension-migration to a web portal which would include additional features. This paper outlines the conceptual standpoints and the present and foreseeable future structure of the web portal.

Purposes of the portal

The main goals of the portal under development are, at present:

- To provide an expert-assisted tool for the case- and site-specific ranking and best-practice selection of landslide risk mitigation measures.
- To allow the synergy between portal administrators, knowledgeable (albeit non-expert) users and landslide risk experts in pursuing the optimization of landslide risk management through the merging of user-input case- and site-specific information with expert-input knowledge
- To allow ongoing, dynamic expert updating of an extensive database of candidate mitigation measures
- To accommodate further expansion of the portal through the future compilation of a Wiki or other knowledge-based best-practice compendium, as well as links to literature, tools, regulations, case studies, etc.

Suitability criteria

As stated previously, suitability criteria for landslide risk mitigation measures should embrace both hazard and consequence mitigation. In the context of the toolbox under development, a set of criteria have been identified and compiled by experts. More specifically, criteria are related to nine macro-categories. Criteria related to hazard mitigation include: (1) functional pertinence; (2) technical reliability; (3) manageability and (4) adaptability. Functional pertinence characterizes how appropriate a given mitigation measure is expected to be in terms of reducing the likelihood of occurrence of a slope movement, given the type of movement and site 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 past experience and the knowledge about the construction technology. Manageability describes the ease of construction and maintenance of a given measures, as well as the degree of safety for workers and persons in general during the construction process. Adaptability describes the capability of a given measure to preserve its functionality and integrity in the face of climate change and induced hazardous events, as well as other environmental and man-induced changes to the site where it is located. The five macro-categories of criteria related to impact refer to five dimensions of vulnerability and consequence; namely: (1) physical; (2) economic; (3) societal; (4) environmental; and (5) cultural. Each dimension refers to different sets of human-valued assets, activities or heritage. Tab. 1 summarizes the macro-categories and criteria for suitability assessment of any given candidate risk mitigation measure or action.

Ranking algorithm: the Analytic Hierarchy Process

Once suitability criteria are available, it is necessary to obtain a ranked list of suitability for a specific case under investigation. A quantitative ranking algorithm would provide a more objective tool to yield repeatable outputs given the set of user and expert inputs. The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing 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 present case, the goal is the optimization of landslide risk mitigation in terms of cost-benefit. Options are the different mitigation actions and measures. Suitability criteria have been defined in a previous section of this paper. 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 weights, and prevents inconsistent subjective assignment of relative relevance for the set of criteria. Formal mathematical aspects of the AHP are not given here; readers are referred e.g. to Saaty (2008).

Inputs to the AHP are provided by both experts and users. More specifically, user inputs include case-specific information regarding:

- Landslide type
- Site conditions
- Expected relevance of potential negative consequences and constraints (physical, ecological, economic, societal, environmental) brought by any mitigation measure or action for the specific case under investigation.

Expert inputs include

- Set of candidate mitigation measures and actions
- Scores for each candidate measure with respect to the set of ranking criteria

Expert inputs will be resident on the toolbox server in the form of a database including the set of candidate measures and/or actions, relevance weights and scores for functional pertinence, technical reliability and manageability, as well as scores for impact assessment for all candidate options. It will be possible to update the database remotely by registered experts, who will be able to provide new scores or update previously assigned scores. Expert inputs will contribute to the compilation of samples of scores, which will be treated statistically in the implementation of the AHP. For instance, if 20 experts will have provided their scores for a given candidate measure, the mean value may be taken as singleton input to the AHP in the compilation of option scores matrices when a user uses the portal. A statistical treatment will allow a greater confidence of extracted parameters, for instance through the detection of possible outliers, and a more complete assessment of the sets of user inputs, thereby providing a valuable source

Table 1. Suitability criteria for mitigation measure ranking

Category	Criteria
Functional pertinence	Type of movement
	Material
	Depth of movement
	Rate of movement
	Groundwater conditions
	Surface water conditions
Technical reliability	Maturity of technology, reliability of design, reliability of performance
Manageability	Ease of construction, safety during construction, durability, ease of maintenance
Adaptability	Climate change, anthropic development, environmental changes
Physical impact	Structures, infrastructures, lifelines
Economic impact	Design, construction, maintenance, indirect costs
Societal impact	Human health, social dynamics, employment, quality of life
Environmental impact	Geological, geomorphological, hydrogeological, ecological environments
Cultural impact	Cultural heritage, landscape

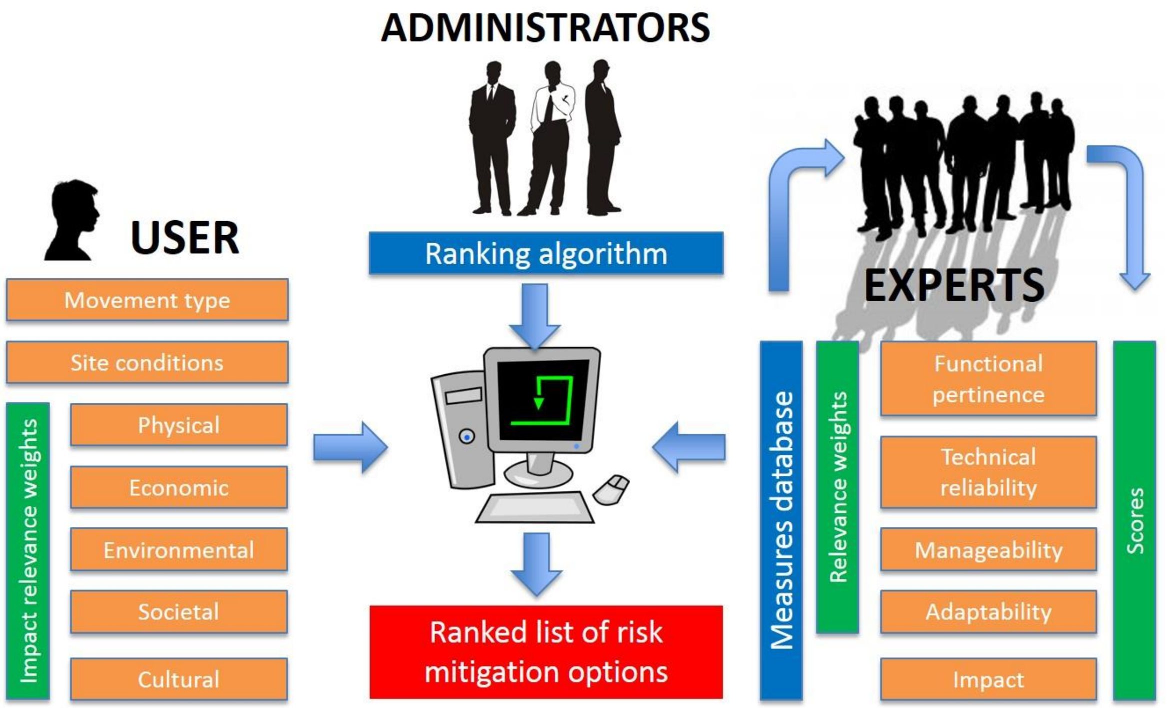

Figure 2. Functional scheme of the toolbox

of state-of-the art expert-based knowledge. Fig. 2 clarifies the expected future synergy between administrators, experts and users in the compilation and utilization of the toolbox.

Technological and programming aspects

In order to best achieve its purposes and achieve a wide diffusion worldwide, the portal is designed as a web-based application. The risk mitigation algorithm based on the AHP is developed using the Python-based Django web framework. Such choice entails the following benefits:

- Easy remote access by the experts' panel and users
- Accessibility through mobile devices
- No software installation required
- Online availability of the most recent version
- Integration with mathematical software for the statistical processing of the expert scores database.
- Possibility to generate output reports for users
- Possibility to extend with popular applications such as Google Maps
- Possibility for users to improve their knowledge of candidate mitigation measures through hyperlinks to technical information, case studies

Given the intuitive quantitative output format of ranking scores, users will be able to perform parametric studies to obtain ranked scores depending on different constraints and consequence factors, thereby allowing a quantitative assessment of the sensitivity of relevance criteria on toolbox outputs and to construct any set of scenarios which they may deem representative of their specific case.

Example application

This section shows a preliminary, partial, work-in-progress example application of the toolbox to a debris-flow case in Norway. Significant additions, variations and improvements to the current functioning may be expected in the course of the toolbox development, and the contents of this section should not be seen as representative of the final product. As shown in Fig. 3, heavy-rainfalls triggered debris flows and the mass invested the road behind an inhabited house. To protect the neighboring houses from further slides, urgent design and implementation of mitigation measures was

Figure 3. Debris flow occurrences on the example site: (a) general view of the impacted area and details of the debris flow impact on: (b) buildings and (c) vegetation.

required. The input landslide and site-specific features are summarized in Tab. 2.

In view of the compilation of the comprehensive set of suitability criteria as described in a previous section, this example application relies of the database of measures and scores of ranking criteria contained in the original SafeLand Toolbox (Lacasse et al., 2013), which classified near 70 mitigation measures. Currently, moreover, the toolbox is able to rank available measures based solely on hazard mitigation-related technical criteria, i.e. technical pertinence and cost. Tab. 3 shows 7 candidate measures currently available in 3 different typological categories. The third column shows the algebraic summation of the products between relevance weights and option scores Σ_{opt} for 8 suitability criteria for each candidate option. As shown in Tab. 3, 'Deflection structure' in the category of "deviating the path of landslide debris" obtains the highest score in sum of technical criteria (without considering relevance weights). However, the score is not considerably larger than those calculated for measures pertaining to very different typological categories. Hence, it may not be straightforward for the user to select the optimal measure. To obtain a decision-making ranking between the measures, three measures that have a similar sum of option scores Σ_{opt} but belonging to different categories are selected for a more refined comparison involving relevance weights. Selected measures are ticked in the rightmost column of Tab. 3. Figure 5 shows the option scores of the 3 selected mitigation measures with respect to the 8 suitability criteria. User-defined importance/priority weights (assigned on a 1-10 scale) for the specific case under investigation are summarized in Tab. 4. The AHP performs the pairwise comparison by processing the above scores. Fig. 4 provides an example screenshot of the current input form. This is a work-in-

Table 2. Characterization of the ground movement at the example site

Item	User input
Type of movement	Flows
Material type	Debris
Depth of movement	Shallow (0.5 to 3 m)
Rate of movement	Moderate to fast
Groundwater	High
Surface water	Torrent

Table 3. Scores of user-selected candidate measures according to the summation of option scores

Typological category	Measure	Σ_{opt}	
Deviating the path of landslide debris	Deflection structure	51	√
Deviating the path of landslide debris	Debris flow/rockfall shed	51	
Arresting and containing landslide debris or rockfall	Debris resisting barrier	48	√
Arresting and containing landslide debris or rockfall	Debris retention basin	48	
Dissipating the energy of debris flows	Drop structure	46	√
Dissipating the energy of debris flows	Debris restraining structure	38	
Dissipating the energy of debris flows	Debris flows impediments	33	

progress version; the graphic output is provisional and is intended to provide an idea of the current status of work. It does not contain all the final features of the toolbox. The Figure displays features such as: (1) the geographic location of the site, the user-input data regarding the features of the movement (as given in Tab. 2); (2) the option scores for each of the measures selected and ticked in Tab. 3, as described above, with respect to the reference set of suitability criteria (also illustrated in Fig. 5); (3) the input form for user-input constraints/relevance factors as tabulated in Tab. 4; and (4) the ranking scores based on constraints and on technical suitability. The "deflection structure" option scores significantly higher than other measures. Tab. 4 shows that the user assigned a greater relevance weight to the "maturity of technology" and "reliability of performance and implementation" criteria than to other criteria in the decision-making process. Fig. 6 shows that measure 'deflection structure' is the best-performing method in terms of technology maturity and reliability of performance and implementation. This explains why the "deflection structure" option obtained a higher output score with respect to others even though the sum of option scores were comparable to the other candidate measures. A different ranking would have been obtained via the AHP if the user had assigned different importance values.

Table 4. Relevance of performance and reliability criteria considered in decision-making

Criterion	Relevance
Maturity of technology	7
Reliability of performance	8
Reliability Uncertainty in design	4
Reliability Uncertainty in implementation	8
Safety during construction	5
Service life required (durability)	5
Aesthetics	3
Typical cost	5

Concluding remarks and future development

The portal, in terms of software implementation, is currently in its early beta version. Moreover, the expert compilation of the database of scores is still at the state of the SafeLand Toolbox and requires substantial integration to achieve the complete set of suitability illustrated in the paper.

In developing the portal, it will also be assessed whether it will be possible to implement algorithms which would make it possible to analyze geographical information and geospatial data, and propose values to tune condition of constraints precisely (e.g. accessibility, residential information, type of slope, land use, geology, topography, etc.) and to validate the ranking algorithm. It may also be possible to refine and improve the significance of expert scores by clustering scores according to soil and movement type, geographical location and other factors which may prove to be relevant.

Acknowledgments

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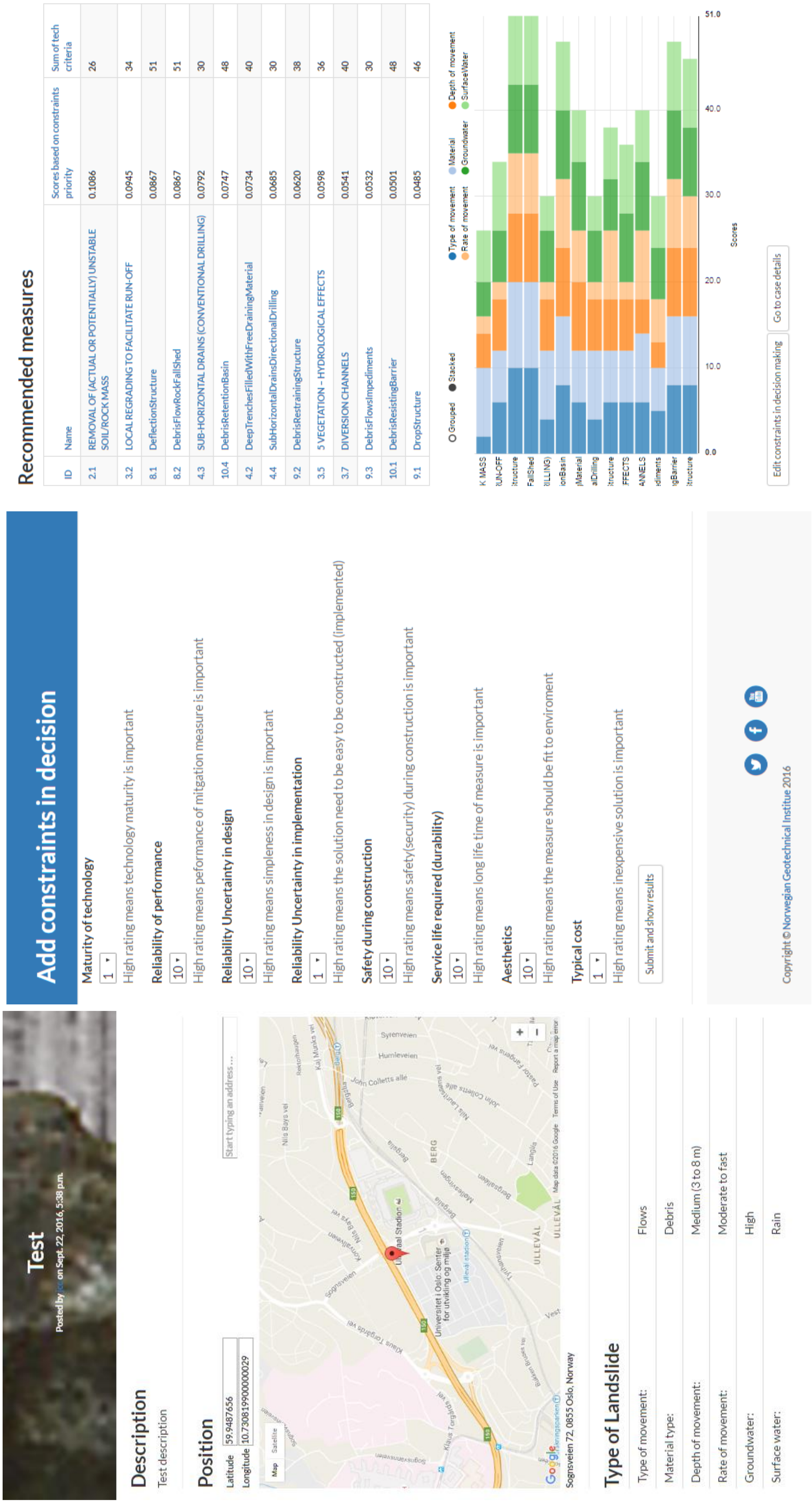

Figure 4. Example of decision-making process as implemented in the provisional version of the portal

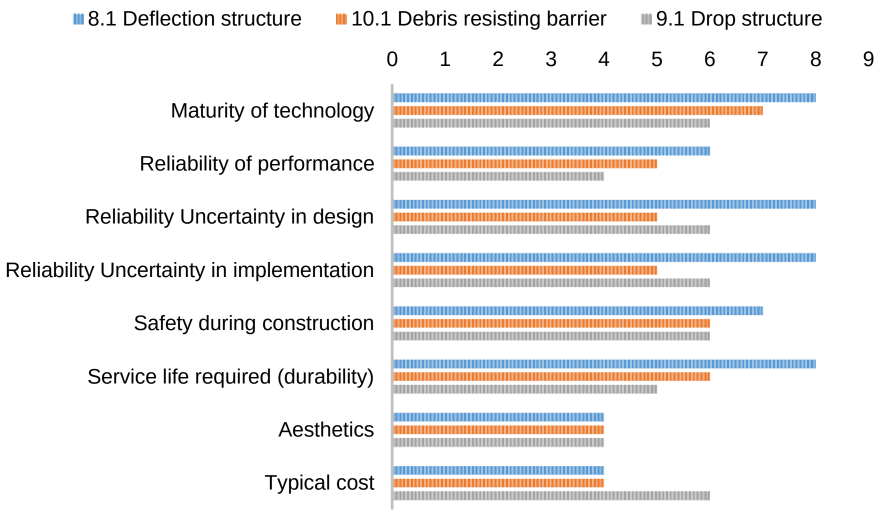

Figure 5. Example application: option scores of 3 user-selected mitigation measures with respect to 8 suitability criteria

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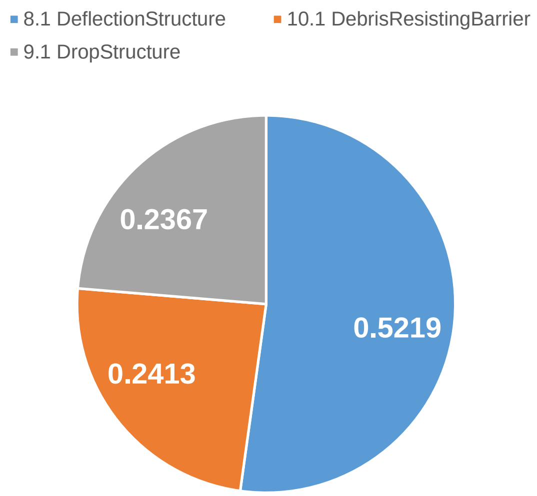

Figure 6. Output scores obtained using the AHP algorithm