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# PROPOSAL OF RISK MITIGATION STRATEGIES BASED ON A CONCEPTUAL PLANNING APPROACH

## A CASE STUDY CONDUCTED IN THE GADRIABACH STUDY SITE, VINSCHGAU VALLEY, ITALY

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## ABSTRACT

In this paper the application of a conceptual procedure for the development of effective risk mitigation strategies is presented through a dedicated case study conducted on the Gadriabach (South Tyrol, Italy), which, over the centuries, has been a threat for settlement, infrastructure and agriculture.

The Conceptual Planning approach provides a workflow to rationalize the planning process and thereby support the planner. Starting from a series of system analytic steps the risk related system shortcomings are identified and successively feasible conceptual risk mitigation solutions are elaborated. In this context the definition of an Ideal Final Result contributes to a clear specification of the risk mitigation targets to be achieved. Operationally, a set of tailored principles shows how to solve the system contradictions. Finally, as a result of the application of the conceptual planning approach, we discuss and compare a set of possible solutions for the risk mitigation problems at hand.

**Keywords**: Concept Plan, risk reduction, planning approach, Vinschgau

## INTRODUCTION

The Gadriabach (Vinschgau Valley) has the second largest debris-flow cone in the South Tyrol according to volume and area (Fischer, 1966). The debris-flow cone, mainly used for agriculture and settlement has a long history of human activity and exposure to natural hazards (e.g. Hoffmann, 1885). The Gadriabach has posed a threat to the villages of Allitz and Laas located on the debris cone for many years and has been the focus of several engineering projects. Despite the large economic investments in torrent control works, debris flow risk couldn't be reduced to an acceptable level and the costs for the maintenance of the full functionality of the protection system arose to relevant levels.

The importance of the aforementioned system deficits was discussed during the initiatives promoted by the Etsch Dialogue, an integrated management initiative. Contextually, for the Gadriabach, unfavorable sediment dynamics and the potential consequences thereof were highlighted as major concerns (Dept. of Hydraulic Engineering, South Tyrol, 2009; Lucarelli et. al, 2009).

Starting from these premises the need of a detailed analysis became apparent. In this paper we apply a Conceptual Planning approach, proposed by Mazzorana (2008), to progressively dissect the initial problem definition with the objective to reformulate and define consistently the problem under consideration (critical system analysis). Moreover, during a step of conceptual design we define the requirements to be met by future protection system entities (Ideal Final Result, IFR, according to Altschuller, 1984). Finally, we propose and compare conceptual solutions for the inherent contradictions originated from systemic or physical system constraints, which are related, in the concrete case, to an existing protection system poorly performing in terms of sediment regulation and risk mitigation. Moreover, the costs related to the maintenance of the protection system (i.e consolidation structures) and arising from the frequent filling of the only retention basin present in the catchment pose a relevant burden for public authorities. The Conceptual Planning approach (CP),

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which is outlined in the following section, contributes to a consistent management process aiming at achieving highest levels in terms of protection, cost efficiency and effectiveness and a commensurate environmental quality.

## METHOD

The Conceptual Planning approach used in this study is based on four pillars: (i) the *System Dynamics Theory* (Sterman, 2000) provided the analytic framework for the analysis of the system, its components and the interrelationships between them; (ii) the *Life Cycle Concept* (Blanchard and Fabrycky, 2006) was considered for the temporal delimitation of the project appraisals in the light of technical and allocative efficiency and optimality considerations; (iii) the *Universal Design Theory* (Tomiyama et. al, 2009; Lossack, 2006) was taken as a formal reference for structuring the design process; and (iv) the *TRIZ-TIPS Theory* (Zobel and Hartmann, 2009; Yang and El-Haik, 2003) provided the theoretical basis for the conceptual and functional specifications of both feasible and technically effective solution pathways for the physical and systemic contradictions identified in the natural system under consideration.

According the aforementioned body of knowledge base (points i-iv) Mazzorana and Fuchs (2010) developed a general guideline for the planning process in natural hazard and risk management. The guideline outlined below as a step-by-step workflow was ideated as a reference scheme to support practitioners in everyday planning activities:

1. Definition of the system boundaries of the considered study site; focusing on the extent of the catchment of interest and any relevant tributaries and deposition areas.
2. Definition of the system characteristics regarding protection system, natural hazard processes, damage potential and vulnerability.
3. Problem identification and description: definition of (with the new and enhanced knowledge status) the problems to be solved with a particular focus on risk mitigation and ecological functionality. Explicit description of the systemic contradictions to be overcome.
4. Formulation of the Ideal Final Result (IFR) to be achieved. Description of a “model” to be approximated. The IRF has to be intended as a specification supporting the planner throughout the planning process. Since the IFR is formulated in an early planning phase it is essential to explicitly refer to the previously identified system contradictions and to define a thoroughgoing target system. Expressed another way, the targets to be attained are formulated in terms of maximization (minimization) objectives (Mazzorana et. al, 2007). An ideal protection system should have, among others, the following characteristics: (i) long durability (high reliability), easy and cheap maintainability; (ii) high functionality (efficiency) with substantial mitigation effects for short return periods and just sufficient mitigation effects for long return period events; (iii) high sediment transport regulation capacity with progressive reduction of the remaining sediment yield potential; (iv) low uncertainties about protection system responses to extreme events, which leads to an easier integration and more effective implementation of early warning systems etc.; (v) and resilient response to extreme loadings (beyond design return period intensities of the phenomena).
5. Analysis of all possible physical, spatial and temporal resources for an optimal application of the IRF. In this phase the planner should go beyond the assessment of available space for hazard mitigation. In addition to traditional consolidation and retention concepts, also possibilities of dosing transported solid material (woody debris) or smoothing in space and time the peak flow intensity (e.g. diverting excessive loads towards damage minimizing sectors), should be explored. From an integrated risk management perspective it could be essential to identify objects to be “sacrificed” in case of a worst case scenario (i.e. damage minimizing sacrifice).
6. Definition of admissible system changes: It should be noted that in this workflow the restriction of the search space for feasible risk mitigation solutions is subsequent to the definition of the IFR which represents a methodological improvement. Put another way, a conceptually ideal solution is modified according to the admissible system changes and not vice versa. Moreover, the planning process is meant to address the removal of obstacles to the full attainment of the IFR.
7. Elaboration of solution concepts and/or variations based on the ideal end result and following the principles shown in Table 1.

8. Evaluation of the developed solution strategies.
9. Selection of the optimal solution concept based on cost-benefit criteria answering for each proposed solution the following questions: (i) what has been enhanced; (ii) what has been worsened; (iii) what has been substituted; and (iv) what remains to do with reference to the attainment of the IFR?
10. Communication of residual risk to affected people.

Concerning the elaboration of the IFR, Mazzorana and Fuchs (2010) proposed a set of tailored principles to assess systemic or physical contradictions on a system level (see Table 1).

**Tab. 1** Principles for the design of effective flood risk mitigation strategies

| Root Principles | Derived Principles |
|---|---|
| (i) Separation Principles | a) Spatial separation: The overall aim is to separate areas characterized by relevant process intensities from areas at risk perspective, i.e. with a relevant accumulation of values at risk.<br>Corollary: Concentrate adverse effect in low vulnerable areas.<br>b) Temporal Separation: The overall aim is to decouple in time the intensity maxima of liquid discharge and sediment transport on the process side, and to displace movable objects at risk from endangered areas during the critical timeframes within the extreme event duration (e.g. by evaluating people at risk).<br>c) Separation by change of status: The aim is to achieve a reconfiguration of critical system configurations during the critical timeframes within the event duration (e.g. by avoiding bridge clogging).<br>d) Separation within the system and its parts: It may be possible to create subsystems with a lower degree of susceptibility while the residual parts of the system remain unaffected (e.g. local structural protection for individual buildings). |
| (ii) Dynamisation Principles | a) Dynamisation of the sediment transport process: The overall aim is to control the sediment transport process (e.g. by dosing it through open check dams) and the wood transport process (e.g. by preventive entrapment through retention structures).<br>b) Ecosystem dynamisation: The overall aim is to enhance ecosystem functionality.<br>c) Dynamisation of mitigation – Modularization of the protection system: The overall aim is to create a flexible modular mitigation concept taking into account the entire range of possible alternatives. This principle allows for adaptation if the parameterization will change in the future. |
| (iii) Combination Principles | a) Combination of mitigation: The overall aim is to efficiently reduce effects with respect to hazard and vulnerability, and to increase the system reliability and maintainability.<br>b) Multipurpose combination: The overall aim is to design parts of the mitigation concept with respect to alternative uses (e.g. modeling the landscape in order to achieve flow deflection without compromising the agricultural use of the area). |
| (iv) Redundancy Principles | a) Redundancy of the worst case: |

| | |
|---|---|
| | b) Redundancy in intervention planning: In particular for a worst-case scenario, certain elements of the mitigation concept should be redundant in order to avoid system failures. |

## CASE STUDY

This section presents the practical application of the previously presented conceptual planning approach in the form of a case study conducted in the Gadriabach study site, Vinschgau Valley, Italy. Point 1 and 2, 5 and 6, 7 and 8 as well as 9 and 10 of the above outlined procedure are summarized for conciseness.

### CRITICAL SYSTEM ANALYSIS (SYSTEM BOUNDARIES AND CHARACTERISTICS)

The Gadria catchment (Figure 1) (South Tyrol, Italy) with a drainage area of 6 km² presents one of the largest fans in the Alps (10.9 km²) with frequent debris flow rates (1-2 per year). Geologically, it consists mostly of highly fractured metamorphic rocks (phyllites, schists, gneiss). The average precipitation in the main valley is quite low (about 500 mm) compared to similar debris flow basins in the Alps. Thunderstorms are responsible for most of debris flow occurrences (Comiti et. al, 2010).

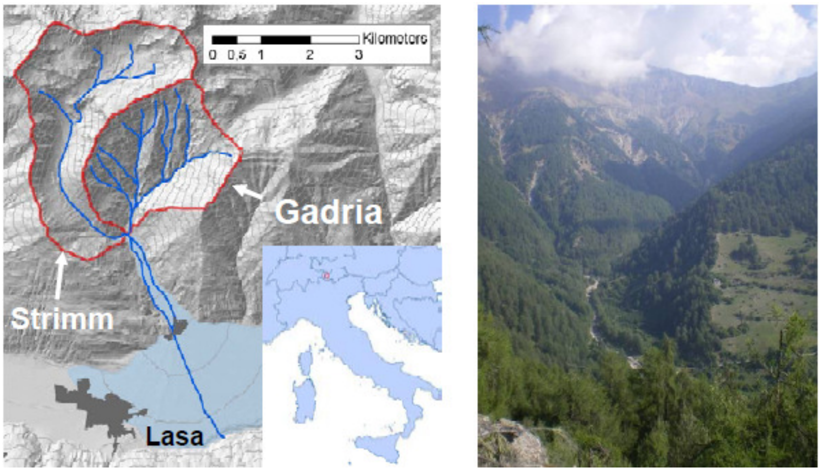

**Fig. 1** Basin map and location (left) and view of the main channel (Comiti et. al, 2010)

- **Event documentation**

The first historical record of a debris-flow event in the Gadriabach dates into the 14th century (AD 1386). Since this time 38 further events have been documented (Dept. of Hydraulic Engineering, South Tyrol, 2010). Only limited event documentation is available for the Strimmbach; however, recently it showed debris flow activities and erosion processes interested the lower part of the stream. In the current situation the Gadria- and the Strimmbach frequently deliver considerable sediment volumes to a single retention basin. Due to a recently constructed deflection dam, the Strimmbach flows into the retention basin in a geometrically unfavourable configuration.

- **Natural hazards**

Lucarelli et al. (2009) estimated in a recent study that the volume of a 100-yr debris flow event can be expected to be up to 160 000 m³ with a peak discharge of 58.5 m³/s. Despite the presence of the deposition basin, the alluvial fan is prone to hazard impacts shown as a hazard zone map in Figure 2. The delineation of the hazard zones has been conducted according to the specific guidelines of the Autonomous Province of Bolzano (Autonomous Province of Bolzano, 2008).

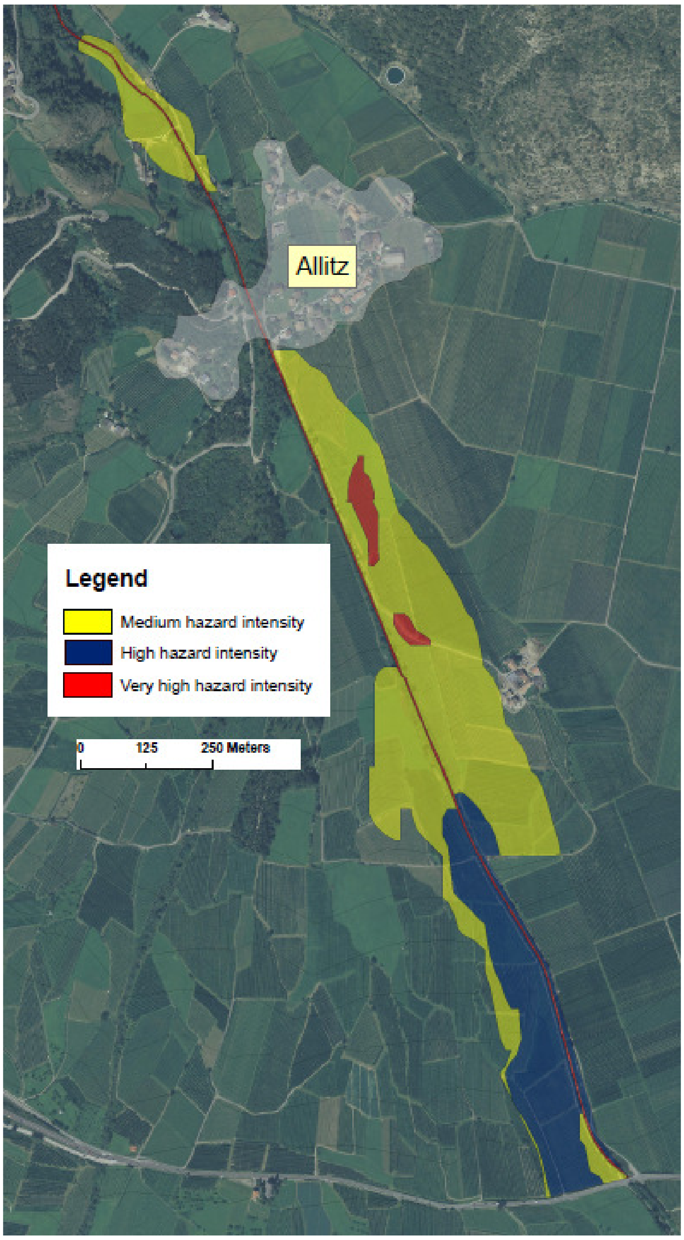

**Fig. 2** Hazard map showing the red, blue and yellow hazard zone on the debris flow cone (Lucarelli et. al, 2009)

The simulation showed that for events with a return period > 30-yr, outburst of the channel boundaries is possible. For events with larger return periods, clogging of the bridge in the village of Allitz is to be expected, which would induce hazard propagation on larger portions of the cone area.

- **Existing mitigation system**

In the late 1800s, a 2 km-long stream reach on the fan was diverted to an artificial, straight paved channel. Consolidation check-dams were built along the upstream natural channel starting in the early 1900s, and in 1975 an open check dam with a retention basin of about 80,000 m³ was built at the fan apex. This now partly prevents debris flows from propagating to the fan but requires very high maintenance costs (approximately 200,000 €/yr). A bedload creek, the Strimmbach, with a drainage area of 7.7 km² joins the Gadriabach at the level of the retention basin (Comiti et. al, 2010).

## PROBLEM DEFINITION AND SYSTEM DEFICITS

The system deficits in the investigated catchment stem from multiple factors. An overview of the specific problems is provided in Table 2.

**Tab. 2** Overview of the system deficits in the Gadriabach and Strimmbach

| **System deficit** | **Description** |
|---|---|
| - Unfavorable system configuration at the confluence of the Gadriabach and Strimmbach | The Strimmbach flows into the Gadriabach at a right angle a few meters upstream of the retention basin, inhibiting a self-dosing effect. On average the sediment volume removed from the retention basin for a 24 month period is 30 000 m³. |
| - Check dams in upper catchment areas are highly damaged or eroded | Due to age and the torrential processes, the check dams are no longer able to fulfill their function (ca. 30% heavily damaged). |
| - Biological engineering measures (constructed between 1980 and 1990) are highly damaged | These measures located above the timberline are only partly able to inhibit erosion. |
| - Increase in magnitude of events due to damaged protection constructions | As a consequence of the above outlined problems the basic disposition of sediment availability is increased. Being equal the precipitation trigger this could result in an increased likelihood of debris flow initiation. |
| - The functionality of the protection system is highly dependent on the quality of periodic maintenance | The planning approaches that characterized the series of interventions realized in the second half of the 20th century reflected the intentions of different planners and therefore exhibit a suboptimal integration from a systems perspective degree of incoherency. Check dams constructed in different period were not purely maintained. Moreover, it was increasingly recognized that cost benefit ratio of the retention basin is unsatisfactory. |
| - Intensified erosion along the Strimmbach | The basic disposition of sediment availability is increased. Being equal the precipitation trigger this could result in an increased likelihood of debris flow initiation. |

## IDEAL FINAL RESULT

The ideal system should operate as follows:

The risks for the endangered objects on the debris cone should be significantly reduced. This entails a reduction of the specific risks for residential buildings and infrastructure (mainly roads) and commensurately for the agricultural areas. Simultaneously the efficiency and the reliability of the protection system should be enhanced. This essentially means to design a sediment dosing system capable of buffering the peaks of the involved hazard processes without generating additional maintenance costs (clear up costs for deposited debris flow volumes). What is sought, to use the terminology of Altschuller (1984), is a self functioning dosing system.

Moreover, the existing protection system should be reconfigured in such a way to exploit its residual functionality with a minimum of maintenance interventions. That means that the condition and efficiency of all existing structures have to be carefully evaluated in order to focus the efforts towards key control structures (Mazzorana et. al, 2007) and to avoid unnecessary expenditures to maintain structures exhibiting insufficient efficiency.

## RESOURCES – ADMISSIBLE SYSTEM CHANGES

On the fan apex no particular restrictions in space are given for possible reconfigurations of the existing protection system and new constructions. On the middle and lower parts of the debris cone the degrees of freedom for possible mitigation measures are given, although these areas are intensively used for agricultural purposes. The residential buildings are irregularly distributed on the cone area and some of them are located nearby to the channel and in close vicinity to the crossing bridge. This configuration may restrict management possibilities.

## ELABORATION OF SOLUTIONS AND THEIR EVALUATION

With regard to the system deficits listed above and the IFR as a reference, various solutions were elaborated to solve the multiple problems.

The most promising solution envisions a change to the existing protection system in the location of the retention basin. Coherently with the principle of separation in space, we proposed to totally change the confluence configuration between the Gadria- and Strimmbach in order to avoid the deposition of solid material in the same retention basin deriving from two different tributaries. As already mentioned diminished deposited volumes would result in minor expenditures for clear-up costs. A further idea is to enhance the confluence between the Gadria- and Strimmbach from a flow dynamic perspective. To achieve a substantial reduction of the peak solid discharges in space and time it is essential to remove the slit dam of the existing retention basin and to gradually buffer sediment dynamics. The necessary dosing effect should be obtained over a larger stream length by increasing the process dynamics. It has to be considered that even in the current situation additional protection elements would be necessary to protect the endangered assets on the middle and lower part of the cone. This situation is only marginally modified by modifications in the fan apex region. With these premises the proposed solution features:

Retarding mounds of various dimensions should be built over a length of ca. 250 m on broadened stream sections in the area of the current retention basin. Smaller retarding mounds are proposed to be placed along the stream centre line, and larger elements at the flattened banks. A similar intervention concept is proposed for the Strimmbach. The junction geometry between the Gadria- and Strimmbach should be modified by reducing the confluence angle from a proximally orthogonal angle to a cut-angled configuration. This creates a system that is adapted to events of varying sizes or return periods. This set of measures results from the application of principles (i) and (ii) and contributes to meet the above listed requirements for enhanced sediment transport efficiency. A sketch of the solution concept is shown in Figure 3.

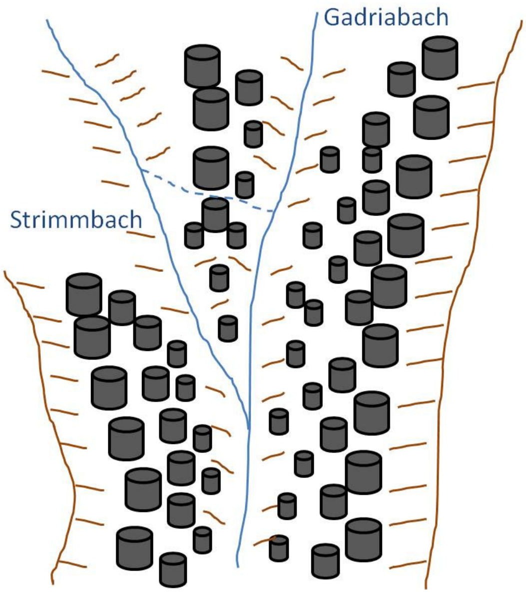

**Fig. 3** Protection system with retarding mounds of Gadria- and Strimmbach

To fulfil the risk mitigation demands given by the assets at risk a further improvement of the flow behaviour along the channel in the middle and lower part of the cone is indispensable. Consequently the concrete proposal is to intervene by constructing local protection measures mainly in the form of deflection walls with the aim to significantly reduce hazard impacts where it is needed. The idea therefore is not to avoid debris flow propagation on the cone but to divert the deposition lobes to areas at minor risk perspective.

The range of the most promising solutions is briefly outlined in Table 3, which in addition contains a raking of the different solution variants according to the cost-benefit ratio.

**Tab. 3** Cost-benefit ranking of proposed solutions

| Solution | Description | Cost benefit ratio | Ranking |
|---|---|---|---|
| A | Solution described in the main text | 1.01 | 1. |
| B | With respect to the solution described in the main text we proposed an increase in channel cross section on the debris cone to increase discharge capacity instead of employing local protection measures | 1.00 | 2. |
| C | With respect to the solution B only a structural modification of the existing geometry of the slit dam aiming at enhancing the current dosing efficiency was proposed. | 0.89 | 3. |

## SELECTION AND COMMUNICATION OF RESIDUAL RISK

The conceptual solutions presented in Table 3 provide a basis for the subsequent detailed planning process which may lead to further adaptations of the concept.

It has to be stressed that further studies are necessary to dimension the single protection system elements. As a consequence, the last two steps of the conceptual approach are in progress.

Concerning the residual risk discussion a communication strategy should be adopted to increase the awareness on the part of the concerned population whose absolute safety is unfeasible and economically not justifiable.

## CONCLUSIONS

In this paper we presented a conceptual planning and problem solving approach for acute problems in terms of risk caused by extreme events in mountain streams.

We demonstrated the applicability of the elaborated concepts in a dedicated case study on the Gadriabach (South Tyrol, Italy). From the perspective of an integrated management of mountain streams the proposed approach facilitates knowledge integration by structuring the relevant information about hazards, induced risks, systemic contradictions and by providing tailored solution principles according to an *ad hoc* defined ideal final result, which, in a nutshell, clarifies the technical and economic targets to be achieved.

Particular emphasize was given to an unambiguous chain of arguments relating system contradictions, their specific solutions on a functional level and the subsequent elaboration of feasible technical concepts.

The method of TRIZ-TIPS, embedded in the concept of system life-cycle engineering, has shown to provide a higher degree of risk reduction than conventional mitigation strategies by including possible alternatives already in the early planning stages. Based on a set of specific heuristics, a high quality spectrum of conceptual solutions for the safety problem recognized in the hydrological system under consideration will result.

The optimal solution for the specific sediment dosing problem identified includes a system of roughness elements in the area of the existing retention basin. The critical feature of this arrangement of roughness elements is an increase in size towards the lateral extent of the channel. This would allow sediment transport for small events, but would contain larger events within the channel. In addition, the flow course of the tributary stream (Strimmbach) should be rerouted such that the confluence angle is optimized.

To validate the elaborated solution concept a physical, numerical modeling program was started in collaboration with the University of Natural Resources and Applied Life Sciences, Institute of Mountain Risk Engineering, Vienna. The aim is to evaluate its validity through the three scientific pillars: physical modelling, numerical modelling and field investigation. Concerning the latter a series of dedicated monitoring activities are planned in the near future (Comiti et. al, 2010).

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